Diet supplementation with *Dalbergia palo-escrito* hexane extract in fattening rabbits: its effect on productive performance, carcass traits, meat characteristics and meatballs Shelf-Life

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**ABSTRACT**

This study was conducted to determine the influence of *Dalbergia palo-escrito* hexane extract supplemented to rabbits on productive performance, blood biochemistry, haematology, carcase traits, meat characteristics and meatballs shelf-life. A hexane extract of *D. palo-escrito* was obtained from leaves of the tree. Average feed consumption daily gain, average daily weight gain, total weight gain and feed conversion ratio, length body, lumbar circumference, carcase traits, texture profile analysis, meat colour, antioxidant properties, water activity as well as shelf life of meatballs (Total viable bacterial counts, staphylococcus counts, enterobacteria counts, antioxidant activity, pH and water activity) were determined. Feed conversion rate was lower (\(p < 0.05\)) in group feed with hexane extract (1.89 and 1.54, for control and hexane extract, respectively). Also, hexane extract decreases feed intake and weight gain. Hot dressing percentage was higher (\(p < 0.05\)) in the hexane extract group (48%) than the control group (47%), but the main carcase cuts were similar (\(p > 0.05\)) between groups. \(L^*\) value was lower (\(p < 0.05\)) in the hexane extract group (51.2 vs 49.4, for control and hexane extract, respectively). The meatballs prepared with the meat obtained from the hexane extract group showed a lower (\(p < 0.05\)) total viable bacterial count after 14 d of storage in refrigeration conditions (8.45 and 4.75 CFU.g\(^{-1}\), for control and hexane extract group, respectively). *D. palo-escrito* hexane extract decreases productive performance, it is possible that albumin: globulin rate indicates a liver damage, but there was no effect on carcase and meat quality and it increased the shelf life of meatballs.

**HIGHLIGHTS**
- Extracts of *Dalbergia palo-escrito* have bioactive compounds
- *Dalbergia palo-escrito* could be used to feed rabbits
- Meatballs increase shelf-life

**Introduction**

The consumption of meat by humans is considered important due to its sensorial and nutritional characteristics as well as being an important source of aminoacids, fatty acids, minerals and vitamins. Nowadays, it is common knowledge that an appropriate diet plays an important role in human health and preventing disease. Some consumers have switched to eating poultry, fish or rabbit meat as these types of meat are considered lean, low in cholesterol and easy to digest (Malave et al. 2013). Although, the level of consumption of rabbit meat is still generally low (Szendrö et al. 2020). Cullere and Dalle Zotte (2018) consider that rabbit meat should be promoted among traditional consumers, and efforts should be made to attract new potential consumers to consume this meat. According to Hermida et al. (2006) rabbit meat has high levels of potassium, calcium, phosphorus and vitamins, in addition to low sodium and cholesterol. Taking into account these nutritional properties, rabbit meat is considered as a functional food (Dalle Zotte and Szendro 2011). Functional foods have a specific and positive effect on an organism’s functionality by promoting additional physiological effects as well as providing nutritive value, thereby improving an individual’s health and reducing the risk of disease (Granato et al. 2020).
Meat is susceptible to oxidation and to decrease the risk of this occurring, certain synthetic antioxidants have been used (Sebranek 2009). Butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are the most common antioxidants used in food, although they have some adverse effects on human health (Movileanu et al. 2013). An alternative to using synthetic antioxidants is the use of plant extracts which have been to have antioxidant properties. This antioxidant activity is due to the presence of phenolic or flavonoid compounds in the extracts (Wang et al. 2020). Plant extracts can be added as a supplement in rabbit feed as described by Dalle Zotte et al. (2016) and Shah et al. (2014) who used ethanolic, methanolic and aqueous extract from different plants including grapefruit, ginger and peppermint.

The genus of Dalbergia has been described as containing synthesised phenolic compounds, flavonoids and sesquiterpenes (The SN 2017), some of which have antioxidant, antibacterial and anti-inflammatory activity (Singh et al. 2017). Furthermore, the leaves from the Dalbergia glabra tree are consumed for ruminants (Sosa-Rubio et al. 2000). But Dalbergia palo-escrito a plant distributed in Mexico and Central America to our knowledge is not studied as rabbit feed, there are only a few studies (Coreno-Hernández et al. 2018). In addition, there are several studies that have demonstrated that plant extracts affect productive performance, carcass and meat quality or meat product quality obtained from rabbits fed with the aqueous extract of Chenopodium ambrosoides (García-Vázquez et al. 2020), natural finely ground herbs and spices enriched with special extracts and essential oils (Elghalid et al. 2020), Citrus lemon powder comprising 1 or 2% of the diet (Elwan et al. 2019) or supplementation of extracts of Lippia citriodora, Raphanus sativus and Solanum lycopersicum (Vizzarri et al. 2017). However, to the best of the authors’ knowledge, there is no information about the use of a hexane extract obtained from D. palo-escrito to supplement rabbits during the fattening period. Therefore, the objective of this study was to determine the influence of Dalbergia palo-escrito hexane extract supplemented to rabbits on productive performance, blood biochemistry, haematology, carcass traits, meat characteristics and meatballs shelf-life.

Materials and methods

**Dalbergia palo-escrito hexane extract**

*D. palo-escrito* leaves were obtained from forestry plant nursery located in Tulancingo, Hidalgo, México, were dried at room temperature for five days. Afterwards, 500 g of dried leaves were placed in one litre of hexane, mixed and put in a flask with stirring for 24 h at room temperature. Then, the mix was filtered through three layers of gauze. Supernatant was dehydrated in a Barnstead 3510 oven (Barnstead International, Dubuque, Iowa, USA) at 50 °C. Hexane extract of D. palo-escrito comprises the following properties, total phenols of 35.4 mg.mL⁻¹, antioxidant properties measured as FRAP and DPPH 10.77 and 50.93 mg.mL⁻¹, respectively, also has antibacterial activity against *Salmonella thyphymurium*, *Listeria monocytogenes* and *Salmonella enteritidis* (Unpublished data). The resulting dried hexane extract was used to add to rabbit feed as indicated in Table 1.

**Experimental design**

The animals were managed according to the institutional committee guidelines on animal care, protocol number CICUA/ICAP 001/2020. Forty-eight rabbits, 35 d of age, with an average live weight of 0.801 kg, unsexed, California x English Pot crossbreed were randomly assigned to two groups. One group received a control treatment (C) while the other group was fed with a hexane extract (HE) obtained from *D. palo-escrito* leaves (2 g.kg⁻¹) as described above, with six repetitions (n = 4 rabbits) of each treatment. Animals were fattened over a period of 28 d at an experimental rabbitry located in Tulancingo, Hidalgo, Mexico. Rabbits were housed in cages measuring 45 × 60 ×

**Table 1.** Ingredients and nutritional composition of the diets on dry matter.

| Ingredient                              | Treatments a | C  |
|-----------------------------------------|--------------|----|
| 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 |
| **Dalbergia palo-escrito hexane extract, %** | 0.24         | 0.00 |

**Nutritional composition calculated**

| Protein, %                              | 15.07        | 15.08 |
| Digestible energy, Mcal MS Kg⁻¹         | 2.6          | 2.6 |
| aNDF, %                                 | 26.02        | 26.19 |
| bADF, %                                 | 14.95        | 15.00 |
| Calcium, %                              | 0.86         | 0.87 |
| Phosphorus, %                           | 0.56         | 0.56 |
| Sodium, %                               | 0.19         | 0.18 |
| Potassium, %                            | 0.97         | 0.97 |

a: HE: Diet with hexane extract; C: Control diet. aNeutral Detergent Fibre. bAcid Detergent Fibre.
40 cm with each one adapted with manual feeders and automatic drinkers. Rabbits were fed daily with isoproteic (15% CP), isoenergetic (2.6 Mcal.kg$^{-1}$) and isofibrous (26% NDF) diets (Table 1) according to the nutritional requirements recommended by NRC (1977) and using nutritional ingredient tables published by FEDNA (2020). The feed was blended and then pelleted using a SKJ120 feed pellet machine (Yuezhen Machinery Co., Shandong, China) and stored in a hermetic container until use.

**Productive performance**

Every week, the live weight of rabbits was registered using a Mettia MTNUV-40 digital scale (Mettia México, CDMX, Mexico). The feed offered and rejected was also measured daily during the fattening period using the same above-mentioned scale. Average of feed consumption daily (FCD) during week 1, 2, 3 and 4; average of daily weight gain (WGD) every week during the experiment, total weight gain (TWG), and feed conversion ratio (FCR) were calculated from the data obtained. After 28 d of fattening, animals were transported to meat laboratory of Instituto de Ciencias Agropecuarias and then slaughtered without previously being subjected to fasting and mechanical concussion stunning according to national legislation (NOM-033-SAG/ZOO 2014). Before slaughtering, the dorsal length of the animals was determined by measuring from the atlas to the last ischia vertebra, while the lumbar circumference of the animals was measured using a measuring tape.

Blood was collected in sterile tubes containing ethylenediaminetetraacetic acid, and samples were sent to the laboratory for analysis using a BC Vet II KontroLab haematology analyser (Kontrolab Instruments, Napoli, Italy). Another tube was used for collecting blood in order to obtain serum for biochemical analysis, to be analysed in a Skyla VB1 biochemical analyser (Lite-ON Technology Corporation, Hsinchu, Taiwan).

**Carcass quality**

Once rabbits were slaughtered, the carcase length of the animals was determined by measuring from the atlas to the last ischia vertebra while the lumbar circumference of the carcasse was measured using a measuring tape, after that the animals were dissected to obtain weights of hot carcases, liver, kidney, digestive system, bladder, feet and skin. Carcases were then stored in refrigeration at 6°C for 24 h.

The carcases were sectioned after 24 h of refrigerated storage as indicated by Blasco et al. (1993). The head was cut at the atlas level, the forequarter was obtained by cutting between the sixth and seventh ribs, the thoracic cage was determined by cutting the last rib, and the loin was attained in the sixth and seventh lumbar vertebra by cutting the abdominal wall transversally to the vertebral column to eventually obtain the foreleg. All of these parts were weighted separately.

Meat colour was measured on the loin surface (*Longissimus thoracis*) using a Minolta CM-508d colorimeter (Minolta, Tokio, Japan). The values were recorded in terms of CIELab colour space using illuminant D65 and 10° standard observer as indicated in the American Meat Science Association meat colour measurement guidelines (AMSA 2012) using lightness (L*), redness (a*), and yellowness (b*) values. The pH was determined using a Hanna HI99163 meat pH metre (Hanna instruments, Cluj-Napoca, Romania) at *Longissimus thoracis* muscle. Water holding capacity (WHC) was measured according to the method described by Honikel (1987) using meat from *Longissimus thoracis* muscle. Cooking loss were measured in loins, samples were put into a plastic bag and cooked at 80°C until reaching an internal temperature of 68°C using a water bath StableTemp (Cole Parmer, Vernon Hills, IL, USA). Cooked samples were cooled at room temperature and then weighted, while cooking loss values were calculated by differences in weight before and after cooking and expressed as a percentage. Once samples were cooled, a texture profile analysis was carried out following the method described by Bourne (1978). Six cubes (1 cm each side) for each loin were used, and samples were cut parallel to muscle fibres. The Brookfield CT3 texture analyser (Brookfield, Middleboro, MA, USA) was set to compression at 50% of the sample and perpendicular to the muscle fibre direction using 1 mm.s$^{-1}$ of crosshead speed. A TA3/1000 probe and a TA-BT-KIT base were used. The samples were compressed twice, and force-time graph of deformation were obtained using Texture Pro CT software (Brookfield, Middleboro, MA, USA), which produced hardness, resilience, cohesiveness, chewiness and springiness values.

**Meatballs**

Meat obtained from legs from each group of rabbits were used to elaborate meat balls (three batches with three meatballs each time). Meat was grounded in a Torrey meat grinder (Torrey, Monterrey, Mexico). One
kg of rabbit leg meat was mixed with 10 g of salt (NaCl) and 200 ml of purified water. Meatballs weighing 50 g each were made and were then placed on a tray covered with a food wrap film and stored at refrigeration temperature (4°C) for 14 d. Meatballs were analysed each week for total viable bacterial counts, Staphylococcus and Enterobacteriaceae using standard methods (NOM-210-SSA1 2014), antioxidant activity using 2,2-Diphenyl-1-picrylhydrazyl (DPPH) reagent as indicated by Brand-Williams et al. (1995), pH using a Hanna HI99163 pH metre (Hanna Instruments, Cluj-Napoca, Rumania), as well as water activity (aw) with a HygroPalm HP23-AW water activity analyser (Rotronic Instrument Corp, NY, USA).

**Statistical analysis**

A one-way analysis was used to evaluate carcass and meat quality. A repeated time one-way design was used to analyse productive performance and meatball quality. All analyses were performed using SPSS software (IBM, Chicago, IL, USA). The statistical models used were:

\[ Y_{ij} = \mu + \beta_i + \epsilon_{ij} + \gamma_j, \]

in which \( Y_{ij} \) = dependent variable, \( \mu \) = mean of the variable, \( \beta_i \) = the fixed effect of \( i \)-th rabbit of the group, \( \gamma_j \) = \( j \)-th cage and \( \epsilon_{ij} \) = experimental error associated with the observation \( Y_{ij} \).

\[ Y_{ijd} = \mu + \beta_i + \tau_j + \beta_i(\tau_j) + \epsilon_{ijk} + \delta_{ijk}, \]

in which \( Y_{ijd} \) = dependent variable, \( \mu \) = mean of the variable, \( \beta_i \) = the fixed effect of \( i \)-th rabbit of the group, \( \tau_j \) = time and \( \beta_i(\tau_j) \) time inside treatment, \( \delta_{ijk} \) = \( i \)-th repetition and \( \epsilon_{ijk} \) = experimental error associated with the observation \( Y_{ijk} \).

**Results**

In order to demonstrate that *D. palo-escrito* hexane extract modify the productive performance, carcass and meat quality, as well as the shelf life of meatballs stored in refrigeration for 14 days, this study measured the effect of a hexane extract from farm to meat product, a concept which has been used over the last few years. Productive performance as averages of daily feed consumption, daily weight gain and feed conversion ratio are shown in Table 2. There were differences (\( p < 0.05 \)) between treatments in all variables measured. Average daily feed consumption increased over the fattening period in control group, recording the highest value at week 4 of fattening period (109.6 g.d\(^{-1}\)). However, there was a difference (\( p < 0.05 \)) between C and HE groups control (109.6 vs 80.8 g.d\(^{-1}\), respectively). Average daily weight gain was also higher (\( p < 0.05 \)) in the control treatment, but in both treatments, the values decreased during the fattening period (42.2 and 31.1 g.d\(^{-1}\) at first week and fourth week, respectively). Animals which consumed the control diet had higher (\( p < 0.05 \)) total weight gain and feed conversion rate (\( p < 0.05 \)) during the fattening period than the group of rabbits fed with the *D. palo-escrito* hexane extract.

| Variable | C     | HE    | SEM  |
|----------|-------|-------|------|
| FCD1, g d\(^{-1}\) | 70.62\(^a\) | 62.25\(^b\) | 3.50 |
| FCD2, g d\(^{-1}\) | 83.74\(^a\) | 66.60\(^b\) | 2.60 |
| FCD3, g d\(^{-1}\) | 96.00\(^a\) | 78.40\(^b\) | 6.95 |
| FCD4, g d\(^{-1}\) | 109.63\(^a\) | 80.82\(^b\) | 5.68 |
| WGD1, g d\(^{-1}\) | 42.21\(^a\) | 22.57\(^b\) | 1.63 |
| WGD2, g d\(^{-1}\) | 38.93\(^a\) | 25.38\(^b\) | 2.73 |
| WGD3, g d\(^{-1}\) | 32.79\(^a\) | 23.07\(^b\) | 3.37 |
| WGD4, g d\(^{-1}\) | 31.16\(^a\) | 19.27\(^b\) | 3.56 |
| TWG, g d\(^{-1}\) | 1016.58\(^a\) | 534.00\(^b\) | 46.5 |
| FCR | 1.89\(^a\) | 1.54\(^b\) | 0.08 |

\(^a,b\)Superscript indicate statistical differences between treatments (\( p < 0.05 \)). \(^a\) HE = Diet with hexane extract; \(^b\) C: Control diet. \(^c\) FCD: Average of feed consumption daily in week 1, 2, 3 or 4. \(^d\) WGD: Average of weight gain daily in 1, 2, 3 or 4 fattening weeks. \(^e\) TWG: total weight gained. \(^f\) FCR: Feed conversion rate.

**Blood analysis**

Blood samples were obtained for determine biochemical parameters and blood analyses (Table 3). The results indicated that using hexane extract had no significant (\( p > 0.05 \)) effect on any of the biochemical parameters, except for the albumin:globulin ratio. Although there were no significant differences (\( p > 0.05 \)) regarding the amount of total protein, albumins and globulins, the albumin:globulin ratio was different (\( p < 0.05 \)), which could mean that there was a liver problem in the group of rabbits that were fed with the *D. palo-escrito* hexane extract. Regarding the blood analysis the majority of parameters were similar between groups (\( p > 0.05 \)), but monocytes, granulocytes and platelets were statistically different (\( p < 0.05 \)) in the rabbits fed with the *D. palo-escrito* hexane extract and control group.

Carcass traits of rabbits that consume the *D. palo-escrito* hexane extract showed lower values for live weight, skin weight, animal length and carcass length (\( p < 0.05 \)), while there was no difference between groups in hip and lumbar carcase circumference, hot carcass weight, hot dressing, feet and gastrointestinal tract weight (Table 4). The live weight, hot carcass weight, cold carcass weight, dressing percentage, primal cuts, kidney fat, scapular fat, meat, fat and bone (Table 5) were similar between treatments (\( p > 0.05 \)).
But numerically, almost variables were lower in group feed hexane extract of *D. palo-escrito*, except for head and bone. It is possible that the extract has some detrimental effect, due some biochemical metabolites were observed high levels in this group.

Meat characteristics affected for the use of hexane extract of *D. palo-escrito* could be shown in Table 6.

The pH value was higher (*p < 0.05*) in the HE group (5.85) than C group (5.73), these values is common in rabbit meat. Other variables are related to pH meat, as L*, a* and b* colour parameters and WHC, all were higher (*p < 0.05*) in the control treatment, however, cooking loss were similar between treatments (*p > 0.05*). One of the most important of meat quality

### Table 3. Blood biochemistry and haematology of rabbits fed with a hexane extract of *Dalbergia palo-escrito*.

| Parameters                      | Treatments^a | SEM  |
|---------------------------------|--------------|------|
| **Biochemical analysis**        |              |      |
| Albumin, g.dL⁻¹                  | 13.49        | 12.75| 3.15 |
| Total protein, g.dL⁻¹            | 23.40        | 24.69| 5.80 |
| Glucose, mg.dL⁻¹                 | 67.15        | 81.43| 12.96|
| Alkaline phosphatase, U.L⁻¹      | 226.31       | 178.68| 15.93|
| Alanine transferase, U.L⁻¹       | 44.56        | 51.36| 2.90 |
| Creatine phosphokinase, U.L⁻¹    | 1320.63      | 1180.23| 59.68|
| Blood urea nitrogen, mg.dL⁻¹     | 8.59         | 18.35| 3.67 |
| Creatinine, mg.dL⁻¹              | 25.52        | 35.44| 10.24|
| Total CO₂, mmol.L⁻¹              | 22.00        | 24.74| 1.41 |
| Ca²⁺, mmol.L⁻¹                   | 8.59         | 9.79 | 1.11 |
| Na⁺, mmol.L⁻¹                    | 150.00       | 150.75| 1.17 |
| K⁺, mmol.L⁻¹                     | 4.93         | 4.53 | 0.20 |
| Globulin, g.dL⁻¹                 | 9.90         | 11.93| 2.67 |
| Urea, mg.dL⁻¹                    | 16.34        | 34.71| 8.11 |
| Albumin/Globulin                 | 1.31         | 1.10 | 0.04 |
| Na⁺/K⁺                          | 29.56        | 34.73| 1.77 |
| **Blood analysis**               |              |      |
| White blood cells, M.μL⁻¹        | 4.69         | 5.34 | 0.64 |
| Lymphocytes, %                   | 35.47        | 31.35| 3.41 |
| Monocytes, %                     | 23.81        | 20.16| 0.98 |
| Granulocytes, %                  | 40.72        | 48.49| 44.61|
| Lymphocytes, 10⁶ cells.L⁻¹       | 1.54         | 1.42 | 0.14 |
| Monocytes, 10⁶ cells.L⁻¹         | 1.07         | 0.89 | 0.98 |
| Granulocytes, 10⁶ cells.L⁻¹      | 2.08         | 3.03 | 0.51 |
| Red blood cells, 10¹² cells.L⁻¹  | 5.49         | 5.87 | 5.68 |
| Haemoglobin, g.dL⁻¹              | 11.16        | 11.73| 0.22 |
| Hematocrit, %                    | 31.28        | 32.46| 31.87|
| Mean corpuscular volume, fl      | 57.21        | 55.60| 0.72 |
| Mean corpuscular haemoglobin, pg | 20.36        | 20.28| 0.20 |
| Mean corpuscular haemoglobin conc, g.dL⁻¹ | 35.49 | 36.53 | 0.73 |
| Platelets, 10⁹ cells.L⁻¹         | 211.00       | 162.83| 13.80|
| Mean platelet volume, fl         | 16.52        | 15.75| 0.33 |

^a,bSuperscript indicate statistical differences between treatments (*p < 0.05*). AHE: Diet with hexane extract; C: Control diet.

### Table 4. Morphometric and carcass trait of rabbits fed with hexane extract of *Dalbergia palo-escrito*.

| Variable                        | Treatment^a | SEM  |
|---------------------------------|--------------|------|
| Live weight, g                  | 1732.35      | 1595.00| 50.88 |
| Animal length, cm               | 29.82        | 28.36 | 0.46 |
| Carcase length, cm              | 31.52        | 30.31 | 0.39 |
| Lumbar circumference, cm        | 22.05        | 21.42 | 0.43 |
| Carcase lumbar circumference, cm| 14.55        | 14.18 | 0.27 |
| Hot carcass weight, g           | 803.52       | 749.06| 27.05|
| Hot dressing (%)                | 47.01        | 48.00 | 0.63 |
| Skin, g                         | 245.47       | 208.05| 9.80 |
| Feet, g                         | 44.64        | 40.52 | 1.99 |
| Complete gastrointestinal tract, g| 453.76     | 429.94| 28.83|

^a,bSuperscript indicate statistical differences between treatments (*p < 0.05*). AHE: Diet with hexane extract; C: Control diet.

### Table 5. Carcase dissection into main cuts of rabbits fed with hexane extract of *Dalbergia palo-escrito*.

| Variable                        | Treatment^a | SEM  |
|---------------------------------|--------------|------|
| Cold carcass weight, g          | 815.64       | 768.15| 29.12|
| Kidney fat, g                   | 8.58         | 7.89  | 0.99 |
| Scapular fat, g                 | 3.29         | 3.00  | 0.38 |
| Head, g                         | 91.41        | 95.26 | 1.91 |
| Forepart weight, g              | 198.17       | 180.78| 7.92 |
| Intermedia part weight, g       | 84.05        | 76.31 | 4.34 |
| Hind part weight, g             | 150.35       | 138.94| 6.54 |
| Legs, g                         | 283.52       | 270   | 10.34|
| Meat, g                         | 193.82       | 181.31| 7.85 |
| Bone, g                         | 84.94        | 85    | 3.68 |
| Dissectible fat, g              | 1.79         | 1.30  | 0.19 |

^a,bSuperscript indicate statistical differences between treatments (*p < 0.05*). AHE: Diet with hexane extract; C: Control diet.
Daily feed consumption increased every week in both treatments (from 70.6 and 62.2 in the first fattening week to 109.6 and 80.8 g.d⁻¹ for the C and HE groups at the end of the experiment, respectively). Similarly, daily weight gain and feed conversion rate were different between groups, HE group has the low average values for variables related to feed consumption and weight gain daily. This observation was also reported in several studies using extracts obtained from different plants such as oregano (Cardinali et al. 2015), Glycyrhiza glabra (Dalle Zotte et al. 2020), Chenopodium ambrosioides (García-Vázquez et al. 2017), Tithonia tubaefornis (Pérez-Martínez et al. 2018) or a mix of plants and species containing carvacrol, thymol, menthol and propylene (Elghalid et al. 2020).

However, García-Valencia et al. (2019) reported a decrease in consumption during the fattening period when using a different concentration of an aqueous extract of D. palo-escrito. This low feed consumption in the hexane extract group might be because D. palo-escrito has some pharmacologically active agents or certain compounds that affect the palatability of the feed, since Acharya et al. (2018) found that Dalbergia volubilis has a slight pungent odour, an astringent taste as well as the presence of polyphenols as tannins. Soares et al. (2020) indicated a tannin presence in food contributes to the organoleptic properties, astringency specifically the bitter taste.

Live weight, animal and carcass length, skin and complete gastrointestinal tract were different (p < 0.05) between the groups of rabbits. In contrast, hot carcass and hot dressing were similar which is important highlighted because the differences are found in the skin and gastrointestinal tract weights. Some studies using plants or plant extracts indicate differences in skin weight as well as animal and carcass length. Some of these studies include Herrera-Soto et al. (2018) who fed rabbits with Ruta graveolens, García-Vázquez et al. (2020) who used an infusion of Chenopodium ambrosioides, and Pérez-Martínez et al. (2018) who fed leaves, stems or complete plants of Tithonia tubaefornis. However, Elghalid et al. (2020) did not find any differences in carcass length when using a mixture of herbal plants and spices enriched with special extracts and essential oils. Dalle Zotte and Cossu (2009) reported that live weight and dressing percentage increased by including a tannin extract during a fattening period for rabbits. However, the low productive performance of HE group maybe is due to D. palo-escrito has high content of phytol, Ma et al. (2020) identified the main compound found in

### Table 6. Meat characteristics of rabbits fed with hexane extract obtained from Dalbergia palo-escrito.

| Variable          | C         | HE        | SEM  |
|-------------------|-----------|-----------|------|
| pH                | 5.73 a    | 5.85 b    | 0.01 |
| L a               | 51.26 a   | 49.39 b   | 0.40 |
| a b               | 1.26 b    | 0.19 a    | 0.12 |
| b                 | 7.20 a    | 6.38 b    | 0.17 |
| WHC, %            | 22.99 a   | 17.67 b   | 1.15 |
| Cooking losses %  | 26.36 a   | 27.93 b   | 0.57 |
| Hardness, N       | 17.87 a   | 23.05 b   | 0.87 |
| Resilience        | 0.18      | 0.18      | 0.00 |
| Cohesiveness      | 0.52 a    | 0.49 b    | 0.00 |
| Springiness       | 0.50      | 0.50      | 0.00 |
| Chewiness         | 4.73 b    | 5.60 a    | 0.23 |

a,b Superscript indicate statistical differences between treatments (p < 0.05). aHE: Diet with hexane extract; C: Control diet.

### Table 7. Quality of meatballs elaborated with meat from rabbits fed with hexane extract of Dalbergia palo-escrito.

| Variable          | C         | HE        | SEM  |
|-------------------|-----------|-----------|------|
| TVBCC             | 3.9       | 6.15 a    | 0.84 b|
| Staphylococci     | 3.56 a    | 5.89 a    | 7.65 a|
| Enterobacteria    | 3.61 a    | 6.28 a    | 9.71 a|
| DPPH (mg mL⁻¹)    | 59.58     | 35.94     | 70.93 a|
| pH                | 5.73 a    | 5.56 a    | 6.40 b|
| a w               | 0.97      | 0.96 b    | 0.94 b|
| DPPH              | 2.2-Diphenyl-1-picrylhydrazyl. |

a,b Superscript indicate statistical differences between treatments (p < 0.05). aHE: Diet with hexane extract; C: Control diet. bTotal viable bacterial counts.

is hardness, this parameter and chewiness in the texture profile analysis was higher (p < 0.05) in the meat from rabbits fed with the D. palo-escrito hexane extract (23.05 N and 5.60, respectively), while cohesiveness was lower (p < 0.05) in this animal group. For resilience and springiness, there no was difference between treatments (p > 0.05).

Several bacteria groups can be present in meatballs which could be related to shelf life. Total viable bacterial counts, Staphylococcus counts and Enterobacteriaceae counts were determined in meatballs manufactured with meat obtained from the rabbits that consumed the D. palo-escrito hexane extract (Table 7). The use of this extract decreases (p < 0.05) total viable bacterial counts, Staphylococcus counts and Enterobacteriaceae. The antioxidant properties of the D. palo-escrito hexane extract were similar (p > 0.05) to the control treatment during over the storage period. The pH of meatballs was higher in treatment using hexane extract over the storage period. Finally, the a w was different (p < 0.05) between treatments.
an essential oil of Dalbergia odorifera, and Islam et al. (2018) suggested phytol has a wide range of pharmacological effects including anxiolytic action.

Regarding the blood and haematology analysis of the rabbits fed with the D. palo-escrito hexane extract recording, there could be physiological deterioration and/or an infection process. The low albumin/globulin ratio indicates possible liver damage, while this group also has a low level of platelets and monocytes and a high level of granulocytes. A low level of albumin is common in pet rabbits with chronic malnutrition (Siegel and Walton 2020), meaning that another analysis is needed to determine the problem. Furthermore, a histological analysis of some organ samples could also be carried out. However, HE group is affected for high content of several bioactive compounds as indicating above, phytol supplementation in sheep alter lipid metabolism (Ding et al. 2021).

Besides, Serena Mezzar et al. (2017) reported phytol when adding an infusion of Chenopodium ambrosioides to feed rabbits. The meat product obtained from rabbits fed with the D. palo-escrito hexane extract increased pH in rabbit meat and similar values were reported when feeding Chenopodium ambrosioides (García-Vázquez et al. 2020), Tithonia tubaeformis (Zepeda-Bastida et al. 2019), Chamomilla and Ruta graveolens (Herrera-Soto et al. 2018). Lightness (L*), redness (a*) and yellowness (b*) parameters of meat colour as well as water holding capacity decreased in rabbit meat fed with the D. palo-escrito hexane extract. These results were similar to those reported by García-Vázquez et al. (2020) when using an infusion of Chenopodium ambrosioides to feed rabbits. However, Zepeda-Bastida et al. (2019) found high values of L* and a* using different parts of Tithonia tubaeformis. Moreover, Cordero-Caballero et al. (2019) did not find any differences when using Cymbopogon citratus, which was also the case with Cardinali et al. (2012) when using an orégano extract to feed rabbits. It is possible that hexane extract of D. palo-escrito have several bioactive compounds that affect colour parameters and WHC.

Hardness, cohesiveness and chewiness values were different between treatments, with the D. palo-escrito hexane extract having the highest values. However, other studies have found that using plants or plant extracts for feeding did not affect meat rabbit texture. Zepeda-Bastida et al. (2019), for example, used different parts of the plant T. tubaeformis for rabbit feed, García-Vázquez et al. (2020) used an infusion of Chenopodium ambrosioides to feed rabbits, while Hernández-Martínez et al. (2018) only found differences in hardness when feeding hydrolysed sorghum to rabbits. North et al. (2019) reported that some bioactive compound feed to animals increase hardness and other parameters of texture profile analysis.

The meatballs were analysed to determine whether microbial growth is affected by feeding the hexane extract to rabbits. The meat product obtained from these animals had a low presence of Staphylococcus and Enterobacteriaceae groups on days 0 and 7, yet after 14 d of storage only Staphylococcus still had a low presence. Moreover, total viable bacterial counts were similar on days 0 and 14 between treatments. Hexane extract of D. palo-escrito has antibacterial effect, North et al. (2019) reviewed the effect of dietary flavonoids on meat of different species, indicating that some bioactive compounds have antibacterial properties. García-Vázquez et al. (2020) found similar results when adding an infusion of Chenopodium ambrosioides to feed rabbits, while Mancini et al. (2015) added Curcuma longa L to burgers to decrease microbial growth, especially staphylococcus and total counts bacteria on day 7 of storage.

The antioxidant properties of meatballs prepared using meat from rabbits fed with the D. palo-escrito hexane extract indicate that treatments were similar (p > 0.05). As mentioned above, D. palo-escrito has antioxidant properties, but it is possible that effect is loss during storage time or during metabolism of the animal. However, Dal Bosco et al. (2019) fed rabbits with Glycyrrhiza glabra L. or used it directly on meat to prepare burgers which led to an increase in antioxidant compounds such as α-tocopherol. Moreover, Vizzarri et al. (2017) fed rabbits with Lippia citriodora, Raphanus sativus and Solanum lycopersicum extracts and found an increase in α-tocopherol and retinol content favouring nutraceutical and nutritional content as well as a longer shelf-life.

The pH for the meatballs showed values between 6.06 to 6.60 on day 14 of storage. A similar pattern of increased pH values over the storage period was found in chorizo elaborated with rabbit meat (Cobos et al. 2014). Mancini et al. (2017) reported that pH
values increased during the storage of burgers added with ginger. However, other authors did not find any effect on pH values when including an infusion of Chenopodium ambrosioides (García-Vázquez et al. 2020), ginger powder (Mancini et al. 2017) and Curcuma longa L powder (Mancini et al. 2015) to feed rabbits. It is possible that chemical compounds present in powder, flours or infusion obtained from different plants or extracts influence pH values in meat during storage.

Water activity was similar between treatments on day 0, but the values increased over the storage period until day 14. Cobos et al. (2014) added wheat fibre to chorizo made with rabbit meat and reported that $a_w$ decreased during storage time stabilising the product and increasing shelf-life. In addition, Zepeda-Bastida et al. (2018) used texturised soybean in their research which showed that $a_w$ decrease during 14 d of storage.

Conclusions

Including D. palo-escrito hexane extract to feed rabbits during the fattening period decreases feed consumption, weight gain, the feed conversion rate while producing a lower live weight. However, HE group has not been affected on carcass traits, although pH, hardness and chewiness values increased. Nonetheless cohesiveness and water holding capacity decreased. Meat balls prepared with meat obtained from HE rabbits group have a low Staphylococcus and total viable bacterial counts during refrigeration storage period, while pH and $a_w$ were stable and had a positive impact on increasing the meatballs’ shelf-life. Those observations possibly are due to bioactive compounds found in the extract of D. palo escrito. Also, further studies are required to elucidate the effect of this extract on the shelf life of meat products and to determine the main molecules present in the extract.

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Ethical approval

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data to support this study are available from co-author (Sergio Soto-Simental)

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