


Fattening rabbits with an ethanol extract of *Dalbergia palo-escrito* Rzed: effects on productive performance, carcass traits, and meat quality



Sarai García-Valencia ^a

Sergio Soto-Simental ^a

Alejandro Palacios-Espinosa ^b

Maricela Ayala-Martínez ^{a*}

^a Universidad Autónoma del Estado de Hidalgo. Instituto de Ciencias Agropecuarias. Av. Universidad No. 133. Col. San Miguel Huatengo, 43775, Santiago Tulantepec de Lugo Guerrero, Hidalgo, México.

^b Universidad Autónoma de Baja California Sur. Departamento de Ciencia Animal y Conservación del Habitat. La Paz, Baja California Sur, México.

*Corresponding author: ayalam@uaeh.edu.mx

Abstract:

The leaves from the *Dalbergia palo-escrito* Rzed tree have a high nutritional content. The objective of this work was to evaluate productive performance, carcass and meat quality, including meatball shelf life when an ethanolic extract of *D. palo-escrito* is used as feed for fattening rabbits. Forty-eight (48) rabbits were divided into two groups to obtain productive parameters and variables indicating carcass quality, meat characteristics, as well as microbial and physicochemical indicators for the shelf-life of meatballs. Total feed consumption was higher ($P<0.05$) in control group, although the feed conversion ratio was lower ($P<0.05$). All morphometric measurements, carcass traits, primal cuts and leg dissections were different ($P<0.05$) between the treatments, except for animal length. Values for pH, water holding capacity and cooking losses were higher ($P<0.05$) in control group, however, the L* value for the texture profile analysis parameters were higher ($P<0.05$) in the ethanolic extract group. Regarding meatballs, the total viable bacterial counts at 7 d of storage were higher ($P<0.05$) in control group. It was concluded that feeding *D. palo-escrito* ethanolic extracts decrease feed intake, weight gain, total weight

gain; these resulted in a decrease in carcass traits, primal cut weight, and carcass quality of rabbit meat. However, the ethanolic extracts did not have an effect on meatballs during storage time and had stable pH and atowatts values during 14 d of storage.

Keywords: Alternative ingredients, Rabbit meat, Productive performance, Tree leaves extract, Meat product.

Received: 15/01/2025

Accepted: 09/09/2025

Introduction

Rabbit meat contains protein and minerals with high bioavailability. It is also low in fat, which contains an adequate proportion of saturated, monounsaturated and polyunsaturated fatty acids for human nutrition, as well as having essential bioactive compounds⁽¹⁾. For these reasons, this type of meat is considered important for the human diet. However, animal production systems need to fulfil the demand for meat in order to feed the human population, but increasing animal protein involves decreasing or preventing diseases that affect productive performance and meat quality. One of the main strategies used in animal production is the use of antibiotics for either therapeutics, prophylactic or growth promoters⁽²⁾. However, this approach increases microorganism resistance to these substances, as bacteria develops different ways of avoiding molecular activity⁽³⁾. Regarding antimicrobial resistance in the food chain, antimicrobial substances should be carefully used to reduce resistance⁽⁴⁾. On the other hand, the meat industry is concerned with satisfying consumer needs in terms of providing nutritional and sensorial quality, appropriate shelf life, as well as innovative packaging for meat and meat products⁽¹⁾.

The future of food additives is changing with increased focus on societal well-being, resulting in the increased use of natural extracts⁽⁵⁾. However, these alternatives need to be studied extensively before expanding their use, as some extracts have been linked to health risks for consumers⁽⁶⁾. These two issues associated with animal production and the meat industry have led to some countries banning certain growth promoters or antibiotics for fattening animals. In rabbit production, the use of these kinds of molecules has increased digestive disorders and mortality rates, mainly in fattening rabbits. Some alternatives are proposed to substitute growth promoters or antibiotics, including plants, spices and their extracts⁽⁷⁾.

There are very few studies on *Dalbergia palo-escrito* Rzed and its use in animal feed. However, some species of *Dalbergia* have reported certain bioactive properties⁽⁸⁾, and *Dalbergia sissoo* leaves have been successfully used to feed goats⁽⁹⁾. Furthermore, other *Dalbergia* species such as *Dalbergia retusa* have been reported to contain anti-staphylococcal effects *in vitro*⁽¹⁰⁾. There is only one study regarding the use of hexane extracts from *D. palo-escrito* to feed growing rabbits⁽¹¹⁾. The aim of this study was to add a *Dalbergia palo-escrito* ethanolic extract to feed fattening rabbits in order to then evaluate the effects on carcass traits and meat characteristics, including meatball shelf life.

Material and methods

Dalbergia palo-escrito Rzed ethanol extract (DPEEE)

The extract of *D. palo-escrito* Rzed leaves was obtained following the methodology described by Garcia-Valencia *et al*⁽¹¹⁾. Briefly, leaves were dried for 7 d at room temperature. One liter of ethanol was added to 500 g of dry plant which was then stirred for 24 h. After this period, the blend was separated and the liquid was dried using a Barnstead 3510 oven (Barnstead International, Dubuque, Iowa, USA). The resulting dried ethanol extract was used to supplement rabbit diets. Different extracts of *D. palo-escrito* using several solvents were characterized for antioxidant and antibacterial properties (Unpublished data). Ethanol extract has FRAP and DPPH values of 9.31 and 50.58 mg mL⁻¹, respectively, and it also inhibits the growth of *Escherichia coli*.

Animal, housing, diets and treatment design

This study was approved by the ethical institutional committee for use and animal care of the Universidad Autónoma del Estado de Hidalgo, protocol number CICUA/ICAP 001/2020. Two groups of 24 rabbits were used to carry out this study. Rabbits were 35 d of age, California x English pot crossbreed, and randomly assigned to receive a control diet (C), while another group was fed with a diet containing an ethanol extract (DPE) obtained from the leaves of *D. palo-escrito* (2 g.kg⁻¹). The experiment was designed so that each treatment had six repetitions (n= 4 rabbits). The study was carried out over 28 d at the facilities of the Instituto de Ciencias Agropecuarias located in Tulancingo, Hidalgo, Mexico. The cages used to house the rabbits measured 45 x 60 x 40 cm and were equipped with feeders and drinkers. The rabbits were subjected to diets with 15% of CP, 2.6 Mcal kg⁻¹, and 26% NDF as indicated in Table 1. Diets were formulated according to NRC⁽¹²⁾ and the FEDNA nutritional ingredient tables⁽¹³⁾. The feed was elaborated using

a SKJ-120 pelletizer (Yuezhen Machinery Co., Shandong, China) which was stored at room temperature after cooling.

Table 1: Ingredients and nutritional composition of the diets

Ingredient	Treatments	
	DPE	Control
Corn, %	21.00	21.00
Sorghum, %	20.00	20.00
Dried distilled grains, %	3.24	3.20
Wheat bran, %	9.00	9.00
Molasses, %	2.00	2.00
Canola meal, %	5.00	5.00
Soybean meal, %	14.00	14.00
Soybean husk, %	10.00	10.00
Barley Straw, %	12.06	12.30
Vitamins and mineral premix, %	3.00	3.00
Calcium carbonate, %	0.50	0.50
<i>Dalbergia palo-escrito</i> ethanolic extract, %	0.24	0.00
Nutritional composition calculated		
Protein, %	15.07	15.08
Digestible energy, Mcal MS kg ⁻¹	2.60	2.60
NDF, %	26.02	26.19
ADF, %	14.95	15.00
Calcium, %	0.86	0.87
Phosphorus, %	0.56	0.56
Sodium, %	0.19	0.18
Potassium, %	0.97	0.97

DPE= diet with *Dalbergia palo-escrito* ethanolic extract; NDF= neutral detergent fiber; ADF= acid detergent fiber.

Growth measurement

The live weight of rabbits along with the feed offered and rejected were measured daily, while data were recorded using a Mettria MTNUV-40 digital scale (Mettria, Mexico City, Mexico). Then, data were used to calculate the average weekly feed consumption (WFC), total feed consumption (TFC), daily average weight gain (DAWG), total weight gain (TWG), and feed conversion ratio (FCR). At the end of fattening, rabbits were carried out to slaughter at the meat lab located in the Instituto de Ciencias Agropecuarias. Mechanical concussion stunning was used to kill the animals according to national legislation⁽¹⁴⁾, and they were then measured for length animal and lumbar circumference before slaughter⁽¹¹⁾.

Carcass traits

Carcass traits were recorded following the indications by Garcia-Valencia *et al*⁽¹¹⁾. Briefly, once rabbits were slaughtered, organs were separated and weighed, while carcass length and lumbar circumference were also measured. Then, the rabbit carcasses were stored for 24 h under refrigeration conditions (6 °C). The carcasses were divided as indicated by Blasco *et al*⁽¹⁵⁾. Briefly, the carcasses were cut into sections to obtain the head, forequarter, thoracic cage, loin, and hind leg, with each part weighed. To measure the meat color, a Minolta CM-508d colorimeter (Konica-Minolta, Tokyo, Japan) was used and configured to determine CIE L*a*b* color space, with an aperture size of 8 mm, an illuminant D65 and 10° standard observer using values of lightness (L*), redness (a*), and yellowness (b*)⁽¹⁶⁾. Color was measured on the loin surface and blooming time was 20 min. A Hanna HI99163 meat pH meter (Hanna Instruments, Cluj-Napoca, Romania) was used to determine pH meat on loins at the level of the *Longissimus lumborum* muscle. Moreover, meat from this muscle was used to determine water holding capacity (WHC) using the method described by Honikel⁽¹⁷⁾. Loins were cooked until a temperature of 68 °C was reached with a water bath (StableTemp, Cole Parmer, USA) used to determine cooking loss. Subsequently, the samples were weighed once they had cooled. The samples were then subjected to a texture profile analysis as described by Bourne⁽¹⁸⁾. Six 1 cm³ cubes for each loin were used, and samples were cut parallel to the muscle fibers. The Brookfield CT3 texture analyzer (Brookfield, Middleboro, MA, USA) was set to 50 % compression using 1 mm s⁻¹ of crosshead speed. The samples were compressed twice, and force-time curves of deformation were obtained through Texture Pro CT software (Brookfield, Middleboro, MA, USA), which determined hardness, resilience, cohesiveness, springiness and chewiness values.

Meatball preparation: The meat obtained from rabbit legs was used to prepare meatballs and evaluated as described by Garcia-Valencia *et al*⁽¹¹⁾.

Statistical analysis

A one-way analysis was used to evaluate carcass traits and meat quality. To analyze productive performance and meatball shelf-life, a repeated time one-way design was used, according to the following model: $Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$.

A mixed model was used to analyze feed consumption, daily weight gain, weekly weight, and feed conversion ratio according to the following model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \alpha_i(\beta_j) + \varepsilon_{ij}$$

Where:

Y_{ij} = Response variable
 μ = Population Media general
 α_i = Factor A (experimental diets)
 β_j = Factor B (weeks)
 $\alpha_i(\beta_j)$ = Nested effect
 ε_{ij} = Experimental error

The differences between the means were evaluated using LSMEANS option ($P<0.05$). All data were analyzed using SAS software version 9.0.

Results and discussion

The use of DPEEE was based on the concept “from farm to the fork”. Several phases of production were monitored including productive performance, carcass traits and meat characteristics, as well as the shelf life of the meatballs stored in refrigeration for 14 d. The feed consumption over 4 wk is shown in Table 2, and there were statistical differences ($P<0.05$) between treatments every week, with feed intake decreasing in rabbits fed with the ethanolic extract diet. This low feed consumption had an effect on average daily weight gain, and there were significant differences ($P<0.05$) between treatments every week. The control group had a higher ($P<0.05$) total feed intake (2,617.57 g), and a lower ($P<0.05$) feed conversion ratio (2.76).

Table 2: Productive performance of rabbits fed with *Dalbergia palo-escrito* ethanolic extracts

Week	Treatments		SEM	P-values
	Control	DPE		
WFC1, g	80.50 ^a	32.71 ^b	4.15	0.00
WFC2, g	94.37 ^a	45.27 ^b	4.43	0.00
WFC3, g	87.70 ^a	45.80 ^b	5.77	0.00
WFC4, g	111.34 ^a	51.16 ^b	9.64	0.00
TFC, g	2,617.57 ^a	1,372.91 ^b	344.68	0.00
WGD1, g d ⁻¹	37.85 ^a	10.47 ^b	12.46	0.00
WGD2, g d ⁻¹	36.76 ^a	18.03 ^b	12.719	0.00
WGD3, g d ⁻¹	32.50 ^a	13.80 ^b	11.45	0.00
WGD4, g d ⁻¹	34.68 ^a	17.68 ^b	12.91	0.00
TWG, g d ⁻¹	949.16 ^a	307.00 ^b	192.58	0.00
FCR	2.76 ^b	5.67 ^a	2.19	0.00

DPE= *Dalbergia palo-escrito* ethanolic extract; SEM= standard error of the mean; WFC1= weekly feed intake in wk 1,2,3 and 4; TFC= total feed consumption; WGD= daily weight gain during wk 1,2,3 and 4; TWG= total weight gain; FCR=feed conversion ratio.

^{abc} Different letters indicate statistical differences between treatments ($P<0.05$).

The relationships between feed intake, daily weight gain, feed conversion rate is important for describing the rabbits' productive performance. Firstly, the average feed intake of rabbits was different ($P<0.05$) between treatments, with the DPE group showing lower intake, daily gain and feed conversion ratio values (2,617 vs 1,372; 949 vs 307; 2.76 vs 5.67 for control and ethanol extract, respectively). It is possible that the DPEEE contains certain bioactive compounds that produce bitter flavors, such as tannin found in the biochemical diversity of *Dalbergia latifolia* using ethanolic extracts⁽¹⁹⁾. The tannin delivers a slightly pungent odor and an astringent taste⁽²⁰⁾, contributing to the development of organoleptic properties, thereby producing a bitter taste in the food⁽²¹⁾.

All morphometric measurements were different ($P<0.05$) between the treatments except for carcass length, although rabbits fed with DPEEE showed lower values. These observations are related to feed consumption and weight gain. Similarly, all carcass traits measured (Table 3) were lower ($P<0.05$) in rabbits fed with DPEEE, including hot and cold carcass weight, dressing percentage, skin, feet and complete viscera. Regarding these values, there is a relationship between morphometric measurements and carcass traits, and it can be observed that the animals with the smallest circumference length produce the lowest carcass parameter values.

Table 3: Morphometric measurements and carcass quality of rabbits fed with *Dalbergia palo-escrito* ethanolic extracts

	Treatments		SEM	P-values
	Control	DPE		
Animal length, cm	30.65 ^a	28.43 ^b	0.53	0.00
Carcass length, cm	29.93	28.75	0.46	0.14
Lumbar circumference, cm	20.93 ^a	16.68 ^b	0.55	0.00
Carcass lumbar circumference, cm	15.07 ^a	10.68 ^b	0.89	0.00
Skin, g	273.21 ^a	156.25 ^b	12.22	0.00
Feet, g	50.50 ^a	36.37 ^b	2.16	0.00
Complete viscera, g	476.42 ^a	365.25 ^b	18.50	0.00
Dressing percentage, %	51.33 ^a	46.73 ^b	0.76	0.00
Live weight, g	1,914.28 ^a	1,252.50 ^b	69.21	0.00
Hot carcass weight, g	997.14 ^a	617.5 ^b	39.62	0.00
Cold carcass weight, g	982.85 ^a	588.12 ^b	38.44	0.00

DPE = *Dalbergia palo-escrito* ethanolic extract; SEM= standard error of the mean.

^{ab} Different superscript indicates statistical differences between treatments ($P<0.05$).

In addition, fat, primal cuts and leg dissection (Table 4) were higher ($P<0.05$) in control treatment. Furthermore, DPEEE had an effect on the rabbits' growth efficiency, including variables measured to determine carcass traits. All morphometric measurements and carcass traits were different between treatments. It is possible that DPEEE contain bioactive compounds that affect the growth of rabbits, such as phytol, which is reported to have an anxiolytic effect⁽²²⁾. These compounds have a calming effect which help to

reduce anxiety, and this has been observed with bioactive compounds associated with gamma-aminobutyric acid (inhibitory neurotransmitter in the central nervous system) such as ellagic acid, kaempferol, luteolin, nangerin, p-coumaric acid, rutin and others found in different plant extracts⁽²³⁾. In another study, *D. sissoo* ethanolic extract was demonstrated to contain cytotoxic and anti-epileptic effects⁽²⁴⁾. These compounds and signs could hinder the growth of the rabbits.

Table 4: Main cuts from rabbit's carcass obtained from animals that consumed *Dalbergia palo-escrito* ethanolic extracts

Variable	Treatments		SEM	P-values
	Control	DPE		
Kidney fat, g	13.35 ^a	3.00 ^b	1.40	0.00
Scapular fat, g	4.00 ^a	1.12 ^b	0.51	0.00
Head, g	103.57 ^a	83.75 ^b	2.78	0.00
Fore part weight, g	234.28 ^a	142.50 ^b	8.69	0.00
Intermedia part weight, g	105.71 ^a	60.00 ^b	5.41	0.00
Hind part weight, g	181.78 ^a	94.37 ^b	9.51	0.00
Legs, g	339.28 ^a	206.25 ^b	12.39	0.00
Meat, g	242.85 ^a	132.5 ^b	10.99	0.00
Bone, g	89.64 ^a	71.25 ^b	2.78	0.00
Dissectible fat, g	2.42 ^a	0.56 ^b	0.25	0.00

DPE = *Dalbergia palo-escrito* ethanolic extract; SEM= standard error of the mean.

^{abc} Different letters indicate statistical differences between treatments ($P < 0.05$).

Data for meat characteristics: The pH, L*, WHC and cooking loss values were higher ($P < 0.05$) in control group, while a* and b* values were similar ($P > 0.05$) between treatments. All the parameters for the texture profile analysis were higher ($P < 0.05$) in the meat from rabbits fed with the *D. palo-escrito* ethanolic extract, except for springiness and hardness. A significant parameter in meat texture is hardness, and the control treatment recorded the highest value in this respect (25.32 vs 17.45 N).

Table 5: Meat quality of rabbits that consumed *Dalbergia palo-escrito* ethanolic extracts

Variable	Treatments		SEM	P-values
	Control	DPE		
pH	5.69 ^a	6.00 ^b	0.51	0.00
L*	48.77 ^a	42.94 ^b	0.81	0.00
a*	1.45	2.13	0.26	0.00
b*	7.03	6.53	0.26	0.00
WHC %	30.21 ^a	20.07 ^b	3.18	0.03
CL %	27.25 ^a	23.02 ^b	1.04	0.00
Hardness, N	25.32 ^a	17.45 ^b	1.69	0.00
Resilience	0.14 ^b	0.21 ^a	0.00	0.00
Cohesiveness	0.48 ^b	0.54 ^a	0.01	0.00
Springiness	0.51	0.54	0.01	0.12
Chewiness	5.30 ^a	3.90 ^b	0.37	0.01

DPE= *Dalbergia palo-escrito* ethanolic extract; SEM= standard error of the mean; WHC= water holding capacity; CL= cooking loss.

^{abc} Different letters indicate statistical differences between treatments ($P<0.05$).

The carcass characteristics in this study were different between treatments ($P<0.05$). All characteristics were lower in rabbits fed with DPEEE indicating that there are bioactive compounds that affect animal growth. It is possible that *D. palo-escrito* could contain some glycosides alkaloids or other compounds that affect feed consumption. The glycosides can have toxic effects including diarrhea, loss of appetite and paralysis⁽²⁵⁾, while Majeed *et al*⁽²⁴⁾ found glycosides during a phytochemical screening of *D. sissoo*. The DPEEE increased pH in rabbit meat. However, there are several studies that indicate pH in meat was similar to control group when plants or their extracts were fed to rabbits. Similar results were found when rabbits were fed with dried bay leaves⁽²⁶⁾, *Silybum marianum*⁽²⁷⁾ and supplemented with oregano and sage leaves⁽²⁸⁾. Color, water holding capacity and pH are related parameters in meat quality. Lightness (L*) color value and water holding capacity were lower in rabbits fed with DPEEE. Other studies obtained similar results when using different plants or extracts as feed, such as an infusion of *Chenopodium ambrosioides*⁽²⁹⁾, or feeding rabbits with cauliflower leaves powder⁽³⁰⁾. However, other studies did not find any differences for color values and WHC when using an oregano extract⁽⁶⁾ or a liquorice (*Glycyrrhiza glabra* L.) extract to feed rabbits⁽³¹⁾.

After deboning the legs, the meat was processed to obtain meatballs in order to determine shelf life. Total viable bacterial counts, *Staphylococcus* counts and *Enterobacteriaceae* counts are shown in Table 6. The use of this extract decreases ($P<0.05$) total viable bacterial counts after 7 d of refrigerated storage, yet afterwards on d 14 counts were similar ($P>0.05$). *Staphylococcus* and *Enterobacteriaceae* counts were similar during the storage period, although the presence of *Enterobacteriaceae* at the start of this analysis was lower in meatballs prepared with rabbit meat from animals fed with *D. palo-escrito* Rzed ethanolic extracts. During storage, total viable counts, *Staphylococcus* and

Enterobacteriaceae increased ($P<0.05$). The antioxidant activity of the DPEEE was similar ($P>0.05$) to the control treatment, however, there were differences ($P<0.05$) in the same treatments throughout the storage period. Firstly, antioxidant activity decreased during the first seven days of storage, however, after 14 d antioxidant activity then increased, although there were no differences ($P>0.05$) between treatments each week. The pH of meatballs was different between treatments ($P<0.05$) during the first 2 wk; however, at the end of the storage, pH values had increased in both treatments, but the values were similar ($P>0.05$). Finally, the water activity (a_w) values were similar ($P>0.05$) between treatments after each storage week. Nevertheless, during the storage time, the values for both treatments decreased ($P<0.05$) at 14 d.

Table 6: Physicochemical characteristics and bacterial groups through storage time of meatballs elaborated with meat from rabbits fed with *Dalbergia palo-escrito* ethanolic extracts

Variable	Treatments						P-values			
	Control			DPE			SEM	T	t	T*t
	0	7	14	0	7	14				
Antioxidant activity, DPPH mg mL ⁻¹	58.01 ^a	36.90 ^b	63.12 ^a	69.14 ^a	36.30 ^b	67.69 ^a	0.01	0.16	0.00	0.37
pH	5.77 ^{Bb}	5.86 ^{Bb}	6.83 ^{Aa}	6.14 ^{Ab}	6.12 ^{Ab}	6.81 ^{Aa}	0.03	0.00	0.00	0.00
a_w	0.980 ^a	0.976 ^a	0.953 ^b	0.980 ^a	0.983 ^a	0.956 ^b	0.02	0.28	0.00	0.78
TVC	3.86 ^c	6.51 ^{bA}	8.50 ^a	3.81 ^c	5.60 ^{bB}	8.44 ^a	0.01	0.00	0.00	0.00
<i>Staphylococcus</i>	3.48 ^c	5.27 ^b	6.82 ^a	3.60 ^c	5.37 ^b	6.57 ^a	0.03	0.93	0.00	0.42
<i>Enterobacteriaceae</i>	3.49 ^c	6.19 ^b	8.38 ^a	3.33 ^c	6.06 ^b	8.32 ^a	0.02	0.06	0.00	0.70

DPE= *Dalbergia palo-escrito* ethanolic extract; SEM= standard error of the mean; TVC= total viable counts.

^{abc} Different letters indicate statistical differences over time within treatment ($P<0.05$). ^{AB} Different letter indicates statistical differences between treatments on a specific day.

The DPEEE fed to rabbits produced an effect on the bacterial growth in meatballs prepared with the meat obtained from these rabbits. In the meatballs, the presence of total viable counts, *Staphylococcus* and *Enterobacteriaceae* groups increased during 14 d of refrigerated storage. Some bioactive compounds such as flavonoids used to feed animals show antibacterial effects as reviewed by North *et al*⁽³²⁾. The antibacterial mechanism of flavonoids includes membrane disruption, efflux pump inhibition, nucleic acid synthesis inhibition and bacterial pathogenicity attenuation⁽³³⁾. It is possible that some of these mechanisms are used to inhibit these bacterial groups in this study. Some works indicated that the use of *Chenopodium ambrosioides* infusion to feed rabbits⁽²⁹⁾ or adding *Curcuma longa* L to burgers demonstrated that microbial growth decreased⁽³⁴⁾, while both studies found that *Staphylococcus* and total counts increased after the storage of meat products for seven days.

The antioxidant properties of meatballs prepared using meat from rabbits fed with DPEEE indicate that treatments were similar ($P>0.05$), however differences were observed during storage time ($P<0.05$). It can be seen that over the first 7 d of storage antioxidant activity

decreased, however it then increased after 14 d of storage. As previously mentioned, *D. palo-escrito* Rzed possesses antioxidant properties, however it is possible that this effect is lost during storage time. The antioxidant activity is mainly regulated by phenolic compounds, although it is influenced by carbohydrates, proteins or other macromolecules⁽³⁵⁾. Meat and meat products have a complex matrix where antagonistic or synergistic interactions are possible, which can in turn influence antioxidant activity during storage time. The antiradical efficiency of phenolic compounds depend on the availability of hydrogen or hydroxyl groups⁽³⁶⁾. Polyphenols present in plants or their extracts could reduce free radicals and convert them into stable materials, while flavonoids can also chelate metals ions⁽³⁷⁾. It is possible that these mechanisms are used in the ethanol extract of *D. palo-escrito* during the first days of meat storage, as some ions are available in meat, such as calcium, magnesium, sodium or others.

The pH for the meatballs showed values of between 6.06 to 6.60 on d 14 of storage. Similar results were reported using *Zanthoxylum bungeanum* Maxim essential oil⁽³⁸⁾, while a similar pattern was also found in rabbit burger added with garlic powder or ginger⁽³⁹⁾. Similarly, rabbits fed with *Pithecellobium dulce* and pH of the meatballs prepared with meat from those animals was similar to this study⁽⁴⁰⁾. It is possible that chemical compounds present in plant extracts influence pH values in meat during storage or the bacterial groups produce metabolites that modified the pH of the products.

Water activity was similar between treatments, however the values decreased after 14 d of storage. The aw is the major parameter in food stability, preventing or limiting microbial growth. However, the use of hurdle technology in marinated, brined and cooked rabbit meat products have aw values of between 0.92 and 0.98 and could be stable in refrigeration conditions⁽⁴¹⁾. Mancini *et al*⁽⁴²⁾ indicated that salt has the ability to decrease aw and can have a bacteriostatic effect on meat products.

Conclusions and implications

The feeding of *D. palo-escrito* Rzed ethanolic extract to rabbits decreases productive performance during the fattening period, as rabbits have a low feed consumption resulting in lower animal growth than the control group as well as low carcass traits. Meat quality was also affected, which resulted in a higher water holding capacity and cooking losses, although texture parameters were similar. Although, the ethanol of *D. palo-escrito* has a positive effect on the shelf-life of rabbit meat, the productive performance, carcass traits and meat quality are lower compared to control group. It is therefore not recommended to use this extract to feed rabbits, and further studies are needed to determine other potential uses of *D. palo-escrito* extracts.

Acknowledgements and conflict of interest

García-Valencia, Sarai received a grant number 715255 from Consejo Nacional de Ciencias Humanidades y Tecnología from Mexican government. The authors would also like to express their gratitude to Christopher Shackley for reviewing the English language.

The authors declare there was no conflict of interest.

Literature cited:

1. Cullere M, Dalle-Zotte A. Rabbit meat production and consumption: State of knowledge and future perspectives. *Meat Sci* 2018;146(9):137-146. <http://doi.org/10.1016/j.meatsci.2018.04.029>.
2. Oliveira NA, Gonçalves BL, Lee SH, Oliveira CAF, Corassin CH. Use of antibiotics in animal production and its impact on human health. *J Food Chem Nanotechnol* 2020;6(1):40-47. <https://doi.org/10.17756/jfcn.2020-082>.
3. Pérez-Rodríguez F, Mercanoglu TB. A state-of-art review on multi-drug resistant pathogens in foods of animal origin: risk factors and mitigation strategies. *Front Microbiol* 2019;10:2091. <https://doi.org/10.3389/fmicb.2019.02091>.
4. Bennani H, Mateus A, Mays N, Eastmure E, Stärk KD, Häsler B. Overview of evidence of antimicrobial use and antimicrobial resistance in the food chain. *Antibiotics* 2020;9(2):49. <https://doi.org/10.3390/antibiotics9020049>.
5. Carocho M, Barreiro MF, Morales P, Ferreira IC. Adding molecules to food, pros and cons: a review on synthetic and natural food additives. *Compr Rev Food Sci Food Saf* 2014;13(4):377–399. <https://doi.org/10.1111/1541-4337.12065>.
6. Cardinali R, Dal Bosco A, Mugnai C, Mattioli S, Ruggeri S, Dalle Zotte A, Sartori A, Cullere M, Castellini C. Effect of different dietary aromatic essences on meat quality of rabbit. *World Rabbit Congress*. 2012;3(6):925–929. <http://world-rabbit-science.com/WRSA-Proceedings/Congress-2012-Egypt/Papers/05-Meat&Quality/Q-Cardinali.pdf>.
7. Dalle-Zotte A, Celia C, Szendrő Z. Herbs and spices inclusion as feedstuff or additive in growing rabbit diets and as additive in rabbit meat: A review. *Livest Sci* 2016;189:82-90. <https://doi.org/10.1016/j.livsci.2016.04.024>.
8. Singh B, Singh JP, Kaur A, Singh N. Phenolic composition and antioxidant potential of grain legume seeds: A review. *Food Res Int* 2017;101:1–16. <http://dx.doi.org/10.1016/j.foodres.2017.09.026>.
9. Suchitra SD, Pandey NN. Toxicity trial on supplementation of Shisham leaves (*Dalbergia sissoo*) in goats. *Vet Pract* 2008;9(1):39–41.

10. Echeverria-Medina MF, Alaba PA, Estrada-Zuñiga ME, Velázquez-Ordoñez V, Barbabosa-Pliego A, Salem MZ, *et al.* Anti-staphylococcal properties of four plant extracts against sensitive and multi-resistant bacterial strains isolated from cattle and rabbits. *Microb Pathog* 2017;113:286-294. <https://doi.org/10.1016/j.micpath.2017.10.053>.
11. García-Valencia S, Soto-Simental S, Ocampo-López J, Ayala-Martínez M. Diet supplementation with *Dalbergia palo-escrito* hexane extract in fattening rabbits: its effect on productive performance, carcass traits, meat characteristics and meatballs shelf-life. *Ital J Anim Sci* 2022;21(1):1533-1542. <https://doi.org/10.1080/1828051X.2022.2130833>.
12. NRC – National Research Council. Nutrient requirements of rabbits. National Academies Press; 1977. <https://doi.org/10.17226/35>.
13. FEDNA - Fundación Española para el Desarrollo de la Nutrición Animal. 2020. Tablas FEDNA de composición y valor nutritivo de los alimentos para la fabricación de piensos compuestos. Consultado Jul 15, 2021. <http://www.fundacionfedna.org/>.
14. NOM-033-SAG/ZOO-2014. Mexican Official Standard. Methods to give death to domestic and wild animals. (in Spanish). <http://www.economianoms.gob.mx/normas/noms/2010/033sagzoo2015.pdf>.
15. Blasco A, Ouhayoun J, Masoero G. Harmonization of criteria and terminology in rabbit meat research. *World Rabbit Sci* 1993;1:3-10. <https://doi.org/10.4995/wrs.1996.278>.
16. AMSA. American Meat Science Association. Meat color measurement guidelines. Champaign. IL. USA. 2012. <https://meatscience.org/publications-resources/printed-publications/amsa-meat-color-measurement-guidelines>.
17. Honikel KO. How to measure the water-holding capacity of meat? Recommendation of standardized methods. In: Tarrant PV, Eikelenboom G, Monin G, editors. Evaluation and control of meat quality in pigs. Current Topics Vet Med Anim Sci, 38. Dordrecht, Germany. Springer; 1987:129.
18. Bourne MC. Texture profile analysis. *Food Technol* 1978;35:62-66.
19. Deshmukh VP, Lunge MS, Rajurkar AV, Dharkar NS, Raut SR, Dhoran VS. Chemical characterization and therapeutics of *Dalbergia latifolia* Roxb: A review. *J Pharmac Phytochem* 2021;10(4):340-345. <https://doi.org/10.22271/phyto.2021.v10.i4d.14174>.
20. Acharya R, Jani SV, Harisha CR, Shukla VJ. Phytopharmacognostical investigations on root and stem of *Dalbergia volubilis* Roxb: An extrapharmacopoeial plant of Ayurveda. *Ayu* 2018;39(3):151–158. https://doi.org/10.4103/ayu.AYU_48_18.

21. Soares S, Brandão E, Guerreiro C, Soares S, Mateus N, de Freitas V. Tannins in food: insights into the molecular perception of astringency and bitter taste. *Molecules* 2020; 25:2590. <http://doi.org/10.3390/molecules25112590>.
22. Islam MT, Ali ES, Uddin SJ, Shaw S, Islam MA, Ahmed MI, *et al.* Phytol: A review of biomedical activities. *Food Chem Toxicol* 2018;121:82-94. <https://doi.org/10.1016/j.fct.2018.08.032>.
23. Flores-Bazán T, Betanzos-Cabrera G, Guerrero-Solano JA, Negrete-Díaz JV, German-Ponciano LJ, Olivo-Ramírez D. Pomegranate (*Punica granatum* L.) and its phytochemicals as anxiolytic; an underreported effect with therapeutic potential: a systematic review. *Brain Res* 2023;1820, 148554. <https://doi.org/10.1016/j.brainres.2023.148554>.
24. Majeed FA, Munir H, Rashid R, Zubair MT. Antimicrobial, cytotoxicity, mutagenicity and anti-epileptic potential of ethanol extracts of a multipurpose medicinal plant *Dalbergia sissoo*. *Biocatal Agric Biotechnol* 2019; 101155. <https://doi.org/10.1016/j.bcab.2019.101155>.
25. Kharkwal H, Panthari P, Pant MK, Kharkwal H, Kharkwal AC, Joshi DD. Foaming glycosides: A Review. *IOSR J Pharm* 2012;12(2):23–28. doi:10.9790/3013-25202328.
26. Palazzo M, Vizzarri F, Arvay J, D'Alessandro AG, Martemucci G, Casamassima D, *et al.* Dietary effect of dried bay leaves (*Laurus nobilis*) meal on selected productive performances and on quality meat traits in growing rabbits. *Livest Sci* 2020;242:104301. <https://doi.org/10.1016/j.livsci.2020.104301>.
27. Cullere M, Dalle-Zotte A, Celia C, Renteria-Monterrubbio AL, Gerencsér Zs, Szendrő Zs, *et al.* Effect of *Silybum marianum* herb on the productive performance, carcass traits and meat quality of growing rabbits. *Livest Sci* 2016;94:31-36. <https://doi.org/10.1016/j.livsci.2016.10.012>.
28. Rotolo L, Gai F, Nicola S, Zoccarato I, Brugiapaglia A, Gasco L. Dietary supplementation of oregano and sage dried leaves on performances and meat quality of rabbits. *J Integr Agric* 2013;12(11):1937-1945. [https://doi.org/10.1016/S2095-3119\(13\)60631-0](https://doi.org/10.1016/S2095-3119(13)60631-0).
29. García-Vázquez L, Zepeda-Bastida A, Ayala-Martínez M, Soto-Simental S. Infusion of *Chenopodium ambrosioides* consumed by rabbits: effects on carcass, meat and burger quality. *Food Sci Technol Campinas* 2020;40(suppl 2):451-457. https://www.scielo.br/scielo.php?pid=S010120612020005010209&script=sci_arttext.

30. Perna A, Simonetti A, Grassi G, Gambacorta E. Effect of a cauliflower (*Brassica oleraceae* var. Botrytis) leaf powder-enriched diet on performance, carcass and meat characteristics of growing rabbit. *Meat Sci* 2019;149:134-140. <https://doi.org/10.1016/j.meatsci.2018.11.013>.
31. Dalle-Zotte A, Celia C, Cullere M, Szendrő Z, Kovács M, Gerencsér Z, Dal Bosco A, Giaccone V, Matics, Z. Effect of an *in vivo* and/or in-meat application of a liquorice (*Glycyrrhiza glabra* L.) extract on fattening rabbits live performance, carcass traits and meat quality. *Animal Feed Sci Technol* 2020;260:114333. <https://doi.org/10.1016/j.anifeedsci.2019.114333>.
32. North MK, Dalle Zotte A, Hoffman LC. The use of dietary flavonoids in meat production: A review. *Anim Feed Sci Technol* 2019;257:114291. <https://doi.org/10.1016/j.anifeedsci.2019.114291>.
33. Wu Y, Jiang L, Ran W, Zhong K, Zhao Y, Gao, H. Antimicrobial activities of natural flavonoids against foodborne pathogens and their application in food industry. *Food Chem* 2024;140476. <https://doi.org/10.1016/j.foodchem.2024.140476>.
34. Mancini S, Preziuso G, Dal Bosco A, Roscini V, Szendrő Z, Fratini F, Paci G. Effect of turmeric powder (*Curcuma longa* L.) and ascorbic acid on physical characteristics and oxidative status of fresh and stored rabbit burgers. *Meat Sci* 2015;110:93-100. <https://doi.org/10.1016/j.meatsci.2015.07.005>.
35. Odabasoglu F, Aslan A, Cakir A, Suleyman H, Karagoz Y, Bayir Y, Halici M. Antioxidant activity, reducing power and total phenolic content of some lichen species. *Fitoterapia* 2005;76(2):216-217. <https://doi.org/10.1016/j.fitote.2004.05.012>.
36. Brand-Williams W, Cuvelier ME, Berset C. Use of a free radical method to evaluate antioxidant activity. *LWT - Food Sci Technol* 1995;28(1):25-30. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5).
37. Lv QZ, Long JT, Gong ZF, Nong KY, Liang XM, Qin T, Huang W, Yang, L. Current state of knowledge on the antioxidant effects and mechanisms of action of polyphenolic compounds. *Natural Product Communications* 2021;16(7), 1934578X211027745. <https://doi.org/10.1177/1934578X211027745>.
38. Wang Z, He Z, Zhang D, Chen X, Li H. Effect of pepper (*Zanthoxylum bungeanum* Maxim.) essential oil on quality changes in rabbit meat patty during chilled storage. *J Food Sci Technol* 2022;59:179-191. <https://doi.org/10.1007/s13197-021-04998-6>.
39. Mancini S, Preziuso G, Dal Bosco A, Roscini V, Parisi G, Paci G. Modifications of fatty acids profile, lipid peroxidation and antioxidant capacity in raw and cooked rabbit burgers added with ginger. *Meat Sci* 2017;133:151-158. <https://doi.org/10.1016/j.meatsci.2017.07.003>.

40. Apáez-Barrios J, Ocampo-López J, Soto-Simental S, Aguilar-Raymundo VG, Ayala-Martínez M. Dietary supplementation with *Pithecellobium dulce* (Roxb) Benth Fruits to fattening rabbits. *Animals* 2023;13(20):3249. <https://doi.org/10.3390/ani13203249>.
41. Tapia MS, Alzamora SM, Chirife J. Effects of water activity (aw) on microbial stability as a hurdle in food preservation. In: Fontana Jr AJ, Schmidt SJ, Labuza TP, editors. *Water activity in foods: Fundamentals and applications*. Chicago, IL, USA: Wiley & Sons; 2020:323-355.
42. Mancini S, Mattioli S, Nuvoloni R, Pedonese F, Dal Bosco A, Paci G. Effects of garlic powder and salt on meat quality and microbial loads of rabbit burgers. *Foods* 2020;9(8):1022. <https://doi.org/10.3390/foods9081022>.