Emirates Journal of Food and Agriculture. 2023. 35(10): 940-947
doi: 10.9755/ejfa.2023.v35.i10.3138
http://www.ejfa.me/

RESEARCH ARTICLE

Effect of *Guazuma ulmifolia* tannins in the diet of Pelibuey lambs on animal performance and meat characteristics

Omar Hernández Mendo[2], Marco Antonio Ayala Monter[1]*, Silvia López Ortiz[3], David Hernández Sánchez[2], Gilberto Aranda Osorio[4], and Ricardo Martínez Martínez[5]

[1]Facultad de Medicina Veterinaria y Zootecnia No. 2, Universidad Autónoma de Guerrero, Guerrero, 41940, México, [2]Programa de Ganadería, Colegio de Postgraduados, Campus Montecillo, Texcoco, Estado de México, 56230, México, [3]Colegio de Postgraduados, Campus Veracruz, Manlio Fabio Altamirano, Veracruz, 91690, México, [4]Departamento de Zootecnia, Universidad Autónoma Chapingo, Texcoco, Estado de México, 56230, México [5]Centro Universitario de la Costa Sur, Universidad de Guadalajara, Autlán de Navarro, Jalisco, 48900, México.

ABSTRACT

The objective of this experiment was to evaluate the response of animal performance and meat characteristics of Pelibuey lambs to tannins of *Guazuma ulmifolia* Lam. in the diet. Twenty-eight male Pelibuey lambs (initial body weight of 23.6 ± 1.0 kg; 5 months old) were randomly assigned to one of four treatments (T): T1, control (base diet); T2, diet 1.5% tannins; T3, diet 2.5% tannins; and T4, diet 1000 IU vitamin E. Vitamin E was used as a positive control treatment. The variables evaluated were daily weight gain (DWG), dry matter intake (DMI), feed conversion, and carcass and meat characteristics. The experimental design was completely randomized, and treatments means were compared with Tukey test ($P<0.05$). None of the evaluated variables were different between treatments ($P>0.05$), except meat color ($P<0.05$), with higher values of L^*(34.88), a^*(11.49), and b^*(2.28) when tannins were added to the diet of the lambs, without affecting the dry matter intake. Including *Guazuma ulmifolia* foliage in sheep feeding could be a feasible alternative.

Keywords: Carcass dressing; Guazuma; Meat quality; Pelibuey sheep; Tannin

INTRODUCTION

In tropical and subtropical regions, due to the need to supplement with commercial concentrates during the dry season, and due to the constant increase in the prices of grains and protein foods, it is feasible to consider foods available in the region, such as those from native trees, which can improve animal performance. In the case of the tropical area of Mexico is characterized by its great biological diversity, where there are foraging trees and shrubs like the Ramón (*Brosimum alicastrum*), Cocoíte (*Gliricidia sepium*), Guaje (*Leucaena leucocephala*), and Guácimo (*Guazuma ulmifolia*), which can be incorporated into animal feeding due to their high protein content (12-30%) and secondary compounds like tannins, which have multiple biological functions, such as natural antioxidants. This latter aspect should be of particular interest in the meat industry, as it increases the oxidative stability and consequently shelf life, which is usually achieved by adding synthetic antioxidants like vitamin E (Leal et al., 2020). However, even that adjusting the concentration of vitamin E and time of feeding remains challenging, it is expensive. The growing demand by consumers for high-quality and innocuous food makes natural antioxidants more acceptable than their synthetic equivalents. The effect of tannins on the meat quality and animal performance has been well documented (Torres et al., 2022); however, research on Guácimo (*Guazuma ulmifolia*) tannins is scarce and inconclusive (Casanova-Lugo et al., 2014; Castrejón-Pineda et al., 2016, Partida-Hernández et al., 2019), despite the species having a high foraging potential adapted to tropical conditions. In the same way, hair sheep are widely distributed in the tropical and subtropical regions, being Pelibuey the most predominantly hair sheep breed in Mexico, which is characterized by its adaptability to a broad range of environmental factors, rusticity, non-

***Corresponding author:**
Marco Antonio Ayala Monter, Facultad de Medicina Veterinaria y Zootecnia No. 2, Universidad Autónoma de Guerrero, Guerrero, 41940, México. **E-mail:** maamonter@hotmail.com

Received: 16 January 2023; **Accepted:** 29 August 2023

seasonality of reproduction, prolificacy and parasite tolerance (Chay-Canul et al., 2016b). However, Pelibuey sheep, despite having a well-developed national market, and currently being promoted for the production of fine cuts aimed at a select market that demands young lamb meat, contributing to improving the small farmer life quality, there is a lack of information about. In Latin-American countries, *G. ulmifolia* has been studied for its important role in popular medicine (Rafi et al., 2020), and particularly because of its chemical composition that has been shown to have high contents of protein and phenolic compounds (Pereira et al., 2019; Le Bodo et al., 2020). We hypothesized that *G. ulmifolia* might have a beneficial effect on animal performance and meat quality when used to feed lambs. Its use, nevertheless, must be controlled, as high doses of tannins in the diet cause a decrease in dry matter intake because of their astringent flavor and their capability of forming complexes, both with metal ions and with macromolecules such as proteins and polysaccharides. Therefore, the objective of this study was to evaluate two levels of tannins present in the foliage of *Guazuma ulmifolia* in the diet, and their effect on the animal performance, carcass and meat characteristics of Pelibuey lambs.

MATERIAL AND METHODS

The lambs care and management procedures were conducted according to the guidelines established by the Animal Welfare Committee of the Colegio de Postgraduados and Mexican federal law of animal health (DOF 25-07-2007).

Location, animals, diets, and treatments

The experiment was carried out in the Experimental Farm of the Colegio de Postgraduados, located in the State of Mexico, Mexico.

Twenty-eight male Pelibuey lambs (23.6±1.0 kg; 5 months old) were used. They were housed in individual pens (2.0 m^2) 15 days before treatment administration to allow them to adjust to the pens, which were equipped with feeders and drinking troughs. The lambs were randomly assigned to one of four treatments (T) (seven lambs/treatment): T1, control (base diet); T2, diet 1.5% tannins; T3, diet 2.5% tannins; and T4, diet 1000 IU vitamin E (Table 1). The *Guazuma ulmifolia* foliage was incorporated as an ingredient of the integral diet at different amounts to supply the required tannin content. The tannin levels used were based on those reported by other authors (Alvarez-Rodriguez et al., 2020). The vitamin E treatment was used as a positive control, and the high level used was in order ensure a positive effect on meat shelf life, which is not discussed in this paper. The experimental diets were balanced according to the nutritional requirements for finishing lambs (NRC, 2007).

Before the experimental period, the lambs were dewormed (Closantil 5%, Chinoin) and immunized (Bobact-8, MSD Animal Health). The lambs were adapted to the diets for 10 days, and the experimental period lasted 52 days. The feed was provided at 08:00 and 16:00 h, and water *ad libitum*.

Table 1: Ingredients and chemical composition of the experimental diets.

Ingredient (%)	Control (base diet)	Diet 1.5% tannins	Diet 2.5% tannins	Diet 1000 IU vitamin E	*Guazuma ulmifolia*
Ground maize	40.17	40.00	40.00	40.17	-
Soybean meal	23.23	20.25	18.24	23.23	-
Maize straw	30.00	21.48	15.65	30.00	-
Molasses	3.00	3.00	3.00	3.00	-
Soybean oil	1.00	1.00	1.00	1.00	-
Minerals[1]	2.00	2.00	2.00	2.00	-
Urea	0.60	0.60	0.60	0.60	-
G. ulmifolia foliage	-	11.67	19.51	-	-
Chemical composition					
Dry matter, %	85.73	86.45	86.69	85.69	83.0
Crude protein, %	20.17	19.95	19.33	20.20	17.2
Ash, %	7.50	7.52	7.89	7.73	10
Neutral detergent fiber, %	18.70	18.42	17.88	19.24	46.6
Acid detergent fiber, %	12.15	14.26	12.69	12.01	26.7
ME, Mcal/kg[2]	2.87	2.84	2.82	2.87	-
NEg, Mcal/kg[2]	1.06	1.08	1.09	1.06	-
TCT, g/kg DM[3]	-	15	25	-	15.03
In vitro DM digestibility, 72 h	66.83	63.33	61.83	66.83	-

[1]Premix of minerals and vitamins (Ca 24%, P 3%, Mg 2%, Na 8%, Cl12%, K 0.50%, and S 0.50%; Cr 5 ppm, Mn 4000 ppm, Fe 2000 ppm, Zn 5000 ppm, I 100 ppm, Se 30 ppm, and Co 60 ppm; vitamin A 500000 IU, vitamin D 150000 IU, vitamin E 1000 IU.
[2]ME=Metabolizable energy, NEg=Net energy of gain; calculated according to NRC (2007).
[3]TCT: Total condensed tannins. 4p=0.0025.

Foliage harvest

The *Guazuma ulmifolia* foliage was harvested manually from forage banks of that species (Fig. 1). To do this, the plants were first de-branched and immediately afterwards, the leaves were removed from the stems. Subsequently the leaves were dried by exposure to the sun on a concrete floor, being turned several times a day to ensure homogeneous drying and prevent fungus formation (Fig. 2). The foliage was then ground in a hammer mill (Azteca, No. 16) with a ½" diameter sieve, and later it was mixed together with the other ingredients to elaborate the diet (Table 1).

Chemical analyses of foliage and experimental diets

Samples of foliage and from each of the diets (Fig. 3) were collected weekly during the experimental period to determine dry matter, ash, crude protein (AOAC, 2005), neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Van Soest et al., 1991), and *in vitro* DM digestibility (ANKOM Technology, USA). The total condensed tannins (TCT) content of *Guazuma ulmifolia* leaves was determined (butanol-HCl method) (Terrill et al., 1992).

Fig. 1. Harvesting *Guazuma ulmifolia* foliage

Fig. 2. Dried *Guazuma ulmifolia* foliage

Fig. 3. Control diet (A) and tannins from *Guazuma ulmifolia* diet (B) samples

Fig. 4. Experimental carcasses

Measurements of animal performance

Dry matter intake (DMI, kg/d) was determined by measuring the offered and refused feed daily. Daily weight gain (DWG, kg/d) was determined from weighing the lambs at the beginning and at end of the experiment, obtaining the mean weight from three successive days. Feed conversion ratio (F/G) was calculated as a ratio of DMI to DWG. The backfat thickness was measured immediately after slaughtering, using a real time ultrasound Sonovet 600 (Medison, Inc., Cypress, California, USA) with a 7.5 Mhz transducer between the 12th and 13th rib. At the end of the experiment, the lambs were subjected to a 12 h fasting period, and slaughtered according to the Official Mexican Norm NOM-033-SAG/ZOO-2014. Prior to slaughtering, the live weight at slaughter (LWS) was recorded.

Measurements of the carcass

After slaughtering, hot carcass weight (HCW) was measured, prior to carcass cooling (Fig. 4). Hot carcass yield (HCY) was calculated by dividing HCW by live weight. The pH was measured at 45 min ($pH_{45\ min}$) and 24 h ($pH_{24\ h}$) using a portable pH meter (HANNA, HI99163) equipped with a penetration electrode, between the 12th and 13th rib. Carcasses were stored at 4 ºC for 24 h, after which cold carcass weight (CCW) was obtained. Twenty-eight samples weighing approximately 250 g, (one/animal) of the *Longissimus dorsi* muscle were taken 24 h postmortem and stored in hermetically sealed polyethylene bags at 4 ºC until their analysis.

Evaluation of meat quality attributes

The moisture content, protein, ash, and ether extract of the meat were obtained (Pereira et al., 2019). Meat color (*L**luminosity, *a**redness and *b**yellowness) was measured using a Minolta colorimeter (Chroma Meter CR-200, Tokio, Japan). The texture of raw and cooked meat was measured in a texture analyzer (TA-XT2 Texture Technologies Corp., Scarsdale, NY, USA) using a Warner-Bratzler blade, and the results were expressed in kg force/cm^2. Water activity (a_w) was measured using an Aqualab (Decagon CX-1, Washington, USA), and the holding water capacity by placing 5 g finely chopped meat in a centrifuge tube with 8 mL of sodium chloride solution 0.6 M, and then the tubes were placed in ice for 30 minutes and subsequently centrifuged (Beckman Coulter J2-HS) at 10,000 × *g* for 15 min. The volume of released water was poured out and the difference reported in millimeters of NaCl 0.6 M solution retained per 100 g meat.

Statistical analysis

Data were analyzed as a completely randomized design using the GLM procedure of SAS (Statistical Analysis System, version 9.1). The means were compared using the Tukey test (P<0.05). Each lamb was considered an experimental unit, and each experimental unit was a replicate. There were seven replicates per treatment. The model used was $Yij = \mu + \tau i + eij$, in which μ is the mean value, τi is the fixed treatment effect, Yij is the observation j in the treatment i, and eij is the error term.

RESULTS AND DISCUSSION

Daily weight gain, dry matter intake, and feed conversion did not differ between treatments, nor did the carcass and meat characteristics variables (P>0.05; Tables 2 and 3), with the exception of meat color, where *L** was higher (P<0.05) on the meat from lambs fed with tannins in the diet, independently of the level. While the *a** value was lower (P<0.05) in the meat under the control treatment, and *b** was higher (P<0.05) only in the meat under treatment with the higher tannin content.

Animal performance

The dry matter intake (DMI) was not different between treatments. Méndez-Ortiz et al. (2018), Álvarez-Rodríguez et al. (2020) and Orzuna-Orzuna et al. (2021) from a meta-analysis study, concluded that there were no significant differences in the growth performance due to the dietary inclusion of condensed tannins, being more important the effect of other nutrients, such as crude protein and crude fat, or perhaps the concentration of tannins included in the experimental diets was low, as suggested by Dentinho et al. (2020). The ingestion of high amounts of tannins (>5% or 50 g/kg DM) reduces fiber digestibility and consequently, voluntary intake (Min et al., 2003), which could explain our results. However, the same authors found that the ingestion of moderate amounts of tannins (1 to 4% or 10 to 40 g/kg DM) improve the digestive metabolism, by joining to the diet protein and forming complexes that prevents its rumen degradation; subsequently, the tannin-protein complex dissociates at acid (2.5 to 3, abomasum) or basic pH (8, intestine); therefore, it increases the absorption of the available protein, and therefore the DMI increased. These inconsistent results might be attributed to the different origins of tannins, which vary greatly in their capacity to bind carbohydrates, as state by Zhao et al. (2019), and also to factors inherent to the animal that affect the response to tannins (Mendez-Ortiz et al., 2018). It is interesting to point out that although there were no differences in animal performance, the Pelibuey lambs being a light-sized breed, the DWG was greater than those of other breeds specialized for meat production. The DMI reported herein was not congruent with the daily weight gain of these animals, as the feed conversion was very high, being 5.42.

Table 2: Animal performance and carcass characteristics of Pelibuey lambs fed with two levels of tannins in the diet.

	Control (base diet)	Diet 1.5% tannins	Diet 2.5% tannins	Diet 1000 IU vitamin E	SEM[1]	*P*-value
Initial live-weight, kg	23.70	24.35	24.01	22.60	1.576	0.872
Final live-weight, kg	39.49	39.46	40.72	37.69	1.393	0.542
Dry matter intake, kg/d	1.41	1.48	1.44	1.41	0.060	0.802
Daily weight gain, kg/d	0.271	0.258	0.286	0.262	0.020	0.781
Feed conversion	5.32	5.85	5.09	5.45	0.268	0.265
Back fat thickness, mm	3.00	3.28	2.85	3.00	0.116	0.095
Live weight at slaughter, kg	36.12	36.56	37.95	34.68	1.255	0.349
Hot carcass weight, kg	18.76	19.03	19.98	18.26	0.774	0.471
Hot carcass yield, %	51.91	52.00	52.64	52.51	0.622	0.795
$pH_{45\ min}$	6.14	6.15	5.99	5.99	0.089	0.412
Cold carcass weight, kg	18.32	18.09	19.29	17.39	0.741	0.361
Cold carcass yield, %	50.68	49.46	50.80	50.00	0.615	0.393

[1]SEM=standard error of the mean

Table 3: Meat characteristics (*Longissimus dorsi*) of Pelibuey lambs fed with two levels of tannins in the diet.

	Control (base diet)	Diet 1.5% tannins	Diet 2.5% tannins	Diet 1000 IU vitamin E	SEM[3]	*P*-value
Moisture, %	77.15	77.49	76.88	76.45	0.386	0.301
Protein, %	22.02	21.63	22.33	21.65	0.229	0.129
Ash, %	4.15	4.13	3.91	4.14	0.069	0.065
Ether extract, %	8.96	8.26	9.13	8.96	0.760	0.851
pH	5.68	5.74	5.53	5.55	0.100	0.398
*L**	33.51^{b}	34.99^{a}	34.77^{a}	33.88^{b}	0.160	0.0001
Colour	10.70^{b}	11.51^{a}	11.47^{a}	11.48^{a}	0.150	0.0002
*a**	1.84^{b}	1.91^{b}	2.65^{a}	1.89^{b}	0.120	0.0001
*b**						
Shear force, g/cm^2						
Raw meat	3.246	3.245	3.218	3.139	0.067	0.651
Cooked meat	2.912	2.881	2.820	2.820	0.057	0.595
a_w[1]	0.989	0.989	0.988	0.987	0.001	0.296
WHC[2]	18.79	18.63	18.92	18.99	0.162	0.421

*L**=Luminosity, *a**=Redness, *b**=Yellowness. [1]a_w: Water activity. [2]Water holding capacity in mL retained water/100 g of meat. [3]SEM=Standard error of the mean. [ab]Values with different literal between columns indicate differences (p<0.05).

Similarly, vitamin E, despite having an important function in growth, immune system, and tissue integrity (Maraba et al., 2018), in the present study it did not affect the animal performance of the animals, even if the dose was greater than recommended (200 IU/d) (NRC, 2007; Leal et al., 2020). The lack of a vitamin E response for animal performance implies that the nutritional requirement of the experimental sheep was met as stated by Belles et al. (2019). It is possible that the animals were subject to factors other than vitamin E treatment, which is highly probable. For instance, the short length of this experiment and small number of animals limited the ability to detect treatment effects on these traits. The effect of vitamin E depends on its concentration in muscle, which in turn depends on the content and chemical form of vitamin E ingested, the length of the feeding period and the individual characteristics of the animal. Although it has been reported that generally, vitamin E supplementation does not consistently affect feedlot performance and carcass characteristics, unless the animals are under stress (Leal et al., 2018; Leal et al., 2020). There is a wide consensus that vitamin E does not improve growth performance or carcass characteristics of light lambs, but its presence is a very useful way to delay the color fading, off-odors formation and lipid oxidation protecting PUFA and proteins from oxidation (Belles et al., 2019; Hampel et al., 2019).

Carcass and meat characteristics

The mean back fat thickness of the lambs in the present study was 3 mm lower than that reported for commercial breeds. It is possible that this response is a genetic effect, since according to Chay-Canul et al. (2016a), Pelibuey lambs normally have a lower fat deposition than breeds specialized for meat production. The absence of effect from the tannins on back fat is consistent with the report by Rojas-Román et al. (2017). It is interesting to point out the interest of consumers in meats with a lower fat content.

The mean weight and yield of the hot carcass found in the animals in this study were 19.01 kg and 52.26%, respectively, which are higher than those obtained by Gómez et al. (2014) and Rojas-Román et al. (2017) in Pelibuey lambs fed with *Guazuma ulmifolia* fruits and tannin extract. This response is basically due to differences in weight and age at the time of slaughter, as well as the content of the digestive tract of the animals; these differences are minimized when the weight of the gastrointestinal content is subtracted from the live weight. Moreover, Pelibuey sheep, being considered a light-sized breed, have a small anatomic structure and carcass yields are lower. It is important to emphasize that adding tannins to the diet of lambs younger than 3 months of age reduces carcass weight (Torres et al., 2022). Therefore, it is suggested to take precautions when extrapolating the results found here.

In general, the values of pH in the present study were within range of values for lamb meat, ruling out dark-cutting or stress problems. The mean pH value observed in this study was 5.6, which is close to the recommended pH for good meat quality of small ruminants, which ranges from 5.5 to 5.8 (Karaca et al., 2016), ruling out dark-cutting or stress problems, similar to that reported by Francisco et al. (2015) and Lobón et al. (2017) in the meat of sheep fed with tannins in the diet. The pH value influences many meat quality traits due to the effect on shelf life, color, and quality of the fresh meat (Lee et al., 2017). As pH was within the normal range, it did not affect the technological properties of lamb meat. The decrease of the pH 24 h *postmortem* is the result of the transformation of glycogen into lactic acid through anaerobic glycolysis, which depends on the intensity of stress that the animal is exposed to before slaughter. Suman et al. (2016) suggest that meat with a pH between 5.4 and 5.6 are the most desirable, due to their organoleptic properties; however, it also depends on the individual animal and the consumer.

The addition of *G. ulmifolia* to the diet of lambs did not affect the chemical composition of meat. The contents of moisture, protein, ether extract, and ash in the meat, as well as the shear force and Aw, are consistent with other findings (Zhong et al., 2016, Denthino et al., 2020; Orzuna-Orzuna et al., 2021) when tannins were added to the diet, whose effect was null. On the other hand, the absence of effect from vitamin E in the studied variables suggests a null relationship with the changes in the chemical characteristics of the meat, beyond its antioxidant effect and fatty acid profile (Belles et al., 2019; Leal et al., 2020), which is not discussed in this paper, but in another one that we are working on.

Meat color is an important characteristic that influences consumer perceptions of the quality of the product, where bright red meat is the usual preference. Fresh lamb meat must have values greater than *L** 34 and *a** 9.5 to be considered acceptable (Khliji et al., 2010). In the present study, we found color values higher than those. Particularly, *L**, *a**, and *b** values were higher in the treatments with 1.5 and 2.5% tannins in the diet (Table 3), indicating colors tending to red. This is an important aspect in the buying decision of the consumer, as it is associated with freshness and quality, when myoglobin oxidation has not set in, possibly due to the antioxidant effect of tannins (Corazzin et al., 2019; Rafi et al., 2020). To this regard, Zhong et al. (2015) proved that condensed tannins maintained the *L**, *a**, and *b** values in the *Longissimus lumborum* muscle, arguing that tannins protect against oxidation and maintain meat color. Nevertheless, other authors do not report changes in the color of the meat from wool lambs fed with 5 to 20 g/kg DM tannins in the diet (Francisco et al., 2015; Liu et al., 2016).

Luciano et al. (2009) found that the inclusion of quebracho tannins in the concentrate offered to sheep improved the colour stability of fresh lamb meat during extended refrigerated storage, which was attributed to the positive effects of dietary tannins on haem pigment concentration and metmyoglobin formation during the storage period. However, the mechanism by which dietary tannins can affect the myoglobin concentration and its redox state is unclear.

Moreover, there are reports that adding vitamin E to the diet of animals can improve meat color stability (Bellés et al., 2018; Leal et al., 2020) by delaying the formation of metamyoglobin from oximyoglobin, although the mechanism of that conversion is not clear (Bellés et al., 2019). Shear force in raw and cooked meat did not differ between treatments, with mean values of 3.21 and 2.85 kg/cm^2, respectively. Dentihno et al. (2020) reported values of 19.6 N/cm^2 (1.99 kg/cm^2) for this variable in Merino lamb meat when using tannins extract in the diet, the latter being similar to the amount of tannins used in the present study. In cooked meat, shear force was lower (2.85 kg/cm^2 *vs* 3.56 kg/cm^2) than that reported by Francisco et al. (2015) in wool lambs fed with tannins in the diet. These differences in resistance to cuts might be due to the age and weight of the animals at the time of slaughter, where resistance to cuts is lower in younger animals given the lower proportion of connective tissue and fat (Arce-Recinos et al., 2022). Besides, the type of muscle tissue has a direct influence, since even being from the same animal, there can be variations, thus affecting shear force.

The a_w and WHC results observed in the meat samples in the present study were not different between treatments. The values are higher than those reported by Hernández-Cruz et al. (2009) and Estrada-Solís et al. (2016) in hair and wool lambs, respectively. A higher a_w is related with a higher amount of water available for bacterial growth, negatively affecting the shelf life of the meat (Albrecht and Correa, 2016). However, neither tannins nor vitamin E affect the water activity and water holding capacity of the meat.

CONCLUSIONS

Including 1.5 and 2.5% tannins from *Guazuma ulmifolia* in the diet of finalizing lambs does not affect animal performance or the physicochemical characteristics of the meat, but it does improve color, which indicates a longer shelf life. This suggests that including *Guazuma ulmifolia* foliage as forage in the feed of sheep can be a feasible alternative in tropical regions of the country, framing it in a context of sustainability.

ACKNOWLEDGEMENTS

We greatly thank CONACyT-México (National Council for Science and Technology) for the scholarship granted to the first author.

CONFLICTS OF INTEREST

No potential conflict of interest was reported by the authors.

Author's contributions

Marco Antonio Ayala Monter designed experiment and methodology, performed experiment, performed data curation, performed formal analysis, prepared the original draft (writing, reviewing and editing).

Omar Hernández Mendo designed experiment and methodology, performed data curation, performed formal analysis, contributed to preparing the original draft (writing, reviewing and editing).

Silvia López Ortiz performed formal analysis, supervised field work, and contributed to writing, reviewing and editing.

David Hernández Sánchez performed formal analysis, supervised field work, and contributed to writing, reviewing and editing.

Gilberto Aranda Osorio performed formal analysis, supervised field work, and contributed to writing, reviewing and editing.

Ricardo Martínez Martínez performed formal analysis, supervised field work, and contributed to writing, reviewing and editing.

REFERENCES

Albrecht, A. and D. L. Correa. 2016. Identification of influence factors on the quality and shelf life of fresh meat throughout the supply chain. In: Kreyenschmidt, J. and S. Dohlen (Ed.), Living Handbook of Perishable Food Supply Chains. PUBLISSO, Cologne.

Álvarez-Rodríguez, J., D. Villalba, E. Molina, B. Serrano-Pérez, J. R. Bertolín and M. Joy. 2020. ¿Afectan los taninos condensados de la dieta a los resultados productivos, la composición de ácidos grasos y el color de la carne de cordero? ITEA. 116: 116-130.

AOAC. 2005. Official Methods of Analysis. 18th ed. Association of Official Analytical Chemists, Washington, DC.

Arce-Recinos, C., J. A. Ramos-Juárez, A. S. Hernández-Cazares, M. M. Crosby-Galvan, B. Alarcon-Zuniga, L. A. Miranda-Romero, J. M. Zaldívar-Cruz, L. Vargas-Villamil, E. M. Aranda-Ibanez, E. Vargas-Bello-Pérez and A. J. Chay-Canul. 2022. Interplay between feed efficiency indices, performance, rumen fermentation parameters, carcass characteristics and meat quality in Pelibuey lambs. Meat Sci. 183: 108670.

Bellés, M., L. N. Leal, V. Díaz, V., Alonso, P. Roncalés and J. A. Beltrán. 2018. Effect of dietary Vitamin E on physicochemical and fatty acid stability of fresh and thawed lamb. Food Chem. 239: 1-8.

Bellés, M., M. M. Campo, P. Roncalés and J. S. Beltrán. 2019. Supranutritional doses of Vitamin E to improve lamb meat quality. Meat Sci. 149: 14-23.

Casanova-Lugo, F., F. J. Solorio-Sánchez, L. Ramírez-Avilés, J. A. Caamal-Maldonado and J. C. Ku-Vera. 2014. Forage yield and quality of *Leucaenaleucocephala* and *Guazumaulmifolia* in tropical silvopastoral systems. Trop. Grassl. 2: 24-26.

Castrejón-Pineda, F. A., P. Martínez-Pérez, L. Corona, V. J. L. Cerdán and M. G. D. Mendoza. 2016. Partial substitution of soybean meal by *Gliricidiasepium* or *Guazumaulmifolia* leaves in the rations of growing lambs. Trop. Anim. Health Prod. 48: 133-137.

Chay-Canul, A. J., J. G. Magaña-Monforte, M. L. Chizzotti, A. T. Piñeiro-Vázquez, J. R. Canul-Solís, A. J. Ayala-Burgos and J. C. Ku-Vera 2016b. Requerimientos energéticos de ovinos de pelo en las regiones tropicales de Latinoamérica. Rev. Rev. Mex. Cienc. Pecu. 7: 105-125.

Chay-Canul, A. J., R. García-Herrera, V. M. Meza-Villalvazo, A. Gomez-Vazquez, A. Cruz-Hernández, J. G. Magaña-Monforte and J. G. Ku-Vera. 2016a. Body fat reserves and their relationship to ultrasound back fat measurements in Pelibuey ewes. Ecosist. Recur. Agropec. 3: 407-413.

Corazzin, M., S. Del Bianco, S. Bovolenta and E. Piasentier. 2019. Carcass characteristics and meat quality of sheep and goat. In: J. Lorenzo, P. Munekata, F. Barba and F. Toldra (Eds.), More than Beef, Pork and Chicken- The Production, Processing, and Quality Traits of other Sources of Meat for Human Diet. Springer, Cham.

Dentinho, M. T. P., K. Paulos, A. Francisco, A. T. Belo, E. Jerónimo, J. Almeida, R. J. B. Bessa and J. Santos-Silva. 2020. Effect of soybean meal treatment with *Cistus ladanifer* condensed tannins in growth performance, carcass and meat quality of lambs. Livest. Sci. 236: 104021.

Estrada-Solís, J., K. A. Figueroa-Rodríguez, B. Figueroa-Sandoval, F. Hernández-Rosas and A. S. Hernández-Cazares. 2016. Microstructure and physical changes in the Mexican cooked lamb meat barbacoa made with chilled and frozen meat. Meat Sci. 118: 122-128.

Francisco, A., M. T. Dentinho, S. P. Alves, P. V. Portugal, F. Fernandes, S. Sengo, E. Jerónimo, M. A. Oliveira, P. Costa, A. Sequeira, R. J. Bessa and J. Santos-Silva. 2015. Growth performance, carcass and meat quality of lambs supplemented with increasing levels of a tanniferous bush (*Cistus ladanifer* L.) and vegetable oils. Meat Sci. 100: 275-282.

Gómez, G. A., H. M. Partida, D. R. Ramírez, R. J. C. Ramírez, G. J. A. Gómez, M. M. González and G. L. Sanginés. 2014. Effect of replacing maize with *Guazuma ulmifolia* fruits on Pelibuey sheep performance and carcass yield. Trop. Subtrop. Agroecosyst. 17: 215-222.

Hampel, V. S., C. H. E. C. Poli, T. Devincenzi and L. Pötter. 2019. Feeding systems and tocopherol level in the diet and their effects on the quality of lamb meat: A meta-analysis. Rev. Bras. Zootec. 48: e20180223.

Hernández-Cruz, L., J. E., Ramírez-Bribiesca, M. I. Guerrero-Legarreta, Hernández-Mendo, O., M. M. Crosby-Galvan and L. M. Hernández-Calva. 2009. Effects of crossbreeding on carcass and meat quality of Mexican lambs. Arq. Bras. Med. Vet. Zootec. 61: 475-483.

Karaca, S., S. Erdogan, D. Kor and A. Kor. 2016. Effects of pre-slaughter diet/management system and fasting period on physiological indicators and meat quality traits of lambs. Meat Sci. 116: 67-77.

Khliji, S., R. Van de Ven, T. A. Lamb, M. Lanza and D. L. Hopkins. 2010. Relationship between consumer ranking of lamb colour and objective measures of colour. Meat Sci. 85: 224-229.

Le Bodo, E., J. L. Hornick, N. Moula, S. A. Zuñiga and J. C. Martínez-Alfaro. 2020. Assessment of gastrointestinal parasites and productive parameters on sheep fed on a ration supplemented with *Guazuma ulmifolia* leaves in Southern Mexico. *Animals*. 10: 1617.

Leal, L. N., J. A. Beltrán, M. Bellés, J. M. Bello, L. A. den Hartog, W. H. Hendriks and J. Martín-Tereso. 2020. Supplementation of lamb diets with Vitamin E and rosemary extracts on meat quality parameters. J. Sci. Food Agric. 100: 2922-2931.

Leal, L. N., J. A. Beltrán, V. Alonso, J. M. Bello, L. A. den Hartog, W. H. Hendriks and J. Martín-Tereso. 2018. Dietary Vitamin E dosage and source affects meat quality parameters in light weight lambs. J. Sci. Food Agric. 98: 1606-1614.

Liu, H., K. Li, L. Mingbin, J. Zhao and B. Xiong. 2016. Effects of chestnut tannins on the meat quality, welfare, and antioxidant status of heat-stressed lambs. Meat Sci. 11: 236-242.

Lobón, S., M. Blanco, A. Sanz, G. Ripoll, J. R. Bertolín and M. Joy. 2017. Meat quality of light lambs is more affected by the dam's feeding system during lactation than by the inclusion of quebracho in the fattening concentrate. J. Anim. Sci. 95: 4998-5011.

Maraba, K. P., V. Mlambo, A. O. Yusuf, U. Marume and A. Hugo. 2018. Extra dietary Vitamin E-selenium as a mitigation strategy against housing-induced stress in Dohne Merino lambs: Effect on growth performance, stress biomarkers, and meat quality. Small Rumin. Res. 160: 31-37.

Méndez-Ortiz, F., C. SandovalCastro, J. VenturaCordero, L. A. SarmientoFranco and J. F. J. TorresAcosta. 2018. Condensed tannin intake and sheep performance: A meta-analysis on voluntary intake and live weight change. Anim. Feed Sci. Technol. 245: 6776.

NRC. 2007. Nutrient requirements of small ruminants. Sheep, goats, cervids, and new world camelids. The National Academy Press, Washington, DC.

Orzuna-Orzuna, J. F., G. Dorantes-Iturbide, A. Lara-Bueno, G. D. Mendoza-Martínez, L. A. Miranda-Romero and H. A. Lee-Rangel. 2021. Growth performance, meat quality and antioxidant status of sheep supplemented with tannins: A meta-Analysis. Animals (Basel). 11: 3184.

Partida-Hernández, M., J. L. Loya-Olguin, A. Gómez-Gurrola, J. C. Ramírez-Ramírez, J. A. Hernández-Ballesteros, T. Amezcua-Jaeger, F. Escalera-Valente and L. Sanginés-García. 2019. Replacement of sorghum grain with *Guazuma ulmifolia* fruit in lambs' diets with different forage. Ecosist. Recur. Agropec. 6: 253-262.

Pereira, G. A., N. M. Araujo, H. S. Arruda, D. P. Farias, G. Molina and G. M. Pastore. 2019. Phytochemicals and biological activities of mutamba (*Guazuma ulmifolia* Lam.): A review. Food Res. Int. 126: 108713.

Rafi, M., M. Nadya, S. Anggraini and M. Bintang. 2020. Phytochemical profile and antioxidant activity of *Guazuma ulmifolia* leaves extracts using different solvent extraction. Indones. J. Pharm. 31: 171-180.

Rojas-Román, L. A., B. I. Castro-Pérez, A. Estrada-Angulo, C. Angulo-Montoya, J. A. Yocupicio-Rocha, M. A. López-Soto, A. Barreras, R. A. Zinn and A. Plascencia. 2017. Influence of long-term supplementation of tannins on growth performance, dietary net energy and carcass characteristics: Finishing lambs. Small Rumin. Res. 153: 137-141.

Suman, S. P., M. N. Nair, P. Joseph and M. C. Hunt. 2016. Factors influencing internal color of cooked meats. Meat Sci. 120: 133-144.

Terrill, T. H., A. M. Rowan, G. B. Douglas and T. N. Barry. 1992. Determination of extractable and bound condensed tannin concentrations in forage plants, protein concentrate meals and cereal grains. J. Sci. Food Agric. 58: 321-329.

Torres, R. N. S., C. P. Ghedini, J. R. Paschoaloto, D. A. V. da Silva, L. M. Coelho, G. A. A. Junior, J. M. B. Ezequiel, O. R. M. Neto and M. T. C. Almeida 2022. Effects of tannins supplementation to sheep diets on their performance, carcass parameters and meat fatty acid profile: A meta-analysis study. Small Rumin. Res. 206: 106585.

Van Soest, P. J., J. B. Robertson and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583-3597.

Zhong, R. Z., H. Y. Li, Y. Fang, H. X. Sun and D. W. Zhou. 2015. Effects of dietary supplementation with green tea polyphenols on digestion and meat quality in lambs infected with *Haemonchus contortus*. Meat Sci. 105: 1-7.

Zhong, R. Z., Y. Fang, Y. Q. Wang, H. X. Sun and D. W. Zhou. 2016. Effects of substituting finely ground sorghum for finely ground corn on feed digestion and meat quality in lambs infected with *Haemonchus contortus*. Anim. Feed Sci. Technol. 11: 31-40.