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FIBER SOURCES IN RABBIT DIETS: PRODUCTIVE PERFORMANCE, CARCASS TRAITS, AND MEAT QUALITY

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ABSTRACT

***Pleurotus ostreatus* is the most widely consumed edible mushroom worldwide, and its cultivation generates large amounts of spent mushroom substrate. When improperly disposed or accumulated, it can contribute to air, water, and soil pollution. Therefore, developing alternative uses for this waste is essential, including its incorporation into animal diets as a potential source of dietary fiber. The objective of this study was to determine the influence of different fiber sources in rabbit diets on productive performance, carcass traits, and meat quality. A one-way experimental design was used to evaluate 45 rabbits (35 days old) of New Zealand x California x Mariposa crossbred genotype. The rabbits were randomly allocated to four dietary treatments: spent *P. ostreatus* substrate (SGP), barley straw (PCE), alfalfa hay (TA), and a mixture of wheat bran and soybean hulls (STCS) for a period of 28 days, in which productive parameters were evaluated. Subsequently, the animals were slaughtered to determine carcass traits and meat quality. The results revealed that the inclusion of SGP increased hot carcass weight and the amount of meat in the legs (P <0.05), but did not affect productive parameters or meat quality (P> 0.05). However, the SCTS group recorded lower final weight and body weight gain. The results allow concluding that spent *P. ostreatus* substrate can feasibly be used as a fiber source in rabbit diets, as its inclusion did not adversely affect productive parameters, carcass traits, or meat quality.**

Keywords: Carcass quality, fiber feed, *P. ostreatus* substrate spent, rabbit meat.

INTRODUCTION

Rabbit meat is considered a healthy and nutrient-rich food, making it an attractive option for health-conscious consumers (Siddiqui et al., 2024). It contains essential amino acids and is a source of unsaturated fatty acids (Szendrö et al., 2020).

The rabbit digestive apparatus has the ability to convert cellulose into other molecules that constitute animal corporal mass (Lytle et al., 2020). Xiccato and Trocino (2020) indicate that rabbits are very efficient at converting protein intake into muscle protein. The main fiber sources used to feed rabbits are alfalfa, lignified fibrous, and cereal co-products (De Blas and Mateos, 2020). In addition, other fiber sources, including leaves and different parts of the trees, have been used to

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evaluate meat quality (Mènon et al., 2023).

Information on the use of barley straw as a feed ingredient for rabbits is scarce and outdated. A study conducted in 1995 reported that the inclusion of 10% barley straw resulted in satisfactory productive performance (Rayana et al., 1995). Similarly, Garcia et al. (1996) evaluated NaOH-treated barley straw as feed ingredient for rabbits and reported an increase in digestible energy, which was attributed to disruption in lignin-carbohydrate linkages by NaOH.

Wheat bran has been a popular ingredient to feed rabbits since the early 20th century, usually used in high quantities and ground to prepare pellets to feed growing rabbits due to the high ileal digestibility of starch (Blas and Gidenne, 2020).

P. ostreatus is one of the most widely consumed edible mushrooms around the world. *P. ostreatus* cultivation generates large amounts of spent mushroom substrate, which is rich in fiber and could be used as a feed ingredient for rabbits (Royse and Sanchez, 2017). The continuous production of *P. ostreatus* therefore results in a constant generation of this by-product (Hanafi et al., 2018). However, unsuitable disposal can contribute to soil, water, and air pollution and may attract sickness vectors such as insects or rats.

Basidiomycetes fungi produce enzymes such as cellulases, xylanases, and laccases in the medium used for growth (Gomes et al., 2016a), then this spent substrate is more digestible and contributes to providing nutrients for the animals, mainly ruminants (Gomes et al., 2016b). However, rabbits are well adapted to utilizing fibrous feed material (Gidenne, 2015).

Alfalfa is widely used as forage source in rabbit diets due to its fiber, protein, and lipid content. According to Dal Bosco et al. (2025), alfalfa-based diets contribute to maintaining a healthy digestive system, increasing bacteria that digest fiber; however, high levels of alfalfa inclusion may negatively affect growth performance (Bosa et al., 2025).

Given the limited information available on the use and comparative effects of different fiber sources in growing rabbits, the objective of this study was to determine the influence of different fiber sources on productive parameters, carcass traits, and meat quality.

MATERIAL AND METHODS

This study was carried out in a rabbitry located at 20°03’45’’ northern latitude and western longitude in Tulancingo, Hidalgo, Mexico. The zone has 20 °C average temperature and 65% relative humidity.

The spent *P. ostreatus* substrate from 60 days of culture was provided by Setas Monarca S.A. de C.V., located in Tulancingo, Hidalgo, Mexico. The spent substrate was dried at room temperature for five days. All other ingredients were purchased from a company specialized in the production and marketing of balanced animal feed.

Forty-five New Zealand x California crossbred rabbits (35 days old; initial body weight, 825.34 + 117.39 g) were randomly allocated to five dietary treatments: control (C), spent *P. ostreatus* substrate (SGP), barley straw (PCE), alfalfa hay (TA), and a mixture of wheat bran and soybean hulls (STCS). The experimental population comprised 20 females and 25 males, with four or five rabbits housed per treatment group. Animals were housed in wire cages (90 x 60 x 40 cm) equipped with manual feeders and automatic drinkers, with water and feed provided *ad libitum*.

The experimental diets are shown in Table 1 and were formulated to be isonitrogenous (16% crude protein), isocaloric (2.5 Mcal kg^{-1} digestible energy), and similar in fiber content (25.5 acid detergent fiber and 15% neutral detergent fiber), according to the NRC recommendations (NRC, 1977) and following the guidelines of De Blas and Mateos (2010). The diets were mixed using an ASF MZ50 mixer (Molinos y Mezcladoras Industriales S. A. de C. V., Ciudad de México, México) and then pelleted using a SKJ-120 pelletizer machine (Yuezhen Machinery Co., Shandong, China).

During the fattening period (28 days), daily feed intake was measured by weighing the offered and rejected feed. The body weight of rabbits was measured every week using a Mettria model MTNUV-40 scale (Mettria, Ciudad de México, Mexico). Data obtained were used to calculate final body weight, weight gain during the fattening period, daily weight gain, weekly feed intake, and feed conversion ratio.

At the end of the growing period, rabbits were transported to the meat laboratory, where body length (from atlas to last coccygeal vertebra) and lumbar circumference were measured using a measuring tape. Subsequently, rabbits were slaughtered without fasting according to the national legislation (NOM-033-SAG/ZOO-2014). After slaughter, carcass length and lumbar circumference were measured. Following eviscerated, the hot carcass, liver, kidneys, spleen, heart, lungs, full and empty intestinal tract, full and empty bladder, skin, and feet were weighed. Carcasses were stored under refrigeration at 4 °C for 24 h. After refrigeration, the cold carcass was weighed and divided into

Table 1. Composition of diets fed to fattening rabbits with different fiber sources.

	Treatments[1]				
	C	SGP	PCE	TA	STCS
Ingredients			g kg^{-1}		
Barley straw	0	0	192	0	0
Spent *P. ostreatus substrate*	0	192	0	0	0
Alfalfa hay	146	0	0	195	0
Wheat bran	100	0	0	0	200
Corn ground	173	343	343	296	254
Canola meal	68	122	122	68	68
Soybean meal	151	152	152	111	141
Sorghum ground	131	111	111	141	121
Molasses	35	12	12	12	12
Soybean hulls	178	50	50	158	187
Vitamins and minerals premix*	18	18	18	18	18
Calculated composition					
Crude protein %			16.00		
Crude fiber %			12.00		
Digestible energy Mcal kg^{-1} MS			2.5		
Neutral Detergent Fiber (NDF) %			25.5		
Acid Detergent Fiber (ADF) %			15.0		
Ca %			0.80		
P %			0.50		
Lys %			0.80		
Met %			0.30		

[1]Control (C) and treatments with fibers, Spent *P. ostreatus* substrate (SGP), Barley straw (PCE), Alfalfa hay (TA) and a mixture of wheat bran and soybean hulls (STCS). *Wisium Premix®: Ca-26%, P- 2.57%, Mg-0.62%, Cu-2000 ppm, Fe-3200 ppm, Zn-2999 ppm, Vit E-500 ppm, Choline -10000 ppm, Vit A-0.13 ppm, Vit D3- 0.01 ppm, Vit B-39.58 ppm, Vit B2-116.80 ppm, Vit B5- 363 ppm, Vit B6- 45.58 ppm.

primary cuts with some modifications to the standard cutting procedure (Blasco et al., 1993). Briefly, the head was separated at the level of the atlas. The fore part was sectioned between the 6th and 7th thoracic vertebrae, while the intermediate part was separated at the level of the last rib. The hind part was sectioned between the 6th and 7th lumbar vertebrae, resulting in the hind legs, which were then dissected into meat, fat, and bone.

Meat quality was evaluated in the loins (*Longissimus lumborum*). Muscle pH was measured using a Hanna model HI99163 pH meter (Hanna instruments, Cluj-Napoca, Romania). Instrumental color of the loin surface was measured according to the CIEL*a*b* system using an iLab S560 colorimeter (Microptix, Wilton, Maine, USA). Measurements were performed using a D65 illuminant and a 2° standard observer, according to the procedure described by King et al. (2023). The samples were placed in cooking bags and cooked until an internal temperature of 68 °C was reached. Samples were then allowed to cool to room temperature, and cooking loss was calculated from the differences between sample weights before and after cooking.

For texture profile analysis (TPA), the loins were cut into 1-cm-thick pieces and analyzed according to Bourne (1978). A Brookfield model CT3 texture analyzer (Brookfield, Middleboro, MA, EUA) equipped with a 4.5-kg cell load and a 2.5 cm-diameter Perspex probe was used. Samples were subjected to two compression cycles to 50% at a speed of 1 mm s^{-1}. The following texture parameters were calculated from the resulting curves: hardness, cohesiveness, springiness, and chewiness, using the Pro CT software (Brookfield, Middleboro, MA, USA).

Data were verified for normality using normal probability plots, and homogeneity of variance was assessed by plotting residuals against fitted values. The data were analyzed using a completely randomized design and analysis of variance (ANOVA) was performed using the GLM procedure. The statistical model utilized was described as follows:

$$Yij = \mu + \beta i + \varepsilon ij$$

where Yij = measured variable, μ = mean of the variable, βi = fixed effect, and εij = experimental error associated with the observation of Yij.

When a significant difference was detected, means were compared using Tukey's test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Productive performance

Productive performance of the rabbits fed with different fiber sources is shown in Table 2. The final weight was similar among the groups (P>0.05). However, total feed intake, weight gain, and daily weight gain were higher in the control and dietary treatments consisting of spent *P. ostreatus* substrate, alfalfa, and barley straw (P<0.05). During the first two weeks, a higher feed intake was observed in the groups fed with *P. ostreatus* substrate (P<0.05). Feed conversion ratio was higher in the group fed with spent *P. ostreatus* substrate. Nevertheless, final weight was different among the treatments (P<0.05). The STCS group had the lowest final weight. Nonetheless, the weight gained was similar among the rest of groups. The content of NDF is related to weight gain. In this regard, Romero et al. (2009) reported greater weight gain in rabbits fed with wheat bran or wheat straw, indicating that this effect is due to the high NDF content in the diet. In addition, the NDF has been associated with rabbit postweaning mortality (Sobri et al., 2019). The age or fattening period has an influence on productive performance. Xiccato et al. (2011) fed rabbits using alfalfa and wheat straw until 53 days of age. De Blas and Gidenne (2020) indicated that increasing the proportion of wheat bran in the rabbit diet decreases digestibility. Fernandes et al. (2022) reported that the highest body weight gain occurs at approximately 53 days of age, after which growth rate decreases, potentially affecting FCR. Additionally, the highest FCR in the PCE group may be attributed to the low digestibility of dry matter and the characteristics of the fiber components of barley (Gidenne et al., 2005).

Morphometric characteristics

The relationship between linear body measures and carcass traits is of interest to rabbit producers, as some allometric measurements are related to rabbit growth. However, some body measurements in rabbit growth are asymmetric (Obasi and Akinsola, 2023). The results for the morphometric measures are shown in Table 3. All groups were similar for all in vivo measurements (P>0.05), except for animal length, where the SPG group had the largest animal length (P<0.05). Setiaji et al. (2023) analyzed the relationships between body types and morphometric measurements, concluding that chest measures predict body weight more appropriately than body length, but the latter has a high correlation with body weight.

Carcass traits

Carcass traits are presented in Table 4. No significant differences were found among groups for most of the variables evaluated (P<0.05). However, hot carcass weight and

Table 2. Productive performance of rabbits fed different fiber sources during fattening.

	Treatments[1]						
	C	SGP	PCE	TA	STCS		SEM
Total feed intake, g	2492.0bc	2832.6a	2737.3ab	2668.3ab	2229.9c	66.0	0.000
Feed intake S1, g	60.3ab	76.6a	76.9a	69.7ab	53.9b	4.3	0.013
Feed intake S2, g	80.8ab	105.3a	94.5ab	89.3ab	74.1b	5.3	0.016
Feed intake S3, g	96.8	102.3	97.9	101.9	77.4	9.9	0.422
Feed intake S4, g	113.6	116.5	119.0	120.2	100.2	6.6	0.278
Final weight, g	1891.4a	1896.3a	1816.9a	1828.3a	1692.9b	65.8	0.240
Gain weight, g	1135.7a	1020.0ab	974.4ab	1010.0ab	840.0b	46.3	0.003
DWG, g	40.56a	36.43ab	34.8ab	36.1ab	30.0b	4.1	0.003
FCR	2.21b	2.80ab	2.83a	2.71ab	2.72ab	0.14	0.033

[1]Control (C) and fibers treatments, Spent *P. ostreatus* substrate (SGP), Barley straw (PCE), Alfalfa (TA), and a mixture of wheat bran and soybean hulls (STCS). FCR=Feed conversion ratio, S=week, DWG=Daily weight gain. [abc] Different superscript letters within columns indicate statistical differences (P<0.05).

Table 3. Morphometric measurements of fattening rabbits fed different fiber sources.

	Treatments[1]						
	C	SGP	PCE	TA	STCS		
Variable	cm					SEM	P-value
Animal length	28.6ab	31.5b	29.4ab	27.9a	29.0ab	0.8	0.019
Lumbar circumference	27.4	27.8	27.8	26.7	26.9	0.8	0.760
Carcass length	32.1	30.9	31.4	31.8	30.1	0.8	0.493
Carcass lumbar circumference	24.3	25.4	25.5	24.1	23.7	0.8	0.405

[1]Control (C) and fibers treatments, Spent *P. ostreatus* substrate (SGP), Barley straw (PCE), Alfalfa (TA) and a mixture of wheat bran and soybean hulls (STCS). [abc] Different superscript letters within columns indicate statistical differences (P<0.05).

Table 4. Carcass traits of fattening rabbits fed different fiber sources.

Part of the carcass	Treatments[1]						
	C	SGP	PCE	TA	STCS	SEM	P-value
Live weight, g	1891.4	1896.2	1816.9	1828.3	1692.9	65.8	0.240
Hot carcass, g	1022.6ab	1103.3a	1008.3ab	1008.2ab	911.7b	46.9	0.113
Skin, g	281.4	287.4	280.9	275.4	252.0	14.7	0.525
Feet, g	34.0	35.0	33.6	32.6	26.4	2.1	0.069
Cold carcass, g	978.9	1051.3	974.3	992.7	871.7	46.8	0.146
Head, g	94.9	99.5	97.0	94.0	92.3	3.2	0.566
Fore part, g	248.3	259.3	242.5	251.6	217.4	11.2	0.127
Intermediate part, g	88.0	101.0	88.0	92.7	80.0	6.2	0.225
Hind part, g	208.29	225.75	207.75	219.33	180.9	12.5	0.150
Legs, g	325.43	352.50	327.25	324.89	288.3	15.9	0.120
Meat, g	240.0ab	256.5a	237.5ab	242.0ab	204.9b	12.3	0.086
Bone, g	72.0	84.8	76.9	69.3	74.6	4.8	0.197
Fat, g	3.1	3.7	4.1	5.2	3.4	0.8	0.406

[1]Control (C) and fiber treatments, Spent *P. ostreatus* substrate (SGP), Barley straw (PCE), Alfalfa (TA), and a mixture of wheat bran and soybean hulls (STCS). [abc] Different superscript letters within columns indicate statistical differences (P<0.05).

dissected meat weight from the legs were higher in the SGP group (P<0.05). Previous studies evaluating different fiber sources have reported no significant effects on carcass traits when dietary inclusion levels were varied, including sugar beet pulp (Margüenda et al., 2012), olive pomaces (Dal Bosco et al., 2012), oat hulls (Liangzhan et al., 2017), oat hay, and a combination with carrot (Quaresma et al., 2023).

The quantity and type of dietary fiber appear to be important in maintaining carcass traits in rabbits. However, there is little information on studies directly comparing different fiber sources within the same study. In the present study, the use of spent mushroom substrate resulted in carcass traits similar to the control, barley straw, and alfalfa treatments. Therefore, the use of spent *P. ostreatus* substrate as a feed ingredient for rabbits can ameliorate the pollution associated with this agroindustrial waste while providing an alternative fiber source.

Spent *P. ostreatus* substrate contains lignocellulolytic enzymes (Luo and Chen, 2024), which may be involved in digesting the feed more efficiently. Mohammed (2023) supplemented rabbits with a multi-enzyme and reported an increased dress weight when using the highest concentration of the multi-enzyme. In another study, the replacement of wheat offal with urea-molasses-treated maize cobs affected the size of organs, including liver and kidneys, in growing rabbits (Mafimidiwo et al., 2022).

No significant differences were observed among treatment groups for viscera and organ weights (Table 5), except for heart weight. Rabbits fed spent *P. ostreatus* substrate showed

Table 5. Viscera and organ weights in fattening rabbits fed different fiber sources.

	Treatments[1]						
Organ or system	**C**	**SGP**	**PCE**	**TA**	**STCS**	**SEM**	**P- value**
Lungs, g	12.0	12.6	11.9	12.3	9.4	1.0	0.200
Heart, g	7.7^{ab}	8.6^{a}	6.3^{ab}	6.4^{ab}	5.1^{b}	0.6	0.003
Gastrointestinal tract full, g	332.4	327.8	343.1	319.0	319.9	15.5	0.789
Gastrointestinal tract empty, g	167.9	164.4	174.4	172.1	152.9	5.3	0.068
Spleen, g	1.1	1.8	1.1	1.3	1.1	0.2	0.275
Liver, g	62.0	74.8	68.5	77.3	60.9	4.4	0.042
Full bladder, g	12.9	10.5	11.9	14.8	17.6	2.0	0.130
Empty bladder, g	3.4	4.9	5.4	5.0	4.0	0.8	0.489
Kidney, g	12.2	12.3	11.3	12.4	12.3	0.6	0.581

[1]Control (C) and fiber treatments, Spent *P. ostreatus* substrate (SGP), Barley straw (PCE), Alfalfa (TA), and a mixture of wheat bran and soybean hulls (STCS). [abc] Different superscript letters within columns indicate statistical differences (P<0.05).

a higher heart weight compared to the other treatment groups (P<0.05). Similar effects on organ weights have been reported in rabbits supplemented with enzymes. Mohammed (2023) found no differences in heart weight but reported higher kidney, liver, and lung weights in rabbits supplemented with Kemzyme, a preparation containing four hydrolases and one protease. These differences may be related to enzyme type since Mohamed et al. (2025) observed that digestive enzymes included in the feed additive may act synergistically with probiotics to improve nitrogen absorption, while higher probiotic inclusion levels increased the weights of the heart, spleen, liver, lungs, and kidneys.

Meat quality

Table 6 shows the meat quality characteristics influenced of rabbits fed diets containing different fiber sources. Meat color differed among treatments (P<0.05). The a*, C, and h values were higher in C, SGP, and PCE groups, while L* values were higher in the TA and STCS groups. There is little information on the effects of fiber sources on rabbit meat color. Xiccato et al. (2011) indicated that lighter meat color is associated with greater energy utilization during transport and fasting due to the fermentation of soluble fiber in the intestine. Different fiber-rich ingredients provide varying amounts of soluble fiber, such as alfalfa or barley straw.

Meat pH was lower in the control, SGP, and STCS treatments (P<0.05). The water holding capacity and cooking loss did not differ (P>0.5) among treatments (P<0.05). Limited information is available on the effects of different dietary fiber sources on meat quality, including pH, water-holding capacity, and cooking loss. However, dietary fiber may influence meat pH, which could be associated with intestinal fiber fermentation (Xiccato et al., 2011).

CONCLUSIONS

Most of the variables evaluated in this study did not differ among treatments, containing different fiber sources. However, rabbits fed spent *P. ostreatus* substrate had greater body length, higher hot carcass weight, and greater meat yield obtained from the legs. These results suggest that spent *P. ostreatus* substrate can be used as an alternative fiber source in diets for growing rabbits. Further research is needed to expand the available information on the use of different fiber sources in rabbit diets, particularly regarding the effects of NDF and ADF levels and the digestibility of these components.

Author contributions

Authors contributed equally to the development of this study. Conceptualization, methodology, provision of resources, data curation, statistical analysis, investigation, supervision, writing of the original draft, and review and editing of the manuscript. All co-authors reviewed and approved the final version of the manuscript before submission.

IA generative declaration

Authors declare that generative AI was not used.

Table 6. Meat quality of rabbit feed different fiber sources.

	Treatments[1]						
	C	SGP	PCE	TA	STCS	SEM	P-value
L*	52.5b	52.7b	54.5a	55.9a	51.9b	0.4	0.000
a*	12.4a	14.2a	11.3ab	6.6c	6.4c	1.2	0.000
b*	-24.3b	-26.2b	-22.7b	-14.6a	-13.2a	2.0	0.000
C	27.3a	29.9a	25.3a	16.0b	15.6b	2.3	0.000
h	0.5ab	0.6a	0.5ab	0.4ab	0.3b	0.1	0.015
pH	5.7b	5.7b	5.8a	5.8a	5.7b	0.01	0.000
CRA, %	22.8	22.2	24.9	26.1	24.0	1.0	0.051
PPC, %	30.25	30.66	28.1	29.2	26.4	1.7	0.411

[1]Control (C) and fiber treatments, Spent *P. ostreatus* substrate (SGP), Barley straw (PCE), Alfalfa (TA), and a mixture of wheat bran and soybean hulls (STCS). [abc] Different superscript letters within columns indicate statistical differences (P<0.05).

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