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## TÍTULO: VALORACIÓN DE LA VAINA DE MEZQUITE (*Prosopis laevigata*) PARA LA ALIMENTACIÓN DE RUMIANTES


PRESENTA:

**LUZ YOSAHANDY PEÑA AVELINO**

**DIRECTOR DE TESIS:**

DR. JUAN MANUEL PINOS RODRÍGUEZ

**ASESORAS:**

DRA. LETICIA YÁÑEZ ESTRADA

DRA. BERTHA I. JUÁREZ FLORES


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## Introducción general

La producción nacional de alimentos no satisface la demanda actual de estos y las proyecciones de la FAO para el año 2050[1], indican que se tendrá que prever un incremento del 70% a nivel global. La escasa precipitación pluvial y la falta de infraestructura en el país para almacenar y retener el agua, provocan bajo rendimiento en aproximadamente el 60% del territorio nacional. Una alternativa, es la valoración de recursos naturales adaptados a las zonas áridas, uno de ellos es el mezquite. El uso de las vainas de mezquite, como alternativa en la alimentación de animales, permite ahorrar el gasto hídrico empleado en la producción de granos convencionales, además reduce los problemas de salinidad ocasionados por abatimiento de acuíferos y la competencia por ingredientes energéticos como el maíz y trigo usados en la alimentación humana. En el Estado de San Luis Potosí, existen alrededor de 116 ha de mezquite[2]; no obstante los antecedentes de las características químicas de las vainas de mezquite (*P. laevigata*) y los trabajos relacionados con las fracciones de estos frutos que en otras especies, han mostrado la generación de mayores ingresos económicos, son escasos.

La alimentación de rumiantes representa alrededor de 70% de la inversión total de una explotación pecuaria[3]. Por lo que la búsqueda de alimentos alternativos que mejoren la productividad y el rendimiento de los animales a un menor costo,

[1] UN Food and Agriculture Organization. (2009). How to feed the word in 2050. Discussion paper prepared for expert forum: 12–13 October 2009, released 23 September 2009.
[2] Rodríguez, F. C., & Maldonado, A. L. J. (1996). Overview of past, current and potential uses of mesquite in Mexico. *Prosopis: Semiarid Fuel wood and Forage Tree Building Consensus for the Disenfranchised. Center for Semi-arid Forest Resources. Texas A&M University. Washington, DC, EEUU. pp*, 6-41.
[3] Koeslag, H. J., & Orozco F.L. (2010). Bovinos de Carne. Editorial Trillas, SEP. México. 117 p.

mejorarían la rentabilidad de la explotación, el acceso de alimentos cárnicos y lácteos y por lo tanto la nutrición humana se vería favorecida. El beneficio económico resultaría de la inclusión sustancial (50%) de vainas de mezquite, debido a que actualmente son de menor costo respecto a los alimentos energéticos convencionales. Por otra parte, la incorporación de carne al mercado que cumpla con los estándares de calidad (química y organoléptica) a menor precio, puede ofrecer mayores oportunidades de comercialización. Sin embargo, algunos de los constituyentes químicos en las vainas parecen limitar el nivel de uso en las dietas de los rumiantes, pero se carece de evidencias experimentales que lo demuestren, pues la mayoría de los estudios se han enfocado en la evaluación de las vainas de otras especies[4].

Por tal razón, la hipótesis de la presente investigación es que las vainas de mezquite (*P. laevigata*) poseen proteína, fibra y grasa en cantidad suficiente para sustituir alimentos energéticos convencionales, como el maíz y el sorgo, en dietas para rumiantes y aunque contienen factores anti-nutricionales como los taninos, a un nivel de 50% de vainas en la dieta de los rumiantes; el bienestar animal, la productividad y el rendimiento animal no se ven disminuidos, pese a que estos metabolitos poseen astringencia (característica química que provoca un menor consumo en los rumiantes), los taninos tienen la capacidad para conjugarse con algunas proteínas, iones metálicos y polisacáridos y formar así complejos que pueden alterar la digestibilidad de los nutrientes[5]. Por lo anterior, el objetivo del presente estudio fue

[4] Galán, A.G, Correa A.D., de Abreu C. M., & Barcelos M.F. (2008). Chemical characterization of integral flour from the *Prosopis spp*. of Bolivia and Brazil. *Archivos Latinoamericanos de Nutrición,* 58: 309-315.

[5] Jansman, A.J.M. (1993). Tannins in feedstuffs for simple-stomached animals. *Nutrition Research Reviews*, 6: (01), 2009-236.

determinar la composición química de las vainas de mezquite *P. laevigata* (rojas y blancas) y sus fracciones (exo-mesocarpio, endocarpio y semilla) y evaluar la eficiencia productiva, económica y organoléptica de la incorporación de vainas en dietas de crecimiento para corderos Rambouillet. Para lograr el objetivo anterior, la presente investigación se realizó en tres etapas: 1) Revisión bibliográfica del uso de las vainas de mezquite durante los últimos 20 años, como alimento para humanos y animales domésticos, (rumiantes y no rumiantes); 2) Determinación de la composición química, taninos, hongos contaminantes ambientales y la digestibilidad *in vitro* de las vainas de mezquite (rojas y blancas) y de las fracciones (exo-mesocarpio, endocarpio y semilla); y 3) Evaluación del comportamiento productivo, el rendimiento de la canal, fermentación ruminal y de química sanguínea en corderos Rambouillet, alimentados con dietas con niveles crecientes de vainas de mezquite (0, 25 y 50%), evaluar la composición química y sensorial de la carne del *Longissimus thoracis et lumborum* de los corderos alimentados con estas dietas.

## Capítulo I. The mesquite pods, a sustainable food and feed source in dry lands

**Resumen**. El objetivo de este capítulo fue analizar y discutir la información de los últimos 20 años respecto al uso de las vainas de mezquite, como alimento para humanos y para animales domésticos (rumiantes y no rumiantes). El mezquite, representa una alternativa de desarrollo que puede mejorar los niveles de vida de la población rural, debido principalmente a la adaptación que mantiene en condiciones de estrés hídrico. Aún más, en la última década, se han realizado investigaciones sobre la incorporación de algunos sub-productos en la dieta humana, por el bajo índice hipoglucémico que muestra y la cantidad de fibra y proteína que posee, además de que no contiene gluten. Por otra parte, las vainas de mezquite constituyen un recurso alimenticio importante para los animales domésticos, principalmente para los rumiantes, por su capacidad de aprovechar la fibra. El manuscrito se someterá para su publicación a la revista *African Journal of Range & Forage Science* (ISSN:1727-9380).

**The mesquite pods, a sustainable food and feed source in dry lands**

Luz Y Peña-Avelino [1], Juan M Pinos-Rodríguez [2*]

[1] Programas Multidisciplinarios de Posgrado en Ciencias Ambientales, Universidad Autónoma de San Luis Potosí (UASLP), Avenida Manuel Nava 201, Zona Universitaria, 78290, San Luis Potosí, México.

[2] Centro de Biociencias, Juan M Pinos-Rodríguez, Centro de Biociencias, km 14.5 Carretera San Luís Potosí-Matehuala, ejido Palma de la Cruz, Soledad de Graciano Sánchez, S.L.P. 78321, México. Tel: 444-8262300 Ext. 1163San Luis Potosí, México

*Corresponding author, email: jpinos@uaslp.mx

**Abstract**

This article presents the current knowledge about Mesquite pods (*Prosopis* spp.) as food and as a feed source. The average nutrients content in whole pods is crude protein 118 g/kg, ether extract 30 g/kg, reduced sugars 444 g/kg and total digestion 689 g/kg, while in pods seed is crude protein 338 g/kg and ether extract 59 g/kg. Addition of 20 % pods in animal diets allows good performance in several species. Pods and seeds have similar nutritional value to conventional grains, but mesquite requires less energy investment to grow. Pods are a sustainable feed source which could replace conventional grains in livestock diets.

**Keywords:** Mesquite, pod, sustainable food and feed.

**Introduction**

The uses of the mesquite trees are classified as wooden and non-wooden. The first in industry and energy production and the non-wooden in food, forage, medicine and

housing which are alternatives with economic benefits that do not affect the environment drastically. Several peer reviews have been published about botanical description, environmental benefits, and multi-purpose use of the mesquite tree (i.e., (Haregeweyn et al. 2013, King'ori et al. 2011, Perroni-Ventura et al. 2010). The mesquite pods as feed for livestock were evaluated and reviewed (Sawal et al. 2004), but in recent years new outcomes have been published showing advances on its use as a sustainable potential feed and food for arid and semiarid regions worldwide.

**Chemical composition of mesquite pods and seeds**

From mesquite pods, four fractions are mechanically obtained: exocarp, mesocarp, endocarp and seed (Freyre et al. 2003). The exocarp is the external covering layer which represents 13% of the pod and it covers the medium layer known as mesocarp or pulp mainly composed by carbohydrates. The endocarp, or internal layer, is a hard case that protects the seed. The seed represent**s** 16% of the pod. The spongy mesocarp and the hard endocarp of the pods can obstruct the sieve during grinding, hindering the proper crushing of the seed which has a high level of protein (31-37%) and energy. Unprocessed seeds pass through animal's bowel undigested, so the pods should be finely ground before feeding to maximize exploitation (Sawal et al. 2004). Using information from several studies (Andrade-Montemayor et al. 2009, Astudillo et al. 2000, Baraza et al. 2008, Barminas et al. 1998, Batista et al. 2002, Choge et al. 2007, De la Rosa et al. 2006, Freyre et al. 2003, Galán et al. 2008, Girma et al. 2011, Koech et al. 2010, Mahgoub et al. 2004, Mahgoub et al. 2005a, Mahgoub et al. 2005b, Pandya et al. 2005, Ravikala et al. 1995, Scott and Eldridge

2005) with nine species of mesquite (*P. alba, P. chilensis, P. cineraria, P. juliflora, P. laevigata, P. nigra, P. pallida, P. ruscifolia, P. tamarugo*) we calculate average values for chemical composition and nutritional characteristics of pods (Table 1) and seeds (Table 2). A chemical variation was found between the same species depending on several factors, e.g. the environmental conditions, soil characteristics, morphology of tree (size, number of seeds, secondary metabolites), maturity and season collection (Astudillo et al. 2000).

Pods had slightly higher crude protein (CP) than conventional grains such as corn, wheat or sorghum (NRC 2001), but there is great variability in protein content with values from 12.5 to 7.1. The average neutral detergent fiber, acid detergent fiber and ether extract composition of *Prosopis* spp. pods (Table 1) is higher than *P. laevigata,* but lower in ash as suggest by Peña-Avelino et al. (2014). However, pods contain more fiber than conventional grains, but lower than roughages and by-products such as corn stover, wheat straw, cotton seed and wheat bran (NRC 2001). Batista et al. (2002) showed that drying increases the degradation of the potentially degradable fraction in dry matter, but has no effect on the effective degradation and suggested that pods had a high degradation rate in the rumen. In 2014, Peña-Avelino et al. (2014) showed some differences *in vitro* degradation of dry matter in whole pods, exo-mesocarp, endocarp and seed of mesquite (*P. laevigata*). They indicated that soluble fraction, total digestion (465, 628, g/kg DM) and degradation rate (0.027/h) is slightly lower compared with the mean chemical composition of *Prosopis* pods (Table 1). Those authors suggested that the low content of sugar free of *P. laevigata* pods influenced these results. However, the digestibility values are comparable to other

conventional cereals (López et al. 2005) such as oat straw (54%), barley (60%), wheat (60%) and corn (71%).

Another relevant feature is the value of metabolizable energy in pods which is similar to corn and molasses cane (NRC 2001). According to their sugars content, the principal free sugar in whole pods is sucrose (83%), then is fructose (11%) and *after is* glucose (6%); similar tendency was found in the fractions exo-mesocarp, endocarp and seed (Peña-Avelino et al. 2014). Fatty acid (C14, C18, C18:2n6c, C20 and C22) concentrations were higher on the red whole pod and endocarp; whereas, fatty acid (C16, C18:1n9t and C18:1n9c) concentration on the white whole pod and seed were higher than in red analogous. Mesquite pods are a potential raw material for human food industry and in the production of bio-fuel (Galán *e*t al. 2008).

The CP content in mesquite seeds is higher than in cotton seeds (NRC 2001). Most fatty acids (FA) in mesquite seeds are unsaturated (Freyre et al. 2003) like oleic and linoleic and the major sterol is b-sitosterol (Astudillo et al. 2000). Gangal et al. (2009) reported an iodine value of 87.3% and a saponification value of 195.4. This iodine number is higher than the palm oil which is 50% (NRC 2001), while the saponification value is similar to sun-flower (188) and flaxseed (195), but higher than olive oil (12.0-18-0). Freyre et al. (2003) mentioned that phosphorus (P) content in mesquite seeds is higher compared to conventional seeds, but a portion is integrated to phytates which decrease the bioavailability of this element. The vitamin C (0.92 mg/100g) and vitamin A (0.98 mg/100g) contents in mesquite seed**s** are higher than in grains such as barley and corn (Barminas et al. 1998).

Mesquite pods also have anti-nutritional factors such as tannins, hemagglutinins, prosopines and some toxic amino acids which have been reported to be responsible of the limited nutritional value of mesquite due to adverse effects in animals and humans (Câmara et al. 2009, Tabosa et al. 2006). Goats fed only with pods during four days showed anorexia, salivation, dehydration and diarrhea. Histopathological analyses demonstrated necrotic lesions in liver, modification in kidney tubules and damage to the lymphoid tissue (Misri et al. 2003). However, the content of anti-nutritional factors (oxalate, 56.9 mg/100g of dry matter (DM); nitrate, 2.9 g/kg DM; phytate, 1.5 g/100g DM; saponins, 0.16g/100g; hemagglutinin, 1UH/100 L; trypsin inhibitor, 9.32UTI/mg DM , polyphenols and tannic acid 0.54 mg/100g DM) found by Galán *et al.* (2008) in mesquite pods do not represent a risk for animals. Also, Peña-Avelino et al. 2014 noted tannins values (0.25 mg/100g DM) and contaminant fungi counts (2.7,$\log_{10}$ CFU/g) were lower than the previously reported. Câmara et al. (2009) suggested that there is a specie dependent intoxication susceptibility, bovines fed with a basal diet including 50% of pods showed intoxication signs after 6 months of diet whereas goats fed with 60-90% had a medium tolerance presenting the intoxication signs after 210 days, on the other hand, sheep can be fed with 70-100% of pods for more than one year without displaying negative effects. Indeed, Cook et al. (2008) found that goats are able to consume mesquite pods (90% of total diet) on a short-term basis (14 days) without experiencing toxicosis.

Cooking and roasting pods are processes that reduce the secondary metabolites concentration and prevent insect and fungi damage (Guim et al. 2006). Dry heating (60-70°C) of mesquite pods decreased tannins from 58 to 48 mg/100 g and

trypsin inhibitor from 495 to 347 UI/g (Barba de la Rosa et al., 2006), although most effective reduction in trypsin inhibitors (73%), lectins (186.81 U/mg), and phenolic compounds was obtained at 80°C (Gallegos-Infante et al. 2013).

**Prosopis pods as human food**

In the ancient Mexican territory, mesquite pods were used by humans as fresh and dry fruits, conserves and flours. In our days, the products of mesquite pods are demanded because they are easily available (Baraza et al. 2008). Meals from pods or seeds have been extensively used as a partial replacement (6-20%) of peanut, walnut and corn flour in cereal bars, sweet cookies and pancakes. Most of the evidence indicate that addition of mesquite flour increases the protein content, sensorial tests and soluble fiber without affecting the physical properties and the sensorial acceptance (Bernardi et al. 2006, Escobar et al. 2009, Estevez et al. 2000). Also, Bernardi et al. (2010) prepared gluten-free bread using mesquite seeds, obtaining a product with higher protein content compared to other gluten-free commercial products. Indeed, in 2013 Felker et al. indicated that flour from mesocarp of mesquite pods does not contain gliadin, peanut, and soy allergens, and that the optimum concentrations for incorporation ranged from 5% for biscuits, 10% for bread, 15% for pancakes/muffins, and 50% in chapatti and drum-dried wheat flour.

In addition, mesquite pods are a source of compounds with beneficial effects on human health. The extract from crushed pods is used for earache, toothache and pain relief from fractures bones (Garg and Mittal 2013). Compounds found in the pods have shown neuroprotective (Mollashahi et al. 2013), cardioprotective and anti-hypertensive effects (Huisamen et al. 2013). In addition, mesquite pod meal lowers

fasting blood glucose levels, stimulates insulin secretion and leads to the formation of β-cells in the type 1 diabetes rat model through a β-cell neogenesis process (George et al. 2011).

**Prosopis pods for animal feeding**

The use of mesquite pods and seeds in diets for broilers, fishes and pigs, and the safe feeding level (10-66%) has been extensively studied (Al-Beitawi et al. 2010, Ausol and Mukhtar 2011, Bhatt et al. 2011, Choudhary et al. 2005, da Silva et al. 2002, Girma et al. 2011, Mabrouk et al. 2008, Pinheiro et al. 1993, Sena et al. 2012). The main objective of most of these studies was to replace conventional grains (corn, wheat, sesame cake, sorghum, soybean meal, cottonseed meal, barley, corn cob meal, milho corn, fish meal) by mesquite pods and seeds meal. Most of the results with broilers and fish indicate the limit concentration of pods as 20% since this amount does not affect the growth performance and carcass characteristics, and reduced feeding cost, although in fish the best results were found using treated mesquite seeds (hydration at 120° for 20 min and oven dried at 60°C for 24 h). In pigs the use of mesquite pods (10-30%) affected negatively the growth performance and some carcass characteristics; however the use of 50% of mesquite meal did not affect the performance or carcass quality. These data suggests that heating improve the feed quality of pods and seed for non-ruminants maybe as a result of a decrease on anti-nutritional components.

The inclusion of pods in the diets for ruminants (cattle, goats and sheep) also has been extensively studied (Andrade-Montemayor et al. 2011, Cook et al. 2010, Koech

et al. 2010, Mahgoub et al. 2004, Mahgoub et al. 2005a, Mahgoub et al. 2005b, Obeidat et al. 2008).

Forages, by-products, conventional grains, and commercial concentrates have been replaced by pods, meal pods and meal seed of mesquite. The included amount of mesquite pods and seed in diets has been from 20 to 50%. In sheep (Mahgoub et al. 2005a, Mahgoub et al. 2005b) and goats (Koech et al. 2010) the addition of 20% pods offers better growth performance than 30% pods. Other evidence suggest that the thermal treatment (150°C/45 min) increases the total degradation of pods in goats (Andrade-Montemayor et al. 2009) maybe as a result of a reduction of anti-nutritional compounds. Recently Pereira et al. (2013) there were indications that mesquite pod meal can be used to replace up to 40% of corn grain, and its addition should not exceed 200 g/kg of dry matter since organic matter intake may affect lactating goats.

Despite off all these experiments the information about the use of mesquite pods in livestock feeding is limited because most studies were made just to evaluate growth performance and digestion, but none was developed to evaluate its environmental impact. The results of dos Santos et al. (2013) indicate that mesquite pods are an alternative feed additive that decreases the undesired production of $CH_4$ and $CO_2$ during ruminal digestion, reducing their emission into the atmosphere. Besides, in most of the studies, mesquite was evaluated simply replacing conventional feeds, with no re-formulation involved. It would be worth to reformulate diets since mesquite pods have different chemical composition as compared to conventional grains, by-products and forages. Moreover, considering that *P. juliflora* is a very

affordable plant occurring in arid and semi-arid regions of the world, it will be worth to explore the more than 40 existing mesquite species and the 10 prosperous species present in Mexico that have extensive arid regions and insufficient livestock production.

**Mesquite pods versus corn for arid lands**

In developing countries the major investment with livestock production is feeding grain because of the cost, most of them are imported from developed countries. One example is Mexico which imports most of the grains for animal feeding from the United States of America. Sixty percent of Mexican territory is arid and semiarid areas. Maize is the most common seasonal crop cultivated although due to a variable annual precipitation (~350 mm) it has a high risk of being successful. For example, in 2010 the annual grain corn production (without irrigation) was 0.36 as-is/ha with only 34.5% of surviving plants, while in the same year the annual average production of mesquite pods was of 3.7 ton/ha (Ruíz 2011). It suggests that the potential production of mesquite pods in the 4 million hectares of arid and semiarid regions of Mexico is around 15 million tons. Our research group developed a comparative energy and cost analysis system for one hectare planted with corn and other with mesquite. Calculations indicated that maize growth requires a higher energy intake, but produces less energy withdrawal in the system as compared to mesquite pods. The average cost of corn production and corn stover was around US $238 per hectare and the average net income was around US $65, which represents only 12% of the mesquite pods production income. Thus, mesquite is a sustainable natural source in regions with water deficit, the investment costs are lower and

present better economic benefits since the pods prices are lower ($0.15/kg) than corn grain (US$0.31/kg). Therefore, the mesquite pods may bring economic benefits to rural populations, since it is a spontaneous source and it does not represent a social cost. Besides, selling the pods could improve the family income without affecting the arid regions rangeland.

**Conclusion**

Mesquite pods have similar chemical composition and nutritional value than conventional grains and by-products. Their use in levels of 20% of total diet does not compromise the performance in ruminant and non-ruminant animals. However, reformulation of the diet should be considered when pods are added. Mesquite pods show advantages over conventional crops such as corn, since the tree does not depend greatly on energy input to produce nutrients. Several applications (food supply, pharmaceutical, gastronomy, alternative medicine, energy, soil restoration, etc.) are been studied and the results are promising for the uses of mesquite. Therefore mesquite pods can be used in the production of human and farm animal's food with certain advantages over conventional grains such as corn. However, more research is needed to achieve a sustainable exploitation.

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**Table 1. Average chemical composition of Prosopis pods spp. (g/kg dry matter).**

| | | | |
|---|---|---|---|
| Dry matter | 906 | Soluble fraction | 569 |
| Crude protein | 118 | Ruminal digestion | 597 |
| Crude fiber | 199 | Total digestion | 689 |
| Neutral detergent fiber | 430 | Degradation rate /h | 0.014 |
| Acid detergent fiber | 299 | Calcium | 4.1 |
| Ether extract | 30 | Phosphorus | 1.6 |
| Ash | 46 | Magnesium | 1.2 |
| Reduced sugars | 444 | Metabolizable energy, Mj/kg DM | 12.2 |

**Table 2. Average chemical composition of Prosopis seeds spp.**

| Nutrient | g/kg DM | Fatty acid | g/100 g fat |
|---|---|---|---|
| Dry matter | 920 | Myristic C14:0 | 2.2 |
| Crude protein | 338 | Palmitic C16:0 | 9.2 |
| Crude fiber | 58 | Stearic C18:0 | 4.5 |
| Ether extract | 59 | Oleic C18:1 | 27.5 |
| Ash | 52 | Linoleic C18:2 | 48.0 |
| Energy, Mj/kg | 18.4 | Linolenic C18:3 | 1.7 |
| Calcium | 2.5 | Arachidic | 3.3 |
| Phosphorus | 2.9 | Others | 3.6 |
| Magnesium | 0.4 | | |
| Copper | 0.03 | | |
| Iron | 0.07 | | |
| Manganese | 0.01 | | |
| Zinc | 0.04 | | |

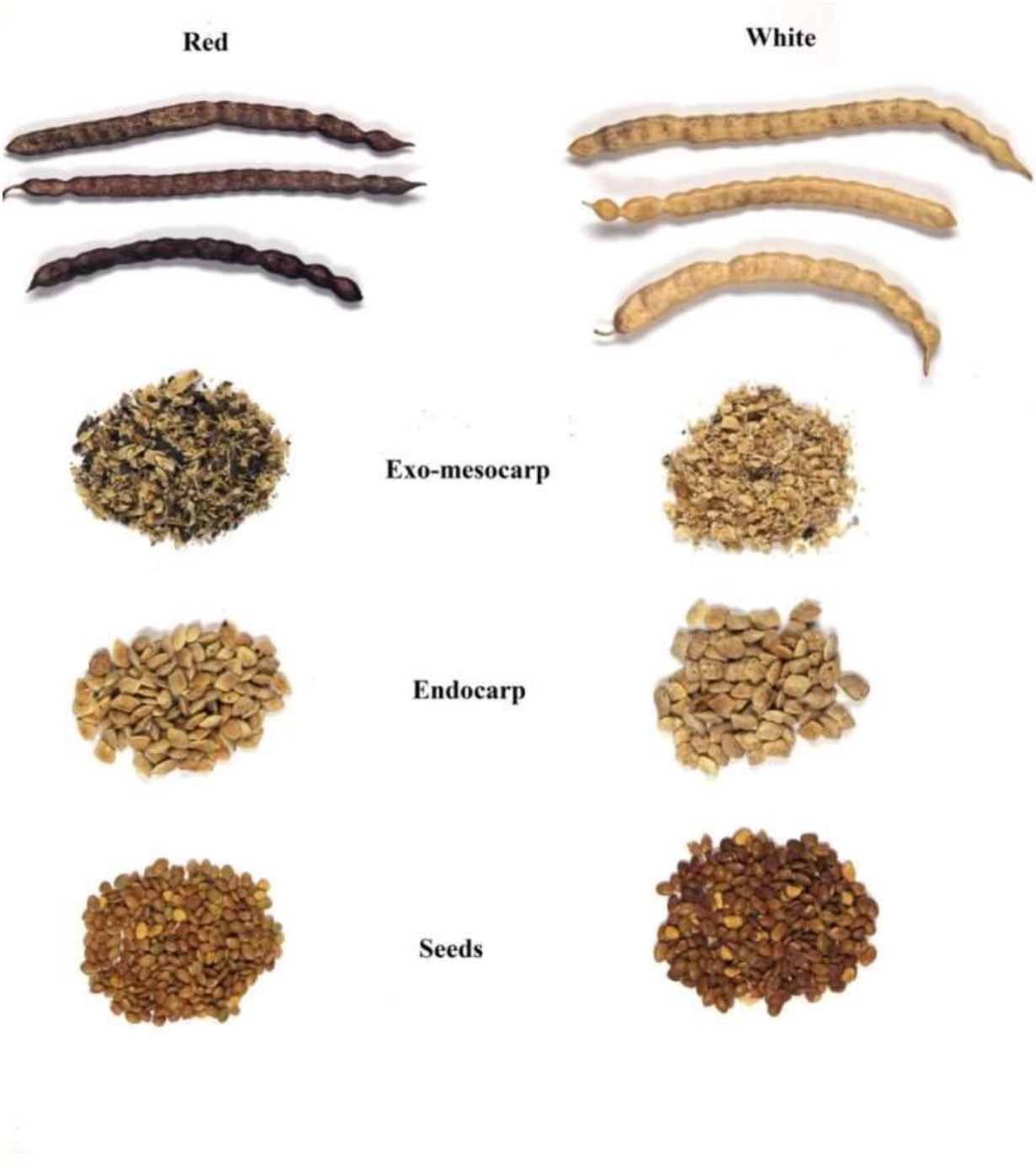


Figure 1. Whole pod, exo-mesocarp, endocarp and seeds of mesquite

## Capítulo II. Chemical composition and *in vitro* degradation of red and white mesquite (*Prosopis laevigata*) pods

**Resumen.** El objetivo del presente estudio fue determinar la composición química, taninos, hongos contaminantes ambientales y la digestibilidad *in vitro* de las vainas de mezquite (rojas y blancas) y las fracciones (exo-mesocarpio, endocarpio y semilla) y caracterizar el aporte nutrimental de esta leguminosa. Los resultados indican que esta leguminosa tiene un alto valor alimenticio por lo que tiene un alto potencial para ser considerada en la industria de la alimentación animal. El manuscrito se publicó en *South African Journal of Animal Science* (ISSN:0375-1589) .

# Chemical composition and *in vitro* degradation of red and white mesquite *(Prosopis laevigata)* pods

**L.Y. Peña-Avelino[1], J.M. Pinos-Rodríguez[2#], L. Yáñez-Estrada[3], B.I. Juárez-Flores[4], R. Mejia[3] & H. Andrade-Zaldivar[2]**

[1] Programas Multidisciplinarios de Posgrado en Ciencias Ambientales
[2] Centro de Biociencias
[3] Facultad de Medicina
[4] Instituto de Investigación en Zonas Desérticas
Universidad Autónoma de San Luís Potosí, San Luis Potosí, 78000, S.L.P. México

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## Abstract

The objective of this study was to compare the chemical composition and ruminal degradation of whole pod, exomesocarp, endocarp and seed fractions of red and white mesquite pods. The pods contained on average 220 g free sugars, 78 g crude protein, 21 g fat per kg dry matter (DM), and a potential DM degradation of 163 g/kg. Contaminant fungi (mostly *Aspegillus* spp.) count was low. Unsaturated fatty acids, mainly linoleic acid, were the predominant (~50%) fatty acids in whole pods and seeds. Sucrose was the largest free sugar proportion. The highest fibre content was found in the endocarp, the highest free sugar was found in the exomesocarp, and the highest crude protein content was found in the seeds. Tannins were more abundant in red pods (0.4 mg/100 g DM) than in white ones. Some differences in nutritional values were found between red and white pods and their components (exomesocarp, endocarp and seeds), although both have a potentially high nutritive value. Whole pods and the endocarp can be used by ruminants; seeds can be used by simple stomach animals; and the exomesocarp can be used in human nutrition because of its low glycaemic index properties.

**Keywords:** Degradation rate, fatty acids, sugar, tannins
[#] Corresponding author: jpinos@uaslp.mx

## Introduction

Several species of mesquite (*Prosopis* spp*.)* are well distributed in and adapted to arid and semi-arid regions of the world. Approximately, 40 species (trees and shrubs) are native to North and South America (Pasiecznik *et al.,* 2001). However, they have been introduced and have adapted to dry lands of Asia, Africa and Australia because of their commercial value, contribution to land rehabilitation, and provision of fodder and firewood (Mwangi & Swallow, 2008; Mworia *et al*., 2011). Mesquite pods (referred to henceforth as fruits) vary in colour from white to red and dark brown. They have been used as human food (Felker *et al*., 2013) and their extracts have been extensively evaluated as a source of nutraceuticals (Bernardi *et al.*, 2010) and pharmaceuticals (Huisamen *et al*., 2013; Mollashahi *et al*., 2013). The fruits are also used as animal feed (de Jesus Pereira *et al*., 2013) which, depending on the colour, may have different effects in the rumen (Cabiddu *et al*., 2010) because of variation in content of phytochemical compounds (mainly polyphenols) (Parveen *et al*., 2010)). Incidents of invasion of mesquite species as a result of seed dispersal by livestock (Sawal *et al*., 2004), wildlife and water have been reported in north-east Ethiopia (Shiferaw *et al*., 2004), forest riverines of Kenya (Muturi *et al*., 2013), and savannas and grasslands of Argentina and southwestern USA (Golubov *et al*., 2001). The fruits are equipped with biological characteristics that foster their rapid invasion into new areas (Shiferaw *et al.,* 2004). For example, they produce many small hard seeds with attractive colours, and are capable of surviving passage through the digestive system of animals. The sweet mesocarp contains a mixture of seeds that can germinate quickly or remain dormant for a long time. When consumed unground, the number of seeds recovered from 1 kg faeces of cattle, warthogs, camels and goats were 2833, 2344, 1642 and 760, respectively (Shiferaw *et al*., 2004; Riet-Correa, 2011). Grinding the fruits helps to break the hard capsule surrounding the seed, improves the digestion of nutrients, and prevents seed

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dispersal. The fruit can be fragmented mechanically into the exomesocarp (13%) (by weight), endocarp (16%), and seeds. The exocarp is the external layer that covers the spongy medium layer, which is known as mesocarp or pulp, and is composed mainly of carbohydrates. The endocarp, or internal layer, is a hard stony case that protects the seeds. The mesocarp and the endocarp may obstruct the sieve during grinding, hindering proper crushing of the seeds, which is where most nutrients are found (Freyre *et al*., 2003). Most previous research compared the chemical composition of several species of mesquite (Astudillo *et al*., 2000; Batista *et al*., 2002; Freyre *et al*., 2003; González-Galán *et al*., 2008; Andrade-Montemayor *et al*., 2009), but none evaluated the effect of fruit colour on nutritional quality. Therefore, the objective of this study was to compare the chemical composition and ruminal degradation of intact fruit (referred to as whole pod), exomesocarp, endocarp and seeds of red and white mesquite varieties.

## Material and Methods

Mesquite fruits were collected from six adult trees (~13 years old) located in the city of San Luis Potosí, México, in May and June 2011. Three trees produced white fruits and three red ones. Approximately 27 kg fruit per tree were collected. One portion (~20 kg) of whole white or red fruits was separated prior to analysis for dry matter (DM), ash, and crude protein (CP). The DM percentage was determined by loss of weight after drying 200 g for each sample at 55 ºC in an air-forced oven until constant weight (AOAC Official Method 930.15; AOAC, 2005). Then, each group of fruits was ground with a Wiley mill using a 1 mm sieve screen (Model 4; Arthur H. Thomas Co. Philadelphia, Pa., USA). Ash content was determined subsequently at 550 ºC for 5 hours in a muffle furnace (Method 942.05; AOAC 2005). The Kjeldahl method was used to determine nitrogen (N) (AOAC Official Method 976.05; AOAC, 2005), with the CP content calculated as N x 6.25. The neutral detergent fibre (NDF) and acid detergent fibre (ADF) were assayed according to procedures described by Van Soest *et al*. (1991) with modified ANKOM 200 fibre analyser apparatus (ANKOM Technology Corporation, Fairport, N.Y. USA). Neutral detergent fibre analysis was conducted using sodium sulphite and alpha amylase (heat stable). A second portion of the fruits (~40 kg) was used to obtain the following fractions: exomesocarp, endocarp and seed. First, the fruits were air-dried for 32 h under a soft shade to facilitate the grinding process by preventing the formation of lumps from water and sugars in the fruits. Dried fruits were ground through a Bear Cat mill with a 3 inch screen (Crary Industries Inc., West Fargo, N. Dak., USA). Then, ground fruits were separated through a 4.76 mm mesh (sieve No.8), where a mixture (outer cuticle, pulp and seed fruits) passed through the sieve and the internal layer or endocarp was separately. The exocarp and mesocarp size were similar and were difficult to separate. Thus, seeds were obtained by manual separation. Then, samples of the exomesocarp, endocarp and seeds were ground again, but with a Wiley mill using a 1 mm sieve screen to determine DM, CP, ash, NDF and ADF, as described above.

To quantify long-chain fatty acids, methyl esters from fatty acids (FAMEs) were obtained by alkaline methanolysis, according to Gómez-Brandon *et al*. (2008). Total fatty acids were extracted from 200 mg samples with 12 mL of chloroform methanol, 2 : 1 (v/v). Total lipid extracts were obtained with a 0.2 M KOH methanol solution and toluene-methanol 1 : 1 by vortexing for 60 seconds and re-extracted twice. FAMEs were extracted with a 4 : 1 hexane-chloroform solution and water, centrifuged at 4545 x *g* for 5 minutes. The upper phase was transferred to another test tube and the lower phase was re-extracted twice with the same solutions, evaporated under a $N_2$ flow to a final volume of 0.5 mL. Ten microlitres of methyl heptadecanoate (C17:0 at 0.26 mg/mL, Sigma-Aldrich) were added as chromatographic standard to 100 µL samples of each extract. Composition analysis was performed in a gas chromatograph with a flame ionization detector (6890N, Agilent Technologies Systems, USA) and a capillary column HP-INOWax 30 m x 0.32 mm x 0.25 µm with programmed temperature (150 ºC) for 1 min, increased by 5 ºC/min to reach 230 ºC for 13 minutes), using helium as carrier gas and a constant flow rate of 1.5 mL/min. The standard used to identify the fatty acids was Fame Mix C14-C22 (Supelco, Bellefonte PA, USA).

Sugar profiles were obtained from a solid-liquid extraction procedure. The crude lipid fraction was removed from a 0.5 g of sample that was dried and finely ground (1 mm) using petroleum ether, with a final volume of 12 mL, centrifuged 4545 x *g* for 10 min (HN-SII Centrifuge International Equipment Company, KY,USA). Petroleum ether was aspirated and discarded twice without siphoning off solid material. Residual petroleum ether was then evaporated with a gentle stream of $N_2$, according by the International AOAC (982.14; AOAC, 2006). Dried and defatted powder were spiked with an internal standard, lactose (6 mg/mL), and extracted with 10 mL 80% aqueous ethanol at 70 ºC for 30 min. The resulting suspension was centrifuged at 11363 x *g* for 15 min. The supernatant was concentrated at 40 ºC under reduced vacuum, until total ethanol removal, and then diluted in water (Mili-Q, TGI Pure Water Systems, USA) to a final volume of 10 mL, according by Barreira *et al.* (2010). The carbohydrate profile was determined by high-performance liquid chromatography with a high refraction detector (HPLC-IR) in an 1100 series chromatographer (Agilent Technologies Systems, Santa Clara, Calif.) with a Zorbax Carbohydrate column (4.6 mm ID x 150 mm (5

µm) at 30 ºC. The mobile phase involved acetonitrile/deionized water, 75 : 25 (v/v), at a flow rate of 1.4 mL/min, and the injection volume was 20 µL. The results were expressed in g/100 g dried weight, calculated by internal standard normalization of the chromatographic peak area. Sugar identification was made by comparing the relative retention times of sample peaks with standards. Reference standards were from Sigma (St Louis, Mo, USA).

Tannin content was determined according to the ISO standard (ISO 9648:1988). A solution of dimethylformamide at 75% (10 mL) was mixed with ground samples (500 mg) and shaken (Speci-Mix Thermolyne, Barnstead International, Boston, Mass, USA) for 60 min for tannin extraction, before centrifugation at 3000 x *g* for 10 min. Supernatant (0.5 mL) was transferred in a test tube containing a mixture of ammonia (0.5 mL) and water (3 mL). In another test tube, 0.5 mL of supernatant was mixed with a 3.5 mL mixture of 0.5 mL ferric ammonium citrate, 0.5 mL ammonium hydroxide and 2.5 mL water. The tube was shaken for 60 sec, and placed to rest for 10 min before an aliquot was transferred into measuring cells to determine absorbance at 525 nm, with an UV-visible spectrophotometer (HP 8453; Agilent Technologies). Tannic content was determined after preparing a calibration curve (0.05, 0.1, 0.2, 0.3, 0.4 mg/mL) with tannic acid.

For contaminant fungi, the horizontal method (PNT-Al-006) based on the norm XF V08-059 was used to quantify yeast and moulds, according to Allaert Vandevenne & Escolá Ribes (2002). One g sample was suspended in 9 mL sterile water, mixed at 25 ºC and diluted. One mL of each dilution (10-1–10-5) was placed in a Petri dish with Sabouraud dextrose agar (SDA) supplemented with 0.40 mg/L gentamicin and 400 mg/L chloramphenicol. The dishes were mixed gently and incubated at 25 ºC for five days. Fungal species were isolated by re-plating, for an additional 72 h incubation, and identified by direct microscopy with cotton lacto-phenol blue staining.

*In vitro* degradation of DM was carried out according to the procedure of Tilley & Terry (1963) and degradation kinetics of DM was conducted as described here. Ruminal fluid was collected from two ruminally cannulated lactating cows that had free access to water and a 70 : 30 forage : concentrate diet offered in two equal portions at 08:00 and 16:00. The forage was a mixture of maize silage and lucerne hay (70 : 30). The concentrate mixture contained wheat middling, corn maize, soybean meal and mesquite fruits (20 : 40 : 20 : 20). For each of seven replications, three tubes of whole pods, endocarp, exomesocarp and seeds from white and red fruits were incubated for 0, 3, 6, 12, 24, 48 and 72 h. *In vitro* ruminal kinetics of DM were calculated using the Gompertz model (2) as outlined in Susmel *et al.* (1999):

$$deg_{(t)} = (a + b) \exp[(-C) \exp(-Dt)]$$

where: deg is the DM degraded (g/kg) at time *t*; *a* is the immediately soluble DM fraction (g/kg), *b* is the insoluble, but potentially degradable fraction (g/kg) over time (t, hr); a+b is the total substrate potentially degradable (soluble and degradable); *C* is the fractional degradation rate of *a*+*b*; and *D is* a parameter to consider the microbial biomass. According to the Gompertz model, fractional rate of degradation varies as a function of time, and an average value (i.e. a constant value comparable with the exponential rate of degradation) can be derived as c = D/C. For each incubation time, the residual DM in each tube was averaged before fitting the data to a nonlinear regression model using the NLIN option of SAS (2002).

Analyses for chemical composition, FAMEs, sugar profile, tannins and fungi contaminant were conducted in triplicate. Analysis of variance of these dependent variables was conducted with SAS (2002), using the GLM procedure and the Tukey test to separate the treatment means. *In vitro* degradation parameters (*a, a*+*b*, and *c*) were subjected to one-way variance analysis using a mixed model (SAS, 2002), that included treatment as a fixed effect and replication as a random effect. Differences among treatments were declared at $P < 0.05$.

## Results and Discussion

Mesquite fruits had an average content of 856 g DM/kg, 329 g NDF/kg DM, 252 g ADF/kg DM, 260 g sugar/kg DM, 78 g CP/kg DM, 41 g ash/kg DM and 21 g fat/kg DM, and 0.25 mg tannins/100 g DM (Table 1). Differences in composition between the white and red whole pods are presented in Table 1. The fungi species identified were mostly from the *Aspergillus* genus (*A. nidulans*, 88 FCU/100 CFU; *A. fumigatus*, 4 FCU/100 CFU; *A. niger*, 3 FCU/100 CFU; *A. flavus* - *A. terreus*, 1 FCU/100 CFU), which is the most common fungus genus found in animal feeds (Azarakhsh *et al*., 2011). Other fungi identified in fruits in this study included *Fusarium* spp. and *Mucor* spp. The counts for all the fungi were considered low according to Mexican regulations (NOM-111-SSA1-1994). Evidence from previous work (Boyd & Cotty, 2001; Canafoglia *et al*., 2007) indicated that fruits are susceptible to damage by insects when growing in the vicinity of crop fields, especially bruchids such as *Algarobius johnsoni*, *A. atratus* and *A. johnsoni* (Kingsolver *et al.*, 1986). Fruits damaged by insects may become reservoirs of fungi, some with aflatogenic capacity. However, the levels of aflatoxins found here were not higher than commonly observed in conventional human foods (Kaaya & Warren, 2005).

**Table 1** Chemical composition of whole pods, exomesocarp, endocarp and seed of mesquite

| Component | Whole pod | | | Exomesocarp | | | Endocarp | | | Seed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | White | Red | SEM | White | Red | SEM | White | Red | SEM | White | Red | SEM |
| Dry matter (DM), g/kg | 855 | 858 | 5.9 | 917[b] | 931[a] | 5.4 | 931 | 932 | 4.4 | 946 | 950 | 6.3 |
| NDF, g/kg DM | 307[b] | 352[a] | 3.3 | 387[b] | 422[a] | 4.4 | 615[b] | 688[a] | 4.1 | 167[b] | 182[a] | 3.9 |
| ADF, g/kg DM | 237[b] | 272[a] | 2.7 | 244[b] | 325[a] | 2.5 | 527[b] | 553[a] | 2.6. | 111[b] | 127[a] | 3.7 |
| Total sugar, g/kg DM | 198[b] | 242[a] | 3.9 | 215[b] | 305[a] | 3.9 | 113 | 110 | 3.9 | 11[a] | 8[b] | 0.6 |
| CP, g/kg DM | 77[b] | 79[a] | 0.7 | 57[b] | 61[a] | 1.7 | 22[b] | 29[a] | 1.1 | 259[b] | 285[a] | 2.9 |
| Ash, g/kg DM | 39[b] | 43[a] | 0.2 | 33[b] | 37[a] | 0.4 | 53[b] | 59[a] | 0.5 | 36[a] | 35[b] | 0.3 |
| Fat, g/kg DM | 27[a] | 15[b] | 0.7 | 20 | 19 | 1.1 | 9 | 10 | 0.8 | 38[a] | 26[b] | 1.1 |
| Tannins, mg/100 g DM | 0.1[b] | 0.4[a] | 0.1 | 0.1 | 0.1 | 0.1 | 0.2[a] | 0.1[b] | 0.02 | 0.4 | 0.4 | 0.02 |
| Fungi, $\log_{10}$ CFU/g | 2.7 | 2.8 | 0.1 | 3.4[a] | 1.0[b] | 0.1 | 2.7[a] | 0.5[b] | 0.05 | 1.3[a] | 0.5[b] | 0.04 |

DM: dry matter; NDF: neutral detergent fibre; ADF: acid detergent fibre; CP: crude protein; SEM: standard error of mean.
[ab] Within rows white and red means for whole pod, exomesocarp, endocarp and seed with different superscripts differ at $P$ <0.05.

**Table 2** Fatty acid profile and individual free sugar in whole pods, exomesocarp, endocarp and seeds of mesquite

| | Whole | | | Exomesocarp | | | Endocarp | | | Seed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | White | Red | SEM | White | Red | SEM | White | Red | SEM | White | Red | SEM |
| Fatty acid, g/100 fat | | | | | | | | | | | | |
| C14:0 | 0.1[b] | 0.2[a] | 0.01 | 0.1 | 0.1 | 0.01 | 0.6[a] | 0.1[b] | 0.03 | 0.1 | 0.1 | 0.01 |
| C16:0 | 21.1 | 18.6 | 1.10 | 18.5 | 19.1 | 1.93 | 20.3 | 18.8 | 0.81 | 15.9[a] | 15.4[b] | 0.49 |
| C18:0 | 4.0 | 4.7 | 0.61 | 4.4 | 4.7 | 0.41 | 4.8[a] | 4.4[b] | 0.42 | 3.9 | 3.7 | 0.40 |
| C18:1n9t | 13.0 | 14.6 | 0.69 | 16.5[b] | 18.1[a] | 0.38 | 14.9 | 15.6 | 0.46 | 17.1[a] | 16.2[b] | 0.55 |
| C18:1n9c | 6.7[a] | 5.1[b] | 0.41 | 47.8 | 46.2 | 0.84 | 49.7 | 52.0 | 1.51 | 1.2 | 1.3 | 0.11 |
| C18:2n6c | 52.0 | 51.8 | 1.88 | 6.2 | 5.5 | 0.69 | 4.9[a] | 3.7[b] | 0.30 | 55.5[b] | 57.9[a] | 0.94 |
| C18:3 | 1.6[b] | 2.1[a] | 0.05 | 4.5 | 4.1 | 0.67 | 2.2 | 2.2 | 0.03 | 2.7 | 2.1 | 0.29 |
| C20:0 | 1.9[b] | 2.6[a] | 0.17 | 1.9 | 2.1 | 0.16 | 2.5[b] | 2.9[a] | 0.04 | 3.2 | 2.9 | 0.22 |
| C22:0 | 0.1[b] | 0.3[a] | 0.02 | 0.1 | 0.1 | 0.01 | 0.1[b] | 0.3[a] | 0.06 | 0.4 | 0.4 | 0.01 |
| Free sugar, g/100 g sugar | | | | | | | | | | | | |
| Glucose | 5.2[b] | 7.2[a] | 0.26 | 2.0 | 1.8 | 0.21 | 3.1 | 2.5 | 0.42 | 0.1[b] | 0.2[a] | 0.01 |
| Fructose | 11.3[b] | 11.8[a] | 0.17 | 12.0[a] | 9.5[b] | 1.00 | 12.9 | 14.4 | 0.87 | 18.4 | 19.1 | 1.34 |
| Sucrose | 83.5 | 81.0 | 1.42 | 86.0 | 88.7 | 1.10 | 84.0 | 83.1 | 1.23 | 81.5 | 80.7 | 1.35 |

[ab] White and red means for whole pod, exomesocarp, endocarp and seed with different superscripts differ at $P < 0.05$.

**Table 3** *In vitro* degradation of dry matter in whole pods, exomesocarp, endocarp and seeds of mesquite

| Gompertz | Whole pod | | | Exomesocarp | | | Endocarp | | | Seed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| parameter | White | Red | SEM | White | Red | SEM | White | Red | SEM | White | Red | SEM |
| *a*, g/kg DM | 492 | 438 | 30.1 | 226[b] | 435[a] | 24.9 | 158 | 147 | 10.9 | 267 | 290 | 20.6 |
| *b*, g/kg DM | 189[a] | 137[b] | 10.3 | 282[b] | 358[a] | 26.7 | 392 | 428 | 29.1 | 389 | 431 | 23.5 |
| *a*+*b*, g/kg DM | 681[a] | 575[b] | 38.1 | 508[b] | 793[a] | 37.1 | 550 | 575 | 33.8 | 656 | 721 | 30.1 |
| *c*, /h | 0.032 | 0.023 | 0.006 | 0.022 | 0.020 | 0.004 | 0.029 | 0.021 | 0.004 | 0.027 | 0.023 | 0.004 |

DM: dry matter.
*A*: soluble fraction; *b*: potentially degradable fraction; *a*+*b*: total degradation; *c*: degradation rate.
[ab] White and red means for whole pod, exomesocarp, endocarp and seed with different superscripts differ at $P < 0.05$.

Nine fatty acids were identified (Table 2). Linoleic acid (C18:2n6c) was the predominant (~50 g/100 g fat) unsaturated fatty acid in whole pods and seeds, followed by oleic acid (C18:1n9c) and elaidic acid (C18:1n9t). Palmitic acid (C16:0) was the major component among the saturated acids. The fatty acid profile reported here was similar to that of conventional vegetable oils (NRC 2001), and was in agreement with the reports of Lamarque *et al*. (1994) and Freyre *et al*. (2003). Sucrose was the free sugar in largest proportion, followed by fructose and glucose. The sugar profile was similar to sugar beet (NRC, 2001) and in similar proportions to those reported by Marangoni & Alli (1988). The values were within the ranges reported by Sawal *et al.* (2004) who reviewed the chemical composition of several mesquite species.

The CP level (Table 1) was similar to conventional grains such as maize, wheat and sorghum. The mesquite fruits contained more fibre than conventional grains, but less than roughages and by-products such as maize stover, wheat straw, cotton seed and wheat bran. Mesquite fruits have been used to replace forages, by-products, conventional grains and commercial concentrates in experiments that did not consider their unique properties when formulating diets (e.g., Mahgoub *et al*., 2005a; b; Andrade-Montemayor *et al*., 2009; Koech *et al*., 2010; de Jesus Pereira *et al*., 2013). Future research, however, should consider these properties when comparing mesquite with conventional feedstuff.

Whole pods, exomesocarp and seed from white and red fruits had similar DM contents (Table 1). As expected, the highest fibre content was found in the endocarp, the highest concentration of free sugar was found in the exomesocarp, and the highest crude protein content was found in the seeds (Table 1). Whole pods, and the exomesocarp, endocarp and seed of the red fruits had higher ($P$ <0.05) NDF, ADF and CP concentrations than those from white fruits, whereas the fat concentration was higher ($P$ <0.05) in whole pods, white fruits and their seeds than those from red fruits. In contrast, whole pods, exomesocarp and endocarp of red fruits had a higher ($P$ <0.05) ash content than the white fruits. Fatty acids (C14, C18, C18:2n6c, C20, C22) concentrations of red whole pod and endocarp were higher than in the white counterparts. In contrast, fatty acids (C16, C18:1n9t, C18:1n9c) concentrations of white whole pod and seed were higher than in the red counterparts. Free sugar profiles were higher ($P$ <0.05) in red whole pod and seed than in the white counterparts.

Tannin level was highest ($P$ <0.05) in the endocarp of white fruits, and was higher in red whole pods than the white whole pods. In the present study, tannin levels were lower than the tannic acid levels reported by González-Galán *et al*. (2008). Tannin level in mesquite fruits may not always be a limiting factor in its dietary inclusion level, as suggested by Mahgoub *et al*. (2004). Contaminant fungi counts were higher in the exomesocarp, endocarp and seed of white fruits compared with the counterpart fractions of red fruits. There are no previous studies that evaluated the effect of fruit colour on chemical composition in mesquite, but evidence with Ilama (*Annonia diversifolia* Safford) fruits indicated that colour influences the chemical composition owing to phytochemical compounds (Julian-Loaeza *et al*., 2011).

In whole pods the potentially degradable fraction (*b* fraction) and total degradation (*a* + *b* fraction) were higher ($P$ <0.05) in white than in red fruits (Table 3). However, in the exomesocarp, the soluble fraction (*a* fraction), the potentially degradable fraction (*b* fraction) and total degradation (*a* + *b* fraction) were higher ($P$ <0.05) in red fruits than in white fruits. There were no differences in degradation rates among the fruit fractions. The highest *in vitro* degradation parameters in exomesocarp could be related to the higher proportion of CP in red fruits compared to white fruits. Whole pods could be a potential raw material for the human food industry. However, they could be used in the production of bio-fuel, as suggested by González-Galán *et al*. (2008). Batista *et al*. (2002) found that digestible DM of fruits was high (approximately 680 g/kg DM), suggesting a high ruminal availability. The digestibility values were comparable with conventional cereal grains such as wheat (895 g/kg DM) and corn (899 g/kg DM) (Aye-Saldar *et al*., 2012).

## Conclusion

Chemical composition and ruminal degradation of mesquite fruits used in this experiment were similar to several conventional animal feeds. Each fraction (exomesocarp, endocarp and seeds) has its distinct composition, which contributed uniquely to the overall nutritional value of the whole pod. Although differences were found between red and white varieties of mesquite, both have great potential for the development of local and sustainable feed production systems with low environmental impact and cost of production.

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## Capítulo III. Growth performance, blood metabolite, body composition, carcass composition, and sensory characteristics of Rambouillet lambs fed mesquite (*Prosopis laevigata*)

**Resumen**. El objetivo del presente estudio fue evaluar la química sanguínea, el comportamiento productivo, el rendimiento de la canal y la fermentación ruminal de 21 corderos Rambouillet, alimentados con dietas compuestas con niveles crecientes de vainas de mezquite (0, 25 y 50%). Así mismo, se evaluó la composición química y sensorial de la carne del *Longissimus thoracis et lumborum* de los corderos alimentados con estas dietas. Los resultados indican que las vainas de mezquite pueden ser usadas hasta con un nivel de inclusión del 50% sin que se observen efectos negativos en los parámetros productivos del animal; además, se logró una disminución en los costos de alimentación, lo cual, representa un ahorro del 37% para el productor. El manuscrito será sometido para su publicación en una revista indexada en el Journal Citation Reports.

**Growth performance, blood metabolite, body composition, carcass composition, and sensory characteristics of Rambouillet lambs fed mesquite (*Prosopis laevigata*)**

**L.Y. Peña-Avelino[1], J.M. Pinos-Rodríguez[2#], B.I. Juárez-Flores[3], L. Yáñez-Estrada[4]**

[1] Programas Multidisciplinarios de Posgrado en Ciencias Ambientales, Universidad Autónoma de San Luis Potosí, Avenida Manual Nava 201, Zona Universitaria, 78290, San Luis Potosí, México. Email: zazil_79406@hotmail.com

[2] Centro de Biociencias, UASLP, km 14.5 Carretera San Luís Potosí-Matehuala, ejido Palma de la Cruz, Soledad de Graciano Sánchez, S.L.P. 78321, México. Email: jpinos@uaslp.mx

[3] Instituto de Investigación en Zonas Desérticas, UASLP, Altair No. 200. Fraccionamiento del Llano, 78377, San Luis Potosí, México. Email: berthajf@uaslp.mx

[4] Laboratorio de Género, Salud y Ambiente, Facultad de Medicina, UASLP, Av. Venustiano Carranza No. 2405. Colonia Los Filtros, 78210, San Luis Potosí, México. Email: lyanez@uaslp.mx

**Abstract**

A feeding trial using twenty-one Rambouillet male lambs (21±1.44 kg body weight) was carried out to evaluate the effects of increasing dietary levels of dry pods of mesquite (*P. laevigata*; PL). Individual feed intake and body weight were recorded during a 72–day experimental period. Substituting PL for maize grain and soybean meal, three diets were formulated: diets at no PL (CON; n= 7), 250 (PL250; n=7), and 500 (PL500; n=7) g/kg of dietary dry matter. This experiment indicated that feeding diets that contain levels of PL pods up to 500 g/kg did not affect growth performance, carcass, meat characteristics, or sensory evaluation. The results indicated that mesquite pods can be used up to PL500 in Rambouillet lambs diets to reduce feed

cost/ton (37%), while maintaining feed efficiency and improving average daily gain without compromising carcass yield or sensorial evaluation.

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**Keywords:** *carcass dressing, feed conversion*, *Longissimus dorsi*

[#]Corresponding author. E-mail: jpinos@uaslp.mx

## Introduction

In semi-arid and arid areas, feed available from natural pasture is limited (Obeidat, et al., 2011) by climatic conditions and shortage of water resources (Rezaei, Rouzbehan, Fazaeli, & Zahedifar, 2013). Moreover, rangeland is affected by an extended dry period and an overloading of cattle, leading farmers to adopt semi-intensive and intensive systems for growing and fattening lambs (Majdoub-Mathlouthi, Said, Say, & Kraiem, 2013). Those systems are based on conventional feeds such as soybean meal, barley, sorghum, wheat, and maize grain, and even if they are known to be excellent sources of nutrients (Obeidat & Shdaifat, 2013), prices have increased significantly recently (Obeidat et al., 2011; Majdoub-Mathlouthi et al., 2013). Mesquite pods may be a good replacement for conventional feeds in regions with water limitations due to their adaptability at varying climates, different soil and salinity conditions, tolerance to drought stress, and low water requirements (Galindo, García, Wendt, & González, 1992; López-Lauenstein, Fernández, & Verga, 2012) . Furthermore, mesquite pods (i.e., *P. laevigata*) are highly nutritious with 11.7% crude protein (Andrade-Montemayor, et al., 2009) and 53.9% soluble carbohydrates, giving them good palatability (de la Rosa, Frias-Hernández, Olalde-Portugal, & González Castañeda, 2006). Mesquite pods yielded 3.7 ton/ha BH in the Altiplano Potosino

whereas the grain corn yield (without irrigation) was 0.57 ton as-is/ha (Ruiz, 2011; SIAP- SAGARPA, 2012).

In several studies, the use of mesquite pods in diets for livestock has been analyzed by partially replacing traditional grains (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005; Mahgoub, Kadim, Johnson, et al., 2005; Obeidat, Abdullah, & Al-Lataifeh, 2008; Obeidat & Shdaifat, 2013; Ravikala, Patel, Murthy, & Wadhwani, 1995). However, their use is controversial, as some authors have argued that food consumption and weight gain decreased at levels above 30% of dietary dry matter (Andrade-Montemayor, et al., 2009; Cook, Scott, & Hartmann, 2008; Tabosa, et al., 2006). These negative effects were attributed to secondary compounds, which limit mesquite pods' nutritive value. In contrast, other authors (Mahgoub, Kadim, Johnson, et al., 2005; Obeidat, et al., 2008; Obeidat & Shdaifat, 2013) have explained that mesquite pods may contribute to feed cost reduction, which is a key component in cost of production. However, no data are available evaluating the effects of feeding mesquite pods to Rambouillet lambs. Thus, the objective of this study was to evaluate the effects of partially replacing maize grain with mesquite pods on growth performance, ruminal fermentation, serum chemistry parameters, carcass and meat characteristics, and sensory evaluation of Rambouillet lambs being fed finishing diets.

## Materials and methods

### *Location, design, animals and diets*

The study was conducted in Real del Potosí, Cerro de San Pedro, San Luis Potosí, México. Geographical coordinates are between parallels 22° 16' and 22° 08'

north latitude, the meridian 100° 42'and 100° 54' west longitude, altitude between 1800 and 2500 m (INEGI, 2009).

Twenty-one Rambouillet non-castrated male lambs, weaned at 2 months of age with 21 ± 1.44 kg of average initial body weight (BWi) were used. The animals were housed individually in shaded pens (1.2 m x 0.8 m) equipped with feeders and water suppliers, under a barn during the experimental period. Animals were randomly assigned to one of the three experimental treatments. They were submitted to 12-day period of adaptation to the experimental diets. During this period, the lambs were feed with alfalfa hay and were gradually changed by one experimental diet. The experimental diets were different mesquite pod levels: diets at no PL (CON; n= 7), 250 (PL250; n=7), and 500 (PL500; n=7) g/kg of dietary dry matter and used to replaced corn maize and soybean meal (Table 1).The experimental diets were formulated to meet the requirements for a growth rate of 300 g/d for fattening male lambs at two month of age (NRC, 1985). Lambs were fed twice a day (two equal meals at 8:00 am and 14:30 pm) for 84 days (12-day period for adaptation to diets and 72-day period for growth performance trial). Diets were mixed every two weeks during the study and were sampled upon mixing to ensure consistency in their chemical composition. Amounts of feed offered to animals were calculated according to previous matter intake and adjustments were made when needed so that refused feed did not exceed 10 % base fresh of daily intake. Refusals were weighed before distribution of morning diets the following day to evaluate diet intake, and representative samples were taken for laboratory analysis. When feeders were found empty, the amount of feed offered was scaled up by 10% on the following day.

Mesquite pods were allowed to air-dry before passing through a Bear Cat mill with a 3-inch screen (Crary Industries, Inc. West Fargo, ND. USA), in order to reduce their size before being added to the diets. This ensured thorough mixing and avoided selection. Feed cost was calculated based on prices of diet ingredients in 2013 and used to calculate the cost of gain (Table 2). Lambs were weighed at the beginning of the study and each 12 d, before the morning feeding. Then, average daily gain (Table 2) was calculated by subtracting the initial body weight (BWi) from the body weight each 12 d. In this way, we evaluated 6 repeated measures within the experimental period. The total weight gain was determined by deducting BWi from the final body weight (BWf) and then dividing it by the duration of the experiment.

***Slaughtering procedures and meat quality evaluation***

At the end of the experiment (84 d) all the animals (n= 21) were harvested by exsanguination using conventional humane procedures. All animals were slaughtered after being fasted for around 18 h. Fasted live weight was recorded immediately before slaughter to determine the hot carcass weight (HCW). All carcasses were chilled 4°C for approximately 24 h and weighed again in order to determine the cold carcass weight (CCW). The difference between the CCW and HCW was used to calculate carcass shrink loss (CSL). Hot and cold carcass dressing were calculated using HCW and CCW divided by BWf and then multiplying the result by 100. Non-carcass edible components were removed and weighed directly after slaughter. Non-carcass components including lungs, trachea, heart, liver, spleen, kidneys, kidney fat, and empty digestive, testes and gastro-intestinal content were weighed. On the next day, carcass conformation and indices were measured as described by Colomer-

Rocher, Morand-Fehr, Kriton, Delfa, & Sierra (1988). Carcass conformation was scored as follows: 1= poor; 2= normal 3= good; 4= very good and 5= excellent. The measurements that were taken are as follows: internal carcass length (L), hind limb length (F), buttock perimeter (B), buttock width (G), thorax depth (Th) and thorax width (Wr), while carcass compactness indices were CCW/L, L/G, G/F, Wr/Th, Th/L and Th/G. Kidney fat cover was estimated comparing carcasses with photographic models of a 3-point scale according to the kidney surface covered with fat. Fatness degree was classified on a scale of 1-5 as follows: 1= very lean carcass; 2=lean carcass; 3= average fat carcass; 4= fat carcass and 5= very fat carcass. Subcutaneous fat thickness was measured using a digital calibrator at 4 cm from the spinal column and measurements at the level of the $13^{th}$ rib were done to measure dorsal fat thickness by using a ruler in a perpendicular position with relation to the external surface of the carcass at 6 cm from the dorsal apophysis of the vertebra (Colomer-Rocher, et al., 1988; Ruiz de Huidobro, Miguel, Cañeque, & Yelasco, 2005).

***Laboratory procedures***

Diets and mesquite pods were analyzed for dry matter, 55 °C in air-forced oven until constant weight, and then ground to pass 1 mm screen (Wiley mill, model 4; Arthur Thomas Co. Philadelphia, PA, USA), following AOAC procedures (930.15; AOAC, 2005) The ash content was determined by the method 942.05 (AOAC, 2005) (550 °C in ashing furnace for 6 h). The Kjeldahl procedure (976.05; AOAC 2005) was used for determining crude protein (Nx6.25). The ether extract was measured using the method described by Camfield, Brown, Lewis, Rakes, & Johnson, (1997),

Goldfisch apparatus (Labconco Corp., Kansas City, MO, USA). The neutral detergent fiber (NDF) and acid detergent fiber (ADF) were assayed according to procedures described by Van Soest, Roberson, & Lewis, (1991) with modifications for use in the ANKOM 200 fibre analyzer apparatus (ANKOM Technology Corporation, Fairport, N.Y.) Neutral detergent fibre analyses were conducted using sodium sulfite and alpha amylase (heat stable).

In order to determine the chemical composition of each *Longissimus thoracis et lumborum* (LTL), (12th and 13$^{th}$ rib), samples were vacuum-packaged and kept at -20° C until the analysis was performed. After that period, the samples were thawed at 4°C for 24 h to measurement shear force; unfrozen samples of LTL were cut parallel to the muscle fiber orientation. A computer-controlled Instron Universal texturometer model 5565 was used (Instron Engineering Corp., Canton, MA, USA). The final pH was measured using Orion 410 pH-meter (Orion Research Incorporated, Boston, MA). The color was measured in the LTL slices. The color coordinates L* (lightness) a*(redness) b*(yellowness) were measured using a Minolta CM-2500 color-meter (Minolta Co. Ltd. Osaka, Japan). Measurements were performed using illuminant A and 10° standard observer. For each muscle slice, average values were calculated from triplicate readings made on non-overlapping areas of the sample.

LTL subsamples were placed in a 100-ml beaker and freeze-dried using a Labconco freeze dryer (Model 4.5, Labconco Corp., Kansas City, MO, USA) until total weight of the beaker and sample did not decrease by more than 0.1 g in a period of 12 h. Moisture contain was calculated by loss in weight due to freeze-drying. After moisture determination, the samples were mixed and powdered using a ceramic mortar. Samples were placed in jars and sealed to prevent samples from regaining

moisture. Samples were then freeze-dried for an additional 12 h before percent protein, fat, and ash determination. Fat contain were determined by ether extract using the method previously described by Camfield, et al., (1997), (Goldfish apparatus (Labconco Corp., Kansas City, MO, USA). Protein contain were determined by using Kjeldahl procedure (AOAC Official Method 976.05; AOAC, 2005) and ash contain were determined by using a muffle furnace (Lindberg Muffle Furnace, Thermolyne Corp., Dubuque, Iowa, USA) heated to 600°C for 6 h (AOAC, 2005).

Samples of LTL were homogenized and one gram of sample was extracted with chloroform-methanol 2:1(v/v) according to Folch, Lees, & Sloane-Stanley (1957). The esterified samples were analyzed using an Agilent Technologies gas chromatograph (HP 6890) fitted with a Supelco SP-2560 capillary column (100 m×0.25 mm×0.20 µm) Supelco, Bellefonte, PA, USA, and flame ionization detector. Helium gas was used as the carrier at a flow rate of 40 ml/min. The injector and detector were held at 240°C and 260°C, respectively. A 1 µl sample was injected at a split ratio of 1:40, the oven temperature was hold at 140°C for 3 min, increased to 170°C at a rate of 7°C for min, and hold at this temperature for 1 min, increased to 215°C at a rate of 7°C min-1, and hold at this temperature for 10 min, and then increased to 240°C at a rate of 2°C min-1, and hold at this temperature for 5 min. Individual fatty acid peaks were identified by comparison with known reference methyl esters (Supelco 37 Component FAME Mix, 47885-U, Sigma-Aldrich Co.). All FA values were expressed as a weight percentage of total fatty acids.

Ruminal fluid samples were collected after the slaughter and pH was recorded using a pH meter (Fisher Accumet, Pittsburgh, PA, USA). Samples were acidified with 3 M *m*-phosphoric acid (1:10) dilution, then cooled (4 °C) for 30 min and centrifuged

(25,000 x *g*; 4 °C for 20 min). Supernatant fluid samples were kept and frozen for the further analysis. Volatile fatty acid concentration was determined (VFA) (Erwin, Marco, & Emery, 1961) in a gas chromatograph with flame ionization detector (6890N, Agilent Technologies Systems, USA) and a capillary column HP-INOWax 30 m x 0.25mm x 0.25 µm with programed temperature (80 °C for 1 min, increases of 20 °C/ min to reach 120 °C/min, increases 10 °C/min to reach 205 °C hold for 2 min), helium as carrier gas at a constant flow rate of 1.5ml/min.

Ammonia N of ruminal fluids was determined according to McCullough, (1967). Standard and measurements were performed at 630 nm with an UV-VIS spectrophotometer (HP 8453; Agilent Technologies).

***Serum chemistry parameters***

To assess the effect of treatments on serum chemistry parameters, blood samples were collected from all animals assigned to each treatment on day one, thirty-six and seventy-two of the experimental period. Blood samples were collected just before the lambs were fed in the morning (8:00 am). Approximately 6 ml of blood was collected by BD vacutainer tubes and transferred to laboratory on ice. Blood samples were centrifuged (3400 g x 15 min) and serum was stored at −20 °C until analyzed. Analyses were performed on groups of 7 samples that were thawed at room temperature (20 °C) for approximately 15 min and homogenized before analysis. Creatinine (Creatinine Jaffé), and uric acid (Mono SL Elitech), were measured using kits of ELITech Clinical System (France) in a spectrophotometer (Benchmark Microplate Reader, Bio-Rad laboratories, USA) and urea-N (BUN Liqui-

UV Lincoln laboratory USA) was measured using a spectrophotometer (Springlab 100, Spinreact, Mexico).

***Sensory evaluation***

*Longissimus thoracis et lumborum,* muscle consumer acceptance was measured following the methodology proposed by Cañeque & Sañudo (2000). The panel consisted in 16 consumers (4 men, 12 women; age=20 to 49 years) at the Dietology Laboratory of the Faculty of Nursing of the Autonomous University of San Luis Potosí. Before the sensory trials, panelists were given precise instructions on how to qualify the LTL muscle meat and fill out the hedonic scale formats (5= like very much; 4= like; 3=neither like nor dislike; 2= dislike; 1= dislike very much). Evaluated variables were appearance, juiciness, texture, flavor, aroma, and hardness (Velasco, Parada, Williams, Campos, & Melín, 2010). After thawing and until reaching an internal temperature of 16-18°C, lamb samples were cut into cubes (approx. 1 $cm^3$) and were cooked until the internal cooking temperature reached (70°C), each panelist was offered three treatments; each treatment was represented by two cubes. Samples were wrapped in aluminum foil and identified with a single random two-digit code; they were kept warm until serving (10-15 minutes after cooking). Sensory tests were performed in three sessions. Panelists also received a glass of water, salt-free bread, and a napkin. At the beginning of the sensory evaluation and between samples, the panelists ate a slice of bread to eliminate the flavor and aroma effects, and drank water to clean out their mouths to return the palate to its initial conditions

***Statistical analysis***

Data were analyzed as a completely random design using SAS, 2002. GLM procedure was used to analyze the fixed effects of treatment on performance, carcass and meat quality traits, with animal serving as the experimental unit. In the multiple comparisons of means the Tukey test was used. MIXED procedure was used to analyze average daily gain, feed intake, feed efficiency ratio, feed efficiency conversion (six periods of 12 d) and serum parameters. The compound symmetry was used as a covariance structure in this model. Additionally, a polynomial contrast was used to test the linear or quadratic effects of feeding PL on measured parameters. Categorical data as conformation, fatness degree, kidney fat cover and sensory evaluation was performed with the nonparametric Kruskal-Wallis test. A probability of less than or equal to 0.05 ($P \leq 0.05$) was considered a significant difference.

**Results and discussion**

**Mesquite *pods***

The chemical composition of mesquite pods in this study was similar to the reported by Andrade-Montemayor, et al. (2009) (Table 1). Baraza, Ángeles, García, & Valiente-Banuet (2008) showed lower values for NDF and ADF and greater values for ash than our results. Others authors have shown some variation in chemical composition of mesquite pods (Andrade-Montemayor, et al., 2009; Baraza, et al., 2008; de la Rosa, et al., 2006) collected in a zone with a greater pluvial precipitation than in this study. Hence, some of the differences in the chemical composition may be due by climatic conditions, defense to diseases and predators or different soil

conditions as indicated by Palacios (2006). To our knowledge there are few literature data gathering in a single study carcass characteristics, serum biochemistry, meat quality and sensorial characteristics of Rambouillet lambs fed mesquite pods. Therefore, the discussion in this study relies on other alternative non-conventional food and previous work on diets with other species of mesquite or similar chemical composition.

***Diets and lambs performance***

Nutrient composition of the three diets was similar between the treatments ($P>0.05$; Table 1). The price of CON diet was $457 USD/tonnes base fresh, and the PL500 diet was $347 USD/tonnes. When maize corn was partially replaced by mesquite pods, the feed cost/tonne was reduced by 24% and 11% for diet of PL500 and PL250, respectively (Table 1). Feed cost/ton was reduced with mesquite diets to compare with CON diet. Our results showed that mesquite is an alternative with economic benefits to farmer, as had been indicated by others authors around of world (Mahgoub, Kadim, Forsberg, et al., 2005; Mahgoub, Kadim, Johnson, et al., 2005; Obeidat, et al., 2008; Obeidat & Shdaifat, 2013). High levels (≤25%) of PL represent an advantage with respect conventional feeds as maize grain, because PL is well distributed and adapted to arid and semi-arid.

No differences were found in grow performance with exception on dry matter intake and cost/kg gain (Table 2). DMI was increased in PL500 diets compared with PL250 and CON diets; this result may be explained by the high content of non-structural carbohydrates (sugars, starches, organic acids, and fructans) and pectin,

providing readily available energy. In agreement with Fimbres-Durazo, Ramírez-Romero, Michel-Gallegos, & Kawas (2013) the sucrose provide a good palatability, in addition to stimulating rumen function. The cost of gain was reduced for lambs fed PL500 and PL250 than for lambs fed CON, these results showed that PL pods represented a good resource of low price as feeding cost of PL500 decreased by 37% and PL250 by 31% compared with CON. The reduction in the cost was due to the fact that the PL pods were cheaper than maize corn. Works related to the use of PL pods (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005; Obeidat, et al., 2008) in the feeding of ruminants indicated that it was effective in reducing the cost of the diet at levels up to 200 g/kg in goats and 300 g/kg in lambs. Additionally, some authors have evaluated non-conventional ingredients for reducing the cost of diets and observed higher costs relative to ours, when used Sesame hulls (by-product of the sesame seed) at level up 125 and 250 g/kg and a similar costs when used Carob pods (*Ceratonia siliqua L*) (Obeidat & Aloqaily, 2010; Obeidat, et al., 2011). Also these authors used lower levels of inclusion, so we concluded that it is cheaper to increase the use of mesquite pods on the diet (50%).

At the beginning of the study, BWi was similar among treatment groups and at study end, final weight and average daily gain were not different for lambs fed mesquite diets. However, total weight gain was 21% numerically greater in PL500 than CON. Regarding on growth performance, our results were consistent to results obtained by Obeidat, et al. (2008) when the lambs consumed diets contained 200 g/kg *P juliflora*, but the results observed by other authors were lower than our results (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005); they who found that feeding Omani native goats and male sheep on diets contained 300 g/kg of *Prosopis*

*juliflora* diets and 450 g/kg of *Prosopis cineraria* diets respectively, reduced growth rate when compared to the control group. Our results were comparable with other researches using carob pods (Obeidat, et al., 2011), sesame meal (Obeidat, et al., 2009), or sesame hulls (Obeidat & Aloqaily, 2010), where the goal was to reduce the cost of diets using local resources. Perhaps the difference between the results obtained in this study and previous work is due by the species of mesquite used and the low concentration of secondary compounds.

Results of daily matter intake were consistent with results obtained by Obeidat, et al. (2008). In the current study with finishing Rambouillet lambs fed various levels of mesquite did not show any of the signs of ill-health, such as diarrhea or impaction, that have been reported in mesquite-fed animals. Tabosa, et al. (2006) conversely it is possible that, the content of non-structural carbohydrates in PL diets provided a good palatability that increased the DMI. Obeidat, et al. (2011) indicated that the intake variation among different diets containing mesquite could be related to diet composition, level of intake of the offered feed and animal species and breed. For example, some authors (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005; Obeidat & Shdaifat, 2013) indicated that not affect feed intake in sheep or goats using levels of 150-250 g/kg of mesquite (*P. juliflora, P. cineraria*), but in diets containing PL pods at level of 45% and 30% feed intake was depressed due to the reduction of the palatability (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005). While Mahgoub, Kadim, Johnson, et al. (2005) reported that feed intake increased for lambs fed on local concentrate containing 350 g/kg of mesquite pods in replacement a commercial concentrate.

Feed conversion was similar among diets. Obeidat, et al. (2008) indicated a better feed conversion when used *P. juliflora* pods, but the level of dietary inclusions were lower compared with levels of inclusion in this study. Moreover, Mahgoub, et al. (2004) and Mahgoub, Kadim, Forsberg, et al. (2005) showed a worse feed conversion when using *P. cineraria* and *P. juliflora,* respectively. Similar results were noted by Obeidat, et al. (2011) using Carob pods (*Ceratonia siliqua L*). However, Obeidat, et al. (2009) and Obeidat & Aloqaily (2010), showed results with value intermediate between the use of *P. juliflora* and *Ceratonia siliqua L.*, using non-conventional feeds. Additionally, Ríos, et al. (2011) showed similar results to ours and mentioned that the feed conversion was influenced by other factors such as age, breed, fed and weather conditions. In addition, feed efficiency was improved with the inclusion of the PL, which contrasted with the results of previous reports (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005) indicating a decrease in feed efficiency when mesquite pods were included at levels above 300 g/kg.

***Carcass and non- carcass characteristics and linear measurements***

Results of carcass performance in lambs fed diets containing mesquite pods are presented in Table 2. There were no differences between treatments (P>0.05) with respect to hot carcass weight (HCW), cold carcass weight (CCW), and cold carcass dressing (CCD), but hot carcass dressing (HCD) and carcass shrunk loss (CSL) were greater in CON. Further, non-carcass components, offals, indexes and subcutaneous fat thickness were similar among all treatments (P>0.05; Table 4). Carcass characteristics were different (P<0.05) in muscle conformation and fatness degree. PL500 and PL250 diets results in greater muscle conformation than the CON diet,

and in the same way, PL500 was greater than CON, and PL250 was intermediate for fatness degree. Additionally, digestive tract, and carcass linear dimensions were similar with exception empty rumen and internal carcass length (L), respectively (P>0.05; Table 4). Empty rumen was greater in lamb fed PL500 than those fed CON and intermediate for lambs fed PL250. Internal carcass length, (L) was superior in lambs fed PL500 and PL250 diets relative to CON.

In our results the greater carcass shrink loss and dressing percentage was noted in CON compared with PL diets. In previous works (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005; Mahgoub, Kadim, Johnson, et al., 2005) authors using mesquite pods reported carcass performance lower than our results. Moreover, no substantial influences of treatments on non-carcass characteristics have been noted in Rambouillet lambs fed fatting diet. In addition, all results of non-carcass characteristics quality were within the range of acceptable values when compared to results obtained by Obeidat, et al. (2008). Overall, results of the current study confirmed that the used of PL in Rambouillet lambs fed fattening diets had not negative effect on the carcass and non-carcass, but different results have been indicated by the incorporation of mesquite pods (Mahgoub, et al., 2004; Mahgoub, Kadim, Forsberg, et al., 2005)

Values of carcass measurements were comparable to those obtained in similar works with non-conventional feeds (Obeidat, et al., 2008; Obeidat, et al., 2009; Obeidat & Aloqaily, 2010), using crossbreds Mexican lambs (Hernández-Cruz, Ramírez-Bribiesca, Guerrero-Legarreta, & Hernámdez-Mendo, 2009) and Mexican hair sheep (Ríos, et al., 2011). Heart, liver, lungs and trachea, rumen fill and feet were somewhat heavier than in previous works (Mahgoub, et al., 2004; Majdoub-

Mathlouthi, et al., 2013; Obeidat, et al., 2008; Obeidat, et al., 2009; Obeidat & Aloqaily, 2010; Obeidat, et al., 2011; Ríos, et al., 2011). However, empty rumen was greater with PL500 compared with PL250 and CON diets, which may have resulted from the difference in DMI. Dietary treatment were formulated with the same quantity of NDF, but the nonstructural carbohydrates was greater in PL diets and could have influenced in palatability for PL500 diet favorably.

In our study, differences were detected among treatments for muscle conformation. In a study using metabolic modifier to improve efficiency of livestock production reported higher values compared with the current research, but fatness degree and kidney fat cover value were lower (Mondragón, et al., 2010). Additionally, carcass linear measurements, indices and subcutaneous fat thickness not were affected by diets, with the exception of buttock perimeter (B) in PL diets compared with CON (Table 3). (Majdoub-Mathlouthi, et al., 2013) showed greater buttock perimeter than our results, which could be due to the type of breed and age of animals. Otherwise, thorax width (Wr), thorax depth (Th), buttock width (G), hind limb length (F), were increased compared with other related reports (Arvizu, et al., 2011; Obeidat, et al., 2008). Hind limb length (F), internal carcass length (L) and thorax depth (Th) were lower compared with others investigations (Majdoub-Mathlouthi, et al., 2013; Obeidat, et al., 2008; Obeidat, et al., 2009; Ríos, et al., 2011).

***Overall ruminal pH, ammonia N and volatile fatty acid***

Not differences ($P>0.05$; Table 5) were noticed among treatments with regard to fluid ruminal pH. Ruminal pH values varied from 6.3 to 6.5, which were within optimum pH range (6.7 ± 0.5) required for maintaining normal cellulolytic organisms

(Van Soest, 1994). Ruminal pH was similar between treatment as reported by Bhatta, Vaithiyanathan, Singh, & Verma (2007) when used *P. cineraria* leaves at level of 50 %. Ruminal $NH_3$-N concentration was significantly affected ($P < 0.05$) by the level of PL diets. In the current study, ruminal $NH_3$-N concentrations in the PL treatments were greater than the recommended value of 70 mg N/l required for maximum microbial protein synthesis (Okorie, Buttery, & Lewis, 1977). Some studies reported that increased protein level or dietary degradation typically resulted in increased ruminal $NH_3$-N concentration (Klevesahl, et al., 2003). Total VFA's in rumen content of lamb fed PL500 was greater compared with sample collected from those fed PL250 and CON, but lower in respect to butyrate and acetate: propionate (A:P). At least for ruminants, short-chain fatty acids (VFA), constitute the major resource for the energy for the animal. According with our results the acetate:propionate:butyrate ratio in the rumen was 40:40:20.

***Serum chemistry parameters***

Furthermore, the effect of treatments on serum parameters (Table 5) were significant, except for creatinine ($P>0.05$). PL500 diets resulted in were greater in blood urea-N and uric acid than CON, and PL250 diet resulted in intermediate level. The concentration of creatinine was similar in all treatments and comparable to the range of serum biochemical reference values (0.90-2.0 mg/dL) reported by (Kahn & Line, 2005). Similar results were reported by Rezaei, et al. (2013) (0.94-0.89 mg/dL). Creatinine is a product of nitrogen metabolism related to muscle contractions, normally excreted by the kidney; low levels may also indicate liver disease (Fimbres-Durazo, et al., 2013). Moreover, uric acid concentration was different between

treatments. PL250 and CON diets showed similar values than the range of reference reported by Eshratkhah, Sadaghian, Khajeye, Ahmadi, & Mostafavi (2008) (0.35-1.35 mg/dL). Additionally, blood urea-N was different between treatments; PL500 was greater than PL250 and CON. In our study, all treatments were increased to normal range of 10-26 mg/dl (Kahn & Line, 2005). Urea-N, which is normally excreted by the kidney, is a by-product of protein metabolism. Serological examination shows slightly increased urea and uric acid values for PL500 diet. In spite of small deviations compared to reference values from literature health status of animals did not changed.

***Meat pH, color, composition chemical and fatty acid composition***

The chemical quality parameters of meat are shown in Table 6. There were no differences in moisture, ashes, and ether extract (P>0.05), in agreement with reports of other authors (Hernández-Cruz, et al., 2009; Komprda, et al., 2012). Similarly to our findings, (Huff-Lonergan & Lonergan, 2005) indicated that lean muscle contains approximately 75% water and others components as protein (20%), lipids or fat (5%), carbohydrates and ash approximately (1%). The lean muscle CP content was greater in lambs fed CON (22.9%) compared to those fed PL (21.6%). This difference could be associated with factors that are involved in protein degradability of PL diets in the rumen or the amino acid profile of the metabolizable protein. Additionally, González-Galán, Duarte-Corréa, Patto de Abreu, & Piccolo-Barcelos (2008) indicated that PL pods contained secondary compounds such as saponins, taninns, trypsin inhibitor, oxalates. These compounds may have an adverse effect on ruminal protein degradation, intestinal digestion and absorption in the small.

Ultimate pH in Rambouillet lambs observed in the current study (Table 6) was similar to that for the reported by Obeidat, et al. (2011) and lower than in other studies which evaluated non-conventional feeds (Obeidat, et al., 2008; Obeidat, et al., 2009; Obeidat & Aloqaily, 2010). Moreover, shear force (tenderness) were similar to results of Mondragón, et al. (2010) and lower than other researchers have reported with non-conventional feeds (Belal S. Obeidat, Abdullah, & Al-Lataifeh, 2008;(Obeidat, et al., 2009; Obeidat & Aloqaily, 2010; Obeidat, et al., 2011). Our results indicated that the meat produced is soft compared to other studies; it may be due the interaction of factors such as age, breed and the type of diet. Additionally, Huff-Lonergan & Lonergan (2005) mentioned that many changes occurred when muscle is converted to meat. For example there is a shift from aerobic to anaerobic metabolism favoring the production of lactic acid, resulting in pH declining to 5.4 to 5.8.

No differences were observed among treatments in shear force. However, whiteness (*L**) of LTL muscle was greater ($P<0.05$) in lambs fed CON than diets with mesquite, whereas whiteness for lambs fed the mesquite diets was not different. Redness (a*) were not different among diets, and yellowness (b*) was greater in CON diet compared with PL diets. L*, and b* meat was higher on CON relative to PL diets; nevertheless our results (i.e. whiteness; *L** redness a* and yellowness; *b**,) were greater than reported by Obeidat, et al. (2008) when lambs were fed diet contained 200 g/kg *Prosopis juliflora*, and other levels of non-conventional feed (Obeidat, et al., 2009; Obeidat & Aloqaily, 2010; Obeidat, et al., 2011) (i.e. sesame meal, sesame hulls and carob pods). Our result could be related to the low levels of secondary compounds such as tannins to produce a clearer meat. Additionally Alcalde & Negueruela (2001) indicated that the light color was associated with the meat of

young animals, and could be used as an indicator of flavor, tenderness and freshness.

The fatty acid composition of the LTL for PL diets is summarized in Table 7. The mayor fatty in LTL lipids were the saturated fatty acid (SFA), palmitic (16:0; 27-28% of total FAME) and stearic acids (18:0; 14-17%), the monounsaturated fatty acid (MUFA), oleic acid (18:1c9; 37-40%) and polyunsaturated (PUFA) linoleic acid (18:2n-6; 2-4%). CON diet increased the concentration of SFA (C15:0; C17:0), MUFA (C16:1:C17:1) and PUFA (C18:2n 6c); further the total UFA, total PUFA n-6 and UFA/SFA and PUFA/SFA ratios. PL250 was higher in stearic (C18:0, SFA) and elaidic acid (C18:1n9c, MUFA), total SFA and total trans fatty acids, while PL500 was greater in oleic acid (C18:1n9c, MUFA). In agreement with our results, Kitessa et al. (2009) and Karami, Alimon, Sazili, Goh, & Ivan (2011) mentioned that C16:0, C18:0 and C18:1 c 9 were present in substantial amounts. However, the content of C18:2 n-6 was reduced when dietary supplementation included protect linseed (Kitessa, et al., 2009) and oil palm fronds (Karami, Alimon, Sazili, Goh, & Ivan, 2011). Our results showed that CON diet resulted in greater concentration of most SFA, MUFA and PUFA n-6 compared to PL. The ratio PUFA n6/n3 did not differ among treatments. Regardless of treatments, the n6/n3 ratio in meat surpassed the recommended value, but PL500 had the lowest value. Nasri et al. (2011) reported a ratio between 8.38-6.15 when using doses of *Quillaria saponaria* (30, 60 and 90 mg/kg). Luciano, et al. (2013) observed a ratio n6/n3 of 3.47 with pasture diet and intermediate values of 5.30-10.85 with pro-oxidants, and 11.72 with concentrates feeds. Human nutrition guide lines indicate that the n-6/n-3 ratio in human diets should not exceed the value 4-5 (Ralph, 2000). According to Simopoulos (2008), a n-6/n-3 ratio decreases the risk

of cardiovascular diseases, some types of cancer and rheumatoid arthritis. Main molecules responsible for the antioxidative properties of herbs and spices are phenolic substances (flavonoids, tannins, proanthocianidins, phenolic acids, and therpens) and some vitamins (Karami, Alimon, Sazili, Goh, & Ivan, 2011), but the interaction between feed and some of these compounds are essentially unknown. The ratio observed in this study was lower than this recommendation as other trials (Alfaia, et al., 2007; Karami, Alimon, Sazili, Goh, & Ivan, 2011), but similar to the ratio reported by Nasri, et al. (2011). The n-6/n-3 ratio and PUFA/SFA, suggest that the inclusion of PL in lambs diets did not produce detrimental effects on fatty acid composition in lamb meat; however, these percentages of fatty acids in lambs meat leave no result from the polyunsaturated fat.

On the other hand, no differences were noted in sensorial characteristics ($P>0.05$; Table 8). Overall, the sensory analysis data did not show any adverse effect on the organoleptic properties of meat samples with respect of mesquite levels. The meat produced by PL500 showed numerical superiority compared with CON, indicating good acceptance by panelists and no adverse effects on attributes of sensory meat quality at level of inclusion of 500 g/kg mesquite.

## Conclusions

This study shows that feeding Rambouillet lambs diets containing mesquite pods did not adversely affect animal health or intake. The inclusion of mesquite at 500 g/kg had no effect on growth performance, carcass characteristics, meat quality and sensory evaluation but reduced the cost of the diet. Therefore, adding mesquite pods to the lambs finishing diets could be economically advantageous practice when

replacing part of corn maize and soybean meal. This non-conventional ingredient is potentially valuable and can be considered as a cheap alternative for livestock feedstuff in arid and semi-arid areas that has *P. laevigata* trees.

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Table 1 Feed ingredients and chemical composition of the experimental diets.

| Item | Dietary Treatment (Trt)[1] | | | | P-value | Contrast[3] | |
|---|---|---|---|---|---|---|---|
| | CON | PL250 | PL500 | SEM[2] | Trt | L | Q |
| Ingredient (g/kg DM) | | | | | | | |
| Corn maize | 642 | 492 | 333 | | | | |
| Soybean meal, 440 g/kg crude protein | 142 | 147 | 152 | | | | |
| *Prosopis laevigata* pods | 0.0 | 250 | 500 | | | | |
| Corn stover | 215 | 110 | 5 | | | | |
| Mineral vitamin premix[4] | 10 | 10 | 10 | | | | |
| Feed cost/ton (USD$) [5] | 405 | 358 | 306 | | | | |
| Chemical composition (g/kg DM) | | | | | | | |
| Dry matter | 957 | 958 | 957 | 2.17 | 8.68 | 8.86 | 6.19 |
| Crude protein | 143 | 144 | 150 | 2.68 | 1.54 | 0.88 | 3.52 |
| Neutral detergent fiber | 225 | 222 | 230 | 4.68 | 2.53 | 2.67 | 2.06 |
| Acid detergent fiber | 128 | 132 | 139 | 2.06 | 4.80 | 2.53 | 8.48 |
| Ash | 46.4 | 47.4 | 48.8 | 1.42 | 2.06 | 0.91 | 8.70 |
| Metabolizable energy (Mcal/kg)[6] | 3.0 | 3.0 | 3.1 | | | | |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
[4] Composition per kg contained (Se 10 mg; K 215 mg; Fe 50 mg; Co 20 mg; Zn 50 mg; Mn1600mg; Cu 300 mg; I 70 mg; Ca 220 mg; P 280 mg; S 30 mg; sal 845 mg; urea 102 mg; vitamin A 150 MUI/kg; vitamin D25 MUI/kg; vitamin E 150 UI/kg; lasalocid 1.3 g/kg).
[5] Calculated based on ingredients prices at the time of preparing the manuscript $12.87 MN
[6] Calculated based on tabular value of NRC (1985).
[ab] Means within the rows with different superscripts are significantly different at $P$ <0.05.

Table 2 Growth performance of Rambouillet male lambs fed diets containing different levels of mesquite pods.

| Item | Dietary Treatment (Trt)[1] | | | | P-value | Contrast[3] | |
|---|---|---|---|---|---|---|---|
| | CON | PL250 | PL500 | SEM[2] | Trt | L | Q |
| Growth performance | | | | | | | |
| Initial body weight (BWi), kg | 23.3 | 21.6 | 22.8 | 4.1 | 0.71 | 0.79 | 0.44 |
| Final BW(BWf), kg | 37.7 | 39.1 | 41.1 | 6.3 | 0.62 | 0.33 | 0.93 |
| Total weight gain, kg | 14.3 | 17.6 | 18.3 | 3.8 | 0.15 | 0.07 | 0.48 |
| Average daily gain, g/d[4] | 222 | 247 | 258 | 19.4 | 0.42 | 0.19 | 0.77 |
| Dry matter intake, kg/d | 1.03[b] | 1.1[b] | 1.2[a] | 0.05 | 0.01 | 0.004 | 0.55 |
| Feed conversion [5] | 5.1 | 5.2 | 5.6 | 0.63 | 0.86 | 0.61 | 0.86 |
| Feed efficiency [6] | 0.2 | 0.2 | 0.2 | 0.02 | 0.89 | 0.98 | 0.63 |
| Cost/kg gain ($US) | 2.3[a] | 1.6[b] | 1.5[b] | 0.27 | 0.0005 | 0.0002 | 0.16 |
| Carcass performance | | | | | | | |
| Hot carcass weight, kg | 18.6 | 18.1 | 18.5 | 3.5 | 0.96 | 0.97 | 0.77 |
| Cold carcass weight, kg | 17.2 | 17.2 | 17.6 | 3.3 | 0.97 | 0.84 | 0.91 |
| Hot carcass dressing, % | 49.3[a] | 45.7[b] | 45.3[b] | 2.5 | 0.01 | 0.007 | 0.21 |
| Cold carcass dressing,% | 44.9 | 43.5 | 42.7 | 2.6 | 0.32 | 0.14 | 0.78 |
| Carcass shrunk loss, % | 9.0[a] | 5.0[b] | 5.5[ab] | 2.9 | 0.04 | 0.04 | 0.11 |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
[4] ADG ((final weight-initial weight)/72 days).
[5] kg DM intake/ kg gain.
[6] kg gain/ kg DM intake.
[ab] Means within the rows with different superscripts are significantly different at $P < 0.05$.

Table 3 Non-carcass component of Rambouillet lambs fed finishing diets containing mesquite pods

| Item | Dietary Treatment (Trt)[1] | | | | P-value | Contrast[3] | |
|---|---|---|---|---|---|---|---|
| | 0 | 25 | 50 | SEM[2] | Trt | L | Q |
| Non-carcass components (kg) | | | | | | | |
| Heart weight, | 0.25 | 0.22 | 0.25 | 0.07 | 0.64 | 0.97 | 0.35 |
| Liver weight | 0.78 | 0.72 | 0.75 | 0.15 | 0.69 | 0.71 | 0.44 |
| Spleen weight | 0.06 | 0.04 | 0.05 | 0.02 | 0.35 | 0.72 | 0.17 |
| Kidney weight | 0.31 | 0.24 | 0.25 | 0.10 | 0.29 | 0.21 | 0.34 |
| Testes weight | 0.16 | 0.16 | 0.26 | 0.15 | 0.37 | 0.99 | 0.17 |
| Lungs and traquea | 0.71 | 0.68 | 0.73 | 0.19 | 0.88 | 0.86 | 0.63 |
| Digestive tract (kg) | | | | | | | |
| Rumen empty | 1.3[ab] | 1.2[b] | 1.7[a] | 0.41 | 0.04 | 0.05 | 0.09 |
| Rumen content | 4.6 | 5.3 | 5.5 | 1.04 | 0.27 | 0.13 | 0.57 |
| Small empty | 0.4 | 0.5 | 0.5 | 0.23 | 0.29 | 0.27 | 0.26 |
| Small intestine content | 0.8 | 0.7 | 0.8 | 0.16 | 0.73 | 0.59 | 0.56 |
| Large intestine empty | 0.6 | 0.5 | 0.8 | 0.41 | 0.37 | 0.33 | 0.30 |
| Large intestine content | 0.9 | 0.9 | 0.9 | 0.19 | 0.86 | 0.59 | 0.95 |
| Offals (kg) | | | | | | | |
| Skin | 4.5 | 4.2 | 4.7 | 0.84 | 0.56 | 0.70 | 0.27 |
| Blood | 1.6 | 1.6 | 1.6 | 0.23 | 0.64 | 1.00 | 0.35 |
| Horned head | 2.0 | 2.0 | 1.9 | 0.26 | 0.90 | 0.78 | 0.72 |
| Feet | 1.2 | 1.2 | 1.1 | 0.17 | 0.68 | 0.39 | 0.89 |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
[ab] Means within the rows with different superscripts are significantly different at $P < 0.05$.

Table 4 Carcass characteristics of Rambouillet lambs fed finishing diets containing mesquite pods

| Item | Dietary Treatment (Trt)[1] | | | | P-value | Contrast[3] | |
|---|---|---|---|---|---|---|---|
| | 0 | 25 | 50 | SEM[2] | Trt | L | Q |
| Carcass characteristic scores | | | | | | | |
| Muscle conformation[4] | 2.3[b] | 3.3[a] | 3.4[a] | 4.5 | 0.006 | 0.004 | 0.08 |
| Fatness degree[5] | 1.8[b] | 2.7[ab] | 3.3[a] | 4.8 | 0.009 | 0.002 | 0.70 |
| Kidney fat cover[6] | 2.2 | 2.1 | 2.0 | 3.7 | 0.35 | 0.15 | 1.00 |
| Carcass linear dimensions (cm) | | | | | | | |
| Internal carcass length, (L) | 65.3 | 65.3 | 63.4 | 4.8 | 0.99 | 0.99 | 0.98 |
| Leg length, (F) | 29.8 | 32.2 | 31.0 | 3.7 | 0.51 | 0.58 | 0.32 |
| Rump width, (G) | 26.8 | 30.9 | 28.0 | 4.3 | 0.23 | 0.63 | 0.10 |
| Rump circumference, (B) | 39.0[b] | 42.6[a] | 43.1[a] | 3.0 | 0.04 | 0.02 | 0.29 |
| Thoracic depth, (Th) | 20.1 | 21.3 | 21.1 | 1.4 | 0.23 | 0.17 | 0.31 |
| Thoracic width,(WR) | 27.4 | 28.5 | 28.0 | 5.1 | 0.92 | 0.83 | 0.72 |
| Indices | | | | | | | |
| L/G | 1.5 | 1.4 | 1.6 | 0.25 | 0.33 | 0.38 | 0.23 |
| Th/G | 0.76 | 0.69 | 0.78 | 0.12 | 0.41 | 0.75 | 0.20 |
| CCW/L (g/cm) | 0.44 | 0.40 | 0.41 | 0.08 | 0.61 | 0.45 | 0.53 |
| G/F | 0.92 | 0.96 | 0.91 | 0.19 | 0.87 | 0.88 | 0.62 |
| Wr/Th | 1.4 | 1.3 | 1.3 | 0.31 | 0.95 | 0.75 | 0.93 |
| Th/L | 0.51 | 0.50 | 0.49 | 0.05 | 0.67 | 0.38 | 0.88 |
| Subcutaneus fat thickness (mm) | | | | | | | |
| Right dorsal | 0.38 | 0.42 | 0.32 | 0.21 | 0.68 | 0.62 | 0.48 |
| Left dorsal | 0.55 | 0.52 | 0.40 | 0.19 | 0.31 | 0.16 | 0.59 |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.[4] 1, Poor; 2, normal; 3 good; 4, very good, 5, excellent, [5] 1, Very lean; 2, lean; 3 rather fatty; 4, fatty, 5, very fatty, [6] 1, Poor; 2, normal; 3 much.

[ab] Means within the rows with different superscripts are significantly different at $P < 0.05$.

Table 5 Overall ruminal pH, ruminal ammonia N and volatile fatty acid (VFA), and serum chemistry parameters of lambs fed diets with different levels of mesquite pods

| Item | Dietary Treatment (Trt)[a] | | | | P-value | Constrast[3] | |
|---|---|---|---|---|---|---|---|
| | CON | PL250 | PL500 | SEM[b] | Trat | L | Q |
| Ph | 6.4 | 6.3 | 6.5 | 0.27 | 0.29 | 0.23 | 0.30 |
| Ammonia N, mg $L^{-1}$ | 62.8[b] | 99.8[a] | 87.1[a] | 38.9 | 0.001 | 0.01 | 0.004 |
| Acetate, Mol 100 $mol^{-1}$ | 40.0 | 38. 8 | 40.6 | 2.33 | 0.34 | 0.64 | 0.17 |
| Propionate, Mol 100 $mol^{-1}$ | 37.9[a] | 37.3[a] | 29.1[b] | 4.18 | 0.001 | 0.009 | 0.06 |
| Butirate, Mol 100 $mol^{-1}$ | 22.0 | 23.9[b] | 30.3[a] | 3.4 | 0.0006 | 0.0002 | 0.16 |
| Total VFA´s, mMol $L^{-1}$ | 54.5[b] | 58.9[b] | 87.1[a] | 17.8 | 0.005 | 0.003 | 0.16 |
| Acetate:Propionate | 1.1[b] | 1.1[b] | 1.4[a] | 0.15 | 0.001 | 0.002 | 0.02 |
| Metabolites (mg/dL) | | | | | | | |
| Creatinine | 1.3 | 0.91 | 0.90 | 0.17 | 0.12 | 0.07 | 0.32 |
| Urea-N | 26.5[c] | 34.4[b] | 38.0[a] | 1.7 | 0.0001 | 0.002 | 0.008 |
| Uric acid | 1.3 | 1.3 | 2.6[a] | 0.37 | 0.02 | 0.14 | 0.13 |

[1] Trt, dietary treatmens were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
[ab] Means within the rows with different superscripts are significantly different at $P$ <0.05.

Table 6 Chemical composition of *Longissimus thoracis et lumborum* muscle from lambs fed for 72 days with different levels of mesquite pods

| Item | Dietary Treatment (Trt)[1] | | | | P-value | Contrast[3] | |
|---|---|---|---|---|---|---|---|
| | CON | PL250 | PL500 | SEM[2] | Trat | L | Q |
| Chemical composition (g/kg DM) | | | | | | | |
| Moisture | 70.7 | 72.1 | 71.1 | 1.1 | 0.09 | 0.56 | 0.04 |
| Ashes | 1.1 | 1.0 | 1.1 | 0.05 | 0.21 | 0.23 | 0.19 |
| Crude protein | 22.9[a] | 20.8[b] | 21.6[ab] | 1.4 | 0.03 | 0.09 | 0.03 |
| Ether extract | 4.1 | 3.6 | 3.8 | 0.87 | 0.55 | 0.58 | 0.35 |
| Ultimate pH | 5.5[b] | 5.7[a] | 5.8[a] | 0.12 | 0.001 | 0.0001 | 0.50 |
| Shear force (kg/$cm^2$) | 1.4 | 1.6 | 1.6 | 0.41 | 0.21 | 0.09 | 0.62 |
| Color coordinates | | | | | | | |
| *L** (whiteness) | 45.8[a] | 42.4[b] | 42.8[b] | 3.1 | 0.0009 | 0.002 | 0.19 |
| *a** (redness) | 9.2[a] | 9.7 [a] | 10.1 [a] | 1.2 | 0.08 | 0.03 | 0.79 |
| *b** (yellowness) | 14.7 | 13.5[b] | 14.0[ab] | 1.2 | 0.005 | 0.06 | 0.007 |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
[ab] Means within the rows with different superscripts are significantly different at $P$ <0.05.

Table 7 Fatty acid composition (g/100g total fatty acid) of *Longissimus thoracis et lumborum* from lambs fed for 72 days with different levels of mesquite pods.

| Ítem | Dietary Treatment (Trt)[1] | | | | P-value | Contrast[3] | |
|---|---|---|---|---|---|---|---|
| | CON | PL250 | PL500 | SEM[2] | Trat | L | Q |
| C10:0 | 0.21 | 0.21 | 0.22 | 0.04 | 0.74 | 0.48 | 0.77 |
| C12:0 | 0.23 | 0.21 | 0.23 | 0.06 | 0.78 | 0.91 | 0.49 |
| C14:0 | 3.8 | 3.6 | 3.6 | 0.49 | 0.63 | 0.35 | 0.84 |
| C15:0 | 0.52[a] | 0.48[a] | 0.34[b] | 0.09 | 0.006 | 0.002 | 0.28 |
| C16:0 | 27.7 | 27.9 | 28.2 | 1.3 | 0.79 | 0.50 | 0.96 |
| C16:1 | 2.8[a] | 2.6[b] | 2.6[ab] | 0.21 | 0.03 | 0.03 | 0.12 |
| C17:0 | 1.5[a] | 1.4[ab] | 1.2[b] | 0.20 | 0.01 | 0.003 | 0.44 |
| C17:1 c9 | 0.98[a] | 0.74[b] | 0.66[b] | 0.14 | 0.00 | 0.007 | 0.27 |
| C18:0 | 14.5[b] | 17.18[a] | 16.5[a] | 1.35 | 0.005 | 0.02 | 0.02 |
| C18:1 t9 | 2.5[ab] | 2.9[a] | 1.7[b] | 0.64 | 0.01 | 0.04 | 0.02 |
| C18:1 c9 | 39.0[ab] | 37.9[b] | 40.9[a] | 1.8 | 0.02 | 0.07 | 0.03 |
| C18:2 n-6 (LA) | 4.5[a] | 3.4[ab] | 2.5[b] | 1.3 | 0.03 | 0.009 | 0.85 |
| C18:3 n-3 (ALA) | 0.51 | 0.34 | 0.38 | 0.15 | 0.14 | 0.15 | 0.16 |
| C18:2 CLA cis9-trans11 | 0.51 | 0.48 | 0.50 | 0.10 | 0.83 | 0.95 | 0.55 |
| C20:4 n-6 (AA) | 0.50 | 0.48 | 0.54 | 0.11 | 0.57 | 0.52 | 0.41 |
| Total SFA | 48.7[b] | 51.1[a] | 50.2[ab] | 1.7 | 0.04 | 0.10 | 0.04 |
| Total UFA | 51.4[a] | 48.8[b] | 49.8[ab] | 1.7 | 0.04 | 0.10 | 0.04 |
| Total MUFA | 45.4 | 44.2 | 45.9 | 1.4 | 0.11 | 0.49 | 0.04 |
| Total PUFA-n3 | 0.51 | 0.34 | 0.39 | 0.15 | 0.14 | 0.15 | 0.16 |
| Total PUFA-n6 | 4.9[a] | 3.8[ab] | 3.0[b] | 1.3 | 0.04 | 0.01 | 0.79 |
| Total trans fatty acid | 3.0[ab] | 3.4[a] | 2.2[b] | 0.66 | 0.01 | 0.04 | 0.02 |
| n6/n3 | 10.2 | 12.5 | 8.3 | 3.8 | 0.15 | 0.36 | 0.08 |
| UFA/SFA | 1.1[a] | 0.99[b] | 0.95[ab] | 0.07 | 0.04 | 0.09 | 0.05 |
| PUFA/SFA | 0.12[a] | 0.09[ab] | 0.07[b] | 0.03 | 0.04 | 0.02 | 0.55 |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
SFA, saturated fatty acid; UFA, unsaturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; n6, omega 6 fatty acid; n3, omega 3 fatty acid. SFA= ∑(C10:0; C12:0; C14:0; C15:0; C16:0; C17:0; C18:0). MUFA= ∑(C16:1; C17:1; C18:1n9t; C18:1n9c). PUFA n3= ∑(C18:3 n-3). PUFA n6= ∑(C18:2n6c C20:4 n-6). Trans = ∑(C18:1n9t; CLA cis9-trans11).
[ab] Means within the rows with different superscripts are significantly different at $P < 0.05$.

Table 8 Sensorial characteristics of *Longissimus thoracis et lumborum* from lambs fed for 72 days with different levels of mesquite pods.

| Item | Dietary Treatment (Trt)[1] | | | | P-value | Contrasts[3] | |
|---|---|---|---|---|---|---|---|
| | CON | PL250 | PL500 | SEM[2] | Trat | L | Q |
| Appearance and acceptation [a] | 3.3 | 3.5 | 3.4 | 0.16 | 0.63 | 0.67 | 0.39 |
| Color [b] | 3.4 | 3.6 | 3.4 | 0.13 | 0.46 | 1.00 | 0.21 |
| Chewiness [c] | 3.4 | 3.4 | 3.5 | 0.11 | 0.57 | 0.59 | 0.36 |
| Intensity, aroma and flavor [d] | 3.2 | 3.3 | 3.2 | 0.15 | 0.67 | 0.92 | 0.38 |
| Hardness [e] | 3.5 | 3.7 | 3.6 | 0.16 | 0.59 | 0.62 | 0.37 |
| Juiciness [f] | 2.8 | 3.0 | 2.9 | 0.18 | 0.47 | 0.39 | 0.39 |

[1] Trt, dietary treatments were (1) no PL (CON), (2) 250 g/kg PL (PL250), and (3) 500 g/kg PL (PL500), [2] SEM, Standard error of means, [3]Contrast: L and Q- linear and quadratic effects.
[ab] Means within the rows with different superscripts are significantly different at $P < 0.05$.
Note:
[a]1, Dislike very much; 2, dislike moderately; 3, neither like nor dislike; 4, like moderately; 5, like very much.
[b] 1, Very dark; 2, dark; 3, intermediate; 4, clear; 5, very clear.
[c] 1, Very high; 2, high; 3, moderate; 4, low; 5, very low.
[d] 1, Very high; 2, high; 3, moderate; 4, low; 5, no perceptible.
[f] 1, Very low ; 2, low; 3, moderate; 4, high; 5, very high.

## Conclusiones generales

Las vainas de mezquite (*P. laevigata*) son un ingrediente no convencional, potencialmente valioso que puede ser considerado como una alternativa económica para la alimentación del ganado en las zonas del país con una baja precipitación pluvial del país.

La composición química y la degradación ruminal de las vainas y sus fracciones son únicas, sin embargo se observaron algunas similitudes con respecto a algunos alimentos convencionales usados en las dietas para rumiantes, lo cual muestra una ventaja para el desarrollo de nuevos productos en la industria.

El uso tanto de 250 como de 500 g/kg de vainas de mezquite en dietas para borregos Rambouillet, no afectó de forma negativa la salud animal, el rendimiento del crecimiento, las características de la canal, la calidad de la carne ó la evaluación sensorial de las características organolépticas del *Longissimus thoracis et lumborum*

Por lo tanto, la adición de las vainas de mezquite podría ser una práctica económicamente ventajosa en la sustitución de grano de maíz y harina de soja

**Implicaciones**

Las zonas áridas y semiáridas del país, se caracterizan por presentar una baja precipitación pluvial e intensas sequias, que afectan la producción de cereales y follaje para el ganado, motivo por el cual, algunos productores compran alimentos concentrados, en su mayoría basados en ingredientes importados. Actualmente, el precio de estos alimentos fluctúa según el mercado internacional, esto aumenta la fragilidad en los sistemas pecuarios en más del 60% del territorio nacional. El desarrollo de áreas destinadas a plantaciones como el mezquite, puede tener beneficios importantes; al ser un árbol de uso múltiple, se puede obtener de él diversos productos que dan la posibilidad al productor de diversificar los ingresos económicos, a la vez que se incrementa el bienestar animal, por la sombra que estos árboles pueden ofrecer durante el año pues permanecen verdes; así mismo, la calidad y fertilidad del suelo se ve favorecida por el reciclaje de nutrientes al incrementarse la fijación de nitrógeno y materia orgánica cuando esta leguminosa está presente. El reto de producir alimentos cárnicos para el consumo humano puede lograrse de forma más sostenible con la incorporación de especies como el *P. laevigata*, dada su alta adaptación al ambiente del Altiplano Potosino.