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Evaluation of three forages as a source of fiber in diets of fattening rabbits in Aguascalientes, Mexico

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ABSTRACT

Objective: To evaluate three forages as a source of fiber in the diets of fattening rabbits.

Design/Methodology/Approach: Whole grain diets with forage oat, mesquite pod, and alfalfa were used. Thirty-six weaned male rabbits were randomly distributed into three treatments (T1, forage oat diet; T2, mesquite pod diet; T3, alfalfa diet). Feed consumption, daily weight gain, total weight gain, and feed conversion were recorded. The animals were slaughtered to evaluate carcass yield. The data were statistically evaluated by analysis of variance and Tukey's test.

Results: T1 recorded greater fattening than both T2 and T3 ($P<0.05$) and the last treatment surpassed T2 in daily weight gain, total weight gain, and feed digestibility. Regarding feed conversion, T1 and T3 had lower results than T2. In carcass yield, T1 was higher than T2 and T3 —which, on its turn, surpassed T2. Finally, no differences were observed in feed consumption between treatments ($P>0.05$). There were also no significant differences in growth.

Study Limitations/Implications: Mexicans have a low consumption of rabbit meat. The mesquite pod could be a viable alternative due to its low cost and availability in semi-arid areas.

Findings/Conclusions: Forage oat recorded the best productive parameters, followed by alfalfa and mesquite pod; however, the latter had a greater economic advantage.

Keywords: Rabbit production, productive parameters, forage oat, mesquite.

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INTRODUCTION

Nowadays, large companies sell rabbit food in the market at very high prices, which limits the profitability of production (Maertens, 1999; Nieves and Calderón, 2001). Likewise, producers are not allowed to change the nutritional composition according to the registered progress and requirements of the rabbits; therefore, producers would benefit from the capacity to formulate and prepare their feeds, using ingredients and forages that are more accessible and inexpensive than alfalfa, which is commonly used in rabbit diets

(Machado *et al.*, 2007; Asar *et al.*, 2010). Forages have different fiber and component contents, which provide them with a particular quality that is reflected in digestive health, mortality rate, feed digestibility, and response in productive parameters (Maertens, 1999; Gidenne, 2015).

In the past, diets were formulated based on the content of crude protein, crude fiber, and some amino acids (NRC, 1977; Nieves *et al.*, 2002; Akande, 2015). Subsequently, European research teams have studied the importance of the quality of the fiber contained in forages, determining the minimum level of acid detergent fiber required to reduce the mortality of weaned rabbits (Gidenne, 2015). On the contrary, alfalfa is the standard forage used as a source of fiber in feed formulation; although it has an acceptable quality, its cultivation requires an enormous volume of water and, in some seasons of the year, it is very expensive. Therefore, using regional, less expensive (Machado *et al.*, 2007; García-Sánchez *et al.* 2023), and more readily available forages which require less water than alfalfa would be advantageous. In this sense, other forages should be analyzed for their inclusion in the diets of rabbits and their productive and digestibility response must be evaluated.

Dairy producers in Aguascalientes have employed several alternative forages that could also be used in rabbit diets due to their good quality. These forages include corn (*Zea mays*) and sorghum (*Sorghum bicolor* L. Moench) silage, as well as winter crops, such as triticale (× *Triticosecale* Wittmack. Ex.), oats (*Avena sativa*), and wheat (*Triticum aestivum* L.) (Llamas and Núñez, 2002). Green forages could be an alternative for rabbit diets, including partially-dehydrated hydroponic corn (Sánchez-Laino *et al.*, 2010).

Feeding costs account for 60 to 70% of the total expenses of a rabbit farm (García-Sánchez *et al.*, 2023). Meanwhile, forages included in more than 30% of the mixed diet provide the minimum fiber required by rabbits. Usually, commercially available feeds use hayed alfalfa as a source of fiber. Alfalfa cultivation has a high-water consumption and its price in the market is consequently high and variable throughout the year, doubling in winter or periods of drought. In contrast, forage oat is a winter crop with low water consumption, high availability, and an adequate and constant price, while the mesquite pod is collected when the fruit ripens and falls and only entails milling costs (Mejía-Haro *et al.*, 2023).

The objective of this research was to evaluate three forages as additional sources of fiber in fattening rabbit diets, considering their availability, cost, and response in terms of productive parameters.

The hypothesis was that using forage oat and/or mesquite pods in a mixed diet for fattening rabbits can yield similar productive parameters to hayed alfalfa.

MATERIALS AND METHODS

The study was carried out from May to December 2022 at the CUNICARNE rabbit farm, located in the community of Las Palomas, municipality of Aguascalientes, in km 12 of highway 42, at 21° 44' 48" N and 102° 21' 04" W, and at 1,885 meters above sea level. It has a semi-dry climate, a mean annual temperature of 17.4 °C, and a mean rainfall of 526 mm (Instituto Nacional de Estadística y Geografía [INEGI], 2017).

Experimental design

Thirty-six one-month old weaned male rabbits, with an average weight of 400 grams, of the California breed, were distributed with a completely randomized design into three treatments: T1, diet with forage oat (*Avena sativa* L.); T2, diet with mesquite pod (*Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M.C. Johnst.); and T3, diet with alfalfa hay (*Medicago sativa* L.). The experimental period lasted 50 days. The first 30 days were considered the growth stage and the following 20 days, the fattening or finishing stage (García-Sánchez *et al*., 2023).

Ingredients and nutritional composition of forage

The forages were milled with a Rayken® RKP 3000 mill (Raiker), with a particle size of 2.54 cm. They were incorporated into the formulation of a diet with 16% crude protein and 2.8 Mcal/kg of metabolizable energy. The diets were isoproteic and isocaloric (Table 1) and were processed in a mixer (Garmak, Michoacán, Mexico) and finally shaped into pellets (Rommel, model Wkl 120c, China). The diets were subjected to a proximal analysis to determine crude fiber (CF), crude protein (CP), fat, and ash by wet chemistry (AOAC, 2012), as well as to analyze their neutral detergent fiber (NDF) and acid detergent fiber (ADF) content (Van Soest *et al*., 1991).

In addition, the Ca and P contents were analyzed by atomic absorption spectrophotometry (Dorta and Ciarfella, 2014). The metabolizable energy was calculated considering the equations of Nolan and Savage (2009).

The rabbits underwent a 10-day pre-experimental adaptation in a stall, divided into individual metal cages with a feeder and a nipple drinker. The animals were weighed with a YL TRD® gram scale, on day 1 of the experimental period and every week until day 50. They were fed *ad libitum*, with food served every day at 9 AM throughout the experimental period. Rejection and consumption per day were also recorded.

Evaluation variables

Feed consumption (g dry matter (DM) and g DM/kg live weight (LW)), daily weight gains (DWG) and total weight gains (TWG) were measured. The feed conversion (FC=WG/dry matter (DM) intake) was calculated with those data. At the end of the fattening period, the rabbits were slaughtered to evaluate the yield and characteristics of the hot carcass. The offal (head, hide, tail, and legs), viscera (liver, heart, kidneys, and lungs), digestive organs (stomach, intestines, and cecum), and perirenal and scapular fat were weighted.

Subsequently, an *in vivo* dry matter digestibility (DMD) test was carried out, using six adult rabbits per treatment. The rabbits were fed 70% of their daily consumption for two weeks to guarantee that they would fully eat the same amount each day. Feces were collected in trays daily and data were recorded for the last 6 days. The feces were dried in a Felisa® 293 D air circulation oven for two days at 60 °C to determine the DM. The indigestible part was then calculated and, the percentage of DMD was calculated by difference (DMD=Dry feces/DM Intake*100).

Table 1. Ingredients and nutritional composition of the rabbit diet (g/100 g on a wet basis).

Ingredients*	T1	T2	T3
Alfalfa hay	0	0	35
Ground *Prosopis laevigata* pods	0	31	0
Oat hay	30.9	0	0
Soy bean meal	9.5	12.2	5.9
Canola meal	4	4	4
Ground corn	32.8	39.5	32
Ground sorghum	14.2	8.7	13.5
Vegetable oil	4.4	0.5	5.6
Fish meal	3	3	3
Monocalcium phosphate	0.7	0.5	0.4
Ca CO_3	0	0	0
Salt	0.3	0.3	0.3
Vitamins**	0.1	0.1	0.1
Trace minerals	0.1	0.1	0.1
TOTAL	100	100	100
Nutritional Composition %			
Dry matter (DM)	88.4	86.6	86.6
Ash	5.2	3.9	6
Crude Protein (CP)	16.0	16.0	16.0
Fat	7.7	4.6	7.1
Crude Fiber (CF)	17.9	17.1	16
Acid Detergent Fiber (ADF)	15.3	13	14.1
Neutral Detergent Fiber (NDF)	23.6	18.2	20.3
Non-Fiber Carbohydrates (NFC)	46.7	47.0	44.7
Metabolizable Energy (Mcal/Kg)	2.824	2.854	2.835
Calcium (Ca)	0.50	0.52	0.67
Phosphorous (P)	0.35	0.32	0.32
Lysine	1.27	1.13	1.19
Methionine + Cisteine	0.91	0.83	0.90

Non-Fiber Carbohydrates *=100−(% NDF+%CP+%Fat+%Ash), Metabolizable Energy=TDN* 4.4* 0.82. *Ingredients expressed in kg as fed basis. **Vitamins Vitafort.

Statistical analysis

The data were evaluated with the Statistical Analysis System (SAS; V. 9.2; 2013) package, using general linear procedures (PROC GLM). The analysis of variance (ANOVA) considered the effect of forage type, according to Model 1. Treatment means were compared using Tukey's test (P=0.05).

$$\text{Model (1)} \quad Y_{ij}=\mu+T_i+\varepsilon_{ij}$$

Where Y_{ij}=Feed consumption, DWG, TWG, DMD, μ=general mean, T_i=effect of the *i*-th type of forage, and ε_{ij}=experimental error.

RESULTS AND DISCUSSION

Productive behavior variables

Feed consumption. No significant differences ($p>0.05$) were recorded between treatments in the growth and fattening phases (Tables 2 and 3). This could be partially due to the pellet shape of the feed in all treatments, avoiding the selection of particles (Loor-Mendoza, 2016). Additional causes can include the similarity in the CP, ME, NDF, and ADF content of the diets and in the initial weight of the rabbits since consumption is related to LW. Another factor that could have influenced the lack of differences in consumption between treatments was the low daily food rejection, which suggests a lower food selectivity between the cylindrical and powdered or divided particles. In addition, consumption/kg LW also showed no differences between fiber sources ($p>0.05$). Contrary to the results of this experiment, García *et al.* (2023) reported lower consumption in diets with 15-30% mesquite pod flour than in the control (alfalfa as a forage source). The nutritional composition of forages has a wide range, mainly regarding the quantity and composition of detergent fibers, which affects digestibility and production parameters (García-López *et al.*, 2019).

Weight gain. The DWG, TGW, and final gain did not show differences between treatments ($p>0.05$) in the growth stage. Meanwhile, the rabbits fed on forage oat (T1) in the fattening or finishing stage had better indicators of productive behavior than rabbits fed on the T2 and T3 forage sources ($p<0.05$) (Table 2). Despite the lack of differences among treatments in feed consumption, other factors were involved with TGW, such as differences in the DMD coefficient. This phenomenon was reflected in differences in the feeding efficiency of the diets and a difference in weight of 3-5 g/d and 63-100 g/d in the period among treatments. The DMD coefficient was higher in the treatments with alfalfa and forage oat (T3 and T1) than those in which rabbits were fed on mesquite pod (T2), potentially influencing the efficiency of feed use and improving total weight gains. Similar results were reported by García *et al.* (2023) in diets with 0, 15, and 30% mesquite pod flour, where rabbits fed on 30% mesquite pod flour gained less weight and recorded lower *in vivo* digestibility than rabbits that received other treatments. In contrast, Igwebuike *et al.* (2013) did not find statistical differences in weight gain and digestibility of dry matter and other nutrients in rabbit diets with 10, 20, 30, and 40% of *Prosopis africana* pulp (Guill. and Perr.) and reported lower values in the three forages evaluated than those reported in this work. The fiber composition of forage oat and alfalfa hay is more advantageous than mesquite pod since the seed of the latter is covered by a very hard cuticle that is difficult to degrade and is not always completely milled, causing differences in its composition and digestibility (Mejía-Haro *et al.*, 2023). The daily weight gains recorded in this research are higher than the 37 g reported by Herrera-Soto *et al.* (2018) for the productive behavior test of different breeds of New Zealand rabbits in fattening.

Feed conversion (FC). The FC of the rabbits in the growth stage did not show differences between the treatments ($p>0.05$) (Table 2). However, in the finishing or fattening stage, the FC of the rabbits fed on forage oat (T1) was lower than the FC of rabbits fed on mesquite pod and alfalfa hay ($p<0.05$) (Table 3). Feed conversion efficiency is highly influenced by fiber digestibility, which is associated with the lignin content of food (Gidenne, 2015). Although forages sometimes contain similar concentrations of acid detergent fiber —which is composed of cellulose and lignin— their use has behaved in different ways since they vary both in the lignin content and in the form in which it is embedded in the cellulose molecule (Moore and Jung, 2001).

Mora-Valverde (2010) mentions that more lignified fibers reduce the size of intestinal villi and can atrophy epithelial tissues, altering the normal functioning of intestinal epithelial cells. According to the results, the quality of forage oat cut at its optimal point as feed for fattening rabbits can surpass the quality of mesquite pod and even alfalfa —largely due to its fiber content and composition. Although forage oat and alfalfa have a similar ADF value, the lignin content of alfalfa is almost three times higher than in oats (Gidenne, 2015),

Table 2. Productive parameters of growing rabbits fed on diets with different fiber sources.

Variable	T1	T2	T3	SE	P Value
Initial weight (g)	403[a]	400[a]	391 [a]	31.4	0.09
Feed intake (g)	2078[a]	2054[a]	2085[a]	66.8	0.09
Final weight (g)	1482[a]	1463 [a]	1474[a]	32.51	0.10
TG (g)	1079[a]	1062 [a]	1083[a]	41.5	0.08
ADG (g)	36[a]	35.3 [a]	36[a]	1.28	0.09
FC (kg/Kg)	1.93[a]	1.94[a]	1.94[a]	0.096	0.10

T1, Oat hay; T2, *Prosopis laevigata* pods; T3, Alfalfa hay; ADG=Average daily gain; FC=Feed Conversion (Kg of feed per Kg of live weight gain); TG=Total gain in the period; SE, Standard error; P value, probability value; *Feed intake per rabbit during the period; **Same letters among rows indicates no significant differences among treatments ($P<0.05$).

Table 3. Productive parameters of fattening rabbits fed on diets with different fiber sources.

Variable	T1	T2	T3	SE
Feed intake (g)*	2265[a]	2276[a]	2267[a]	133.6
Feed intake, g DM/kg LW d^{-1}	57.5 [a]	60.3 [a]	57.1 [a]	3.259
Initial weight, (g)	1482[a]	1463[b]	1474[a]	32.5
Final weight (g)	2433[a]	2315[c]	2389[b]	82.3
TG (g)	952[a]	852[c]	915[b]	94.0
ADG (g)	47.6[a]	42.7[c]	45.7[b]	4.7
FC (Kg/Kg)	2.37[c]	2.67[a]	2.49[b]	0.26
In vivo Digestibility (% DM)	70.7[a]	67.7[b]	69.8[a]	0.785

T1, Oat hay; T2, *Prosopis laevigata* pods; T3, Alfalfa hay; ADG=Average daily gain; FC=Feed Conversion (Kg of feed por Kg of live weight gain); TG=Total gain in the period. *Feed intake per rabbit during the period. Feed intake, g/kg LW d^{-1}=Feed intake per kg LW per day; SE, Standard error; P Value, probability value. **Different letters in the same row indicate significant differences among treatments ($p<0.05$).

which partially affects its quality. Meanwhile, the mesquite pod has a higher ADF content than the two other forages and a high level of lignin, which limits its quality (Angeles-Hernandez *et al.*, 2022; Mejía-Haro *et al.*, 2023). For its part, the digestibility of dry matter in oats and alfalfa was higher than in mesquite pods, reflecting a better feed conversion. However, the feed conversion difference between the three forages is only 10 to 12%.

García *et al.* (2023) reported 2.4 and 2.5 feed conversions in diets with 15 and 30% mesquite pod, respectively; these results are similar to the findings of this study. Meanwhile, Adamu *et al.* (2013) reported feed conversions of 6.45, 6.83, 6.30, and 6.31 in rabbits, replacing corn with 10, 20, 30, and 40% *Prosopis africana*, respectively. The genus *Prosopis* contains anti-nutritional compounds that can negatively impact the digestibility of the diet and productive parameters of rabbits, depending on the concentration and the species. This characteristic must be taken into account during the formulation of diets (Akande and Alabi, 2021).

Carcass yield and characteristics

Table 4 shows that, regarding carcass weight and yield, the forage oat (T1) diet had better results than T2 and T3 ($p<0.05$). These carcass yields are closely related to the weight at slaughter and the weight of the viscera. T1 rabbits had a higher weight at slaughter than T2 and T3 rabbits, while the weight of the viscera was lower in T1 than in T2, perhaps due to the type of fiber. The lower digestibility of mesquite pod could cause greater growth of the viscera, mainly in the fattening period, because the development of the rabbit's digestive system increases according to age, weight, and type of diet at the moment of weaning (Carabaño *et al.*, 2020). García *et al.* (2023) also reported lower carcass yields in rabbits fed on diets with 15 and 30% mesquite pod than rabbits fed on diets that included 30% alfalfa. For their part, Igwebuike *et al.* (2013) reported no differences in the carcass yield of rabbits fed on diets with 0, 10, 20, 30, and 40% of *Prosopis africana* and lower values than in this study. Overall, if the digestive organs (mainly, stomach and intestines) are heavier, the carcass yield will be lower (Hernández et al., 2015). In addition, the carcass yield will be influenced by the weight of the rabbits at the time of slaughter, as well as their diet, sex, and the climatic conditions in which they develop (Pilco et al., 2018).

Table 4. Yield and characteristics of rabbit carcasses.

Variable	T1	T2	T3	SE	P Value
Weight of offal (g HB)	411[a]	319[c]	386[b]	2.957	<0.0001
Viceras weight (g HB)	530[b]	619[a]	520[c]	4.75	<0.0001
Weight of peri-renal and scapular fat (g HB)	107[c]	118[b]	146[a]	1.92	<0.0001
Slaugther Live weight (g HB)	2387[a]	2261[c]	2342[b]	17.1	<0.0001
Carcass weight (g HB)	1337[a]	1203[c]	1290[b]	9.796	<0.0001
Carcass (%)	56[a]	53[c]	55[b]	0.08	<0.0001

T1, Oat hay; T2, *Prosopis laevigata* pods; T3, Alfalfa hay; Offal=skin, head, feet; Viceras=Kidnies, liver, lungs, heart, intestines, cecum and urunary bladder. SE, Standard error; P value, probability value. *Different letters in the same row indicate significant differences among treatments ($p<0.05$). HB=Humid basis.

Economic analysis of the diets

Feed costs (Table 5) show that kg of feed formulated with mesquite pod meal is the less expensive (T2), followed by forage oat (T1) and alfalfa hay. Overall, alfalfa maintains a high price throughout the year, and in certain months, it is even more expensive since it is a forage preferably used for other species, such as horses and dairy cows (Estrada-Prieto, 2018). On the contrary, rural communities collect mesquite pods from the ground and subsequently dry and grind them (Mejía-Haro *et al.*, 2023), resulting in lower expenses. They can also be obtained from other farmers at affordable prices. As for forage oat, it is available at affordable prices throughout the year, without major fluctuations. Taking into account the production cost of one kg of rabbit (*i.e.*, feed) and considering alfalfa as the standard forage, using mesquite pod and forage oat as a source of forage instead of alfalfa reduces costs to 80% and 89%, respectively. Additionally, this replacement contributes to lower or even zero water consumption.

Table 5. Costs of diets that included different forage sources.

Variable	T1	T2	T3
Cost per kg of feed ($)	8.9	7.85	9.8
Feed intake in the growing period (g DM)	2078	2054	2085
Feed intake in the fattening period (g DM)	2265	2276	2267
Total feed intake (g DM)	4343	4330	4352
Weight gain in the growing period (kg)	1.079	1.062	1.083
Weight gain in the fattening period (kg)	0.951	0.852	0.915
Total weight gain (kg)	2.03	1.914	1.998
Cost of feeding ($)	38.65	33.99	42.65
Cost of feeding/kg of live weight gain ($)	19.04	17.76	21.35
Cost of feeding/kg of live weight gain (%)	89	80	100

T1, Oat hay; T2, *Prosopis laevigata* pods; T3, Alfalfa hay. $, mexican pesos (MXN).

Implications

According to the results of this study, forage alternatives to alfalfa achieve similar productive parameters and improve the economic yield of the meat of fattening rabbits in Aguascalientes. Rabbit producers should include locally-sourced forage in their diets and reduce their costs and the use of water; they would also no longer need to purchase high-cost balanced feed to sustain their rabbit meat production business.

CONCLUSIONS

The three forages evaluated have good productive parameters; however, the diet with forage oat recorded the best parameters in weight gain, feed digestibility, and feed conversion, followed by alfalfa and, in third place, the mesquite pod. Although there were no differences in consumption between treatments, rabbits whose diet included forage oat had the best feed conversion. In conclusion, using mesquite pods as a source of fiber in the diet is more profitable than forage oat and alfalfa.

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