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Performance and meat quality of growing New Zealand White rabbits fed fodder radish (*Rhapanus sativus* L.)

Performance e qualidade da carne de coelhos da raça Nova Zelândia Branco em crescimento alimentados com silagem de nabo forrageiro (*Rhapanus sativus* L.)

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Highlights

Rabbits fed fodder radish silage maintained adequate feed intake.
The fodder radish silage diet reduced rabbit growth performance.
The fodder radish silage diet resulted in lower carcass weights.
Fodder radish silage did not compromise rabbit meat quality.

Abstract

This study evaluated the effects of fodder radish silage on the performance and carcass and meat characteristics of growing rabbits. Forty-four New Zealand White rabbits were equally assigned to one of two dietary treatments: a Control Diet (CD), consisting of commercial pelleted rabbit feed, and a Silage Diet (SD), consisting of a 1:1 mixture (as-fed basis) of fodder radish silage and commercial pelleted rabbit feed. Rabbits were housed in pairs from 35 to 75 days of age and fed *ad libitum*, with daily feed adjustments to maintain approximately 10% refusals. Body weight was recorded at the beginning of the experiment and weekly until slaughter at 75 days of age. Performance variables (dry matter intake, average daily gain, and feed conversion ratio) and carcass and meat characteristics (carcass and cut yields, pH, color, water-holding capacity, cooking loss, and shear force) were evaluated. Rabbits fed the

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CD showed greater average daily gain and better feed conversion ratio (P < 0.05) than those fed the SD. The CD also resulted in higher (P < 0.05) hot and cold carcass weights and lower (P < 0.05) shear force. Overall, the nutritional composition of the silage diet negatively affected growth performance and quantitative carcass traits but did not impair the meat quality of growing New Zealand White rabbits.
Key words: Carcass traits. Body development. Ensiling. Animal nutrition.

Resumo

Este estudo teve como objetivo avaliar os efeitos da silagem de nabo forrageiro para coelhos em crescimento sobre o desempenho e características da carcaça e carne. Foram utilizados 44 coelhos da raça Nova Zelândia Branco, distribuídos uniformemente entre dois tratamentos: Dieta Controle (DC), composta por ração comercial peletizada para coelhos; Dieta Ensilada (DE), composta por silagem de uma mistura de nabo forrageiro e a ração comercial, na proporção de 1:1, com base em matéria natural. Os coelhos foram alojados em dupla em gaiolas dos 35 até os 75 dias de idade. As dietas foram fornecidas *ad libitum*, com ajuste diário para garantir 10% de sobras. Os coelhos foram pesados no início e semanalmente até o abate que ocorreu aos 75 dias de idade. Foram avaliados o desempenho (consumo de matéria seca, ganho de peso diário e conversão alimentar) e as características da carcaça e da carne (rendimento de carcaça e de cortes, pH, cor; capacidade de retenção de água, perda de peso por cocção e força de cisalhamento). DC apresentou maior ganho de peso diário e melhor conversão alimentar (P < 0,05) do que DE. Houve também maiores (P < 0,05) pesos de carcaça quente e fria e menor (P < 0,05) força de cisalhamento para DC. Dessa forma, a composição nutricional da dieta ensilada influenciou negativamente o desempenho e as características quantitativas da carcaça, mas não comprometeu a qualidade da carne de coelhos Nova Zelândia.
Palavras-chave: Carcaça. Desenvolvimento corporal. Ensilagem. Nutrição animal.

Introduction

Fodder radish (*Raphanus sativus* L.), a member of the Brassicaceae family, is widely used in agriculture as a cover crop during the off-season. Its primary functions include weed control, reducing soil erosion, and contributing to green manuring (Omokanye et al., 2021; Mbambalala et al., 2023).

This species contains considerable amounts of protein (13–26% of dry matter) and minerals, particularly calcium and phosphorus, making it a promising alternative feed resource for animals. It is most commonly used in ruminant nutrition as either fresh forage (Omokanye et al., 2021; Keim et al., 2020) or silage (Zhou et al., 2021). However, no studies have reported the use of fodder radish in rabbit diets, either as fresh forage or silage.

Ensiling forage crops extends the availability of forage resources, particularly during periods of feed scarcity (Araújo et al., 2025). Nevertheless, studies evaluating the use of silage in rabbit diets remain limited. Existing research has investigated silages produced from corn, oats, and sunflower (Garcia et al., 2021); ramie (*Boehmeria nivea*), carpet grass (*Axonopus scoparius*), Mexican sunflower (*Tithonia diversifolia*), and mulberry leaves (*Morus* spp.) (Villa-Ramírez & Hurtado-Villegas, 2016); cassava (*Manihot esculenta*) (Shaahu et al., 2020); and alfalfa (*Medicago sativa*) (Pin et al., 2023).

Producing silage intended for rabbit feeding requires specific management practices (Magalhães et al., 2024). In the case of fodder radish, its high moisture content and low concentration of soluble carbohydrates require the addition of complementary ingredients to ensure adequate fermentation and silage quality (Pahlow et al., 2003). A practical alternative is to include commercial rabbit feed, following the concept of an ensiled total mixed ration, which consists of co-ensiling forage, concentrate, and mineral ingredients.

Studies evaluating ensiled total mixed rations for rabbits are scarce. Therefore, this study evaluated the performance and carcass, and meat characteristics of growing rabbits fed fodder radish silage.

Material and Methods

The experiment was approved by the Ethics Committee on Animal Use of the Federal University of Paraná (UFPR) under protocol no. 055/2024 and was conducted at the Rabbit Research and Teaching Laboratory, Canguiri Experimental Farm (UFPR).

The experiment followed a randomized block design with two treatments and 22 replicates (one cage containing two animals constituted one experimental unit), totaling 44 New Zealand White rabbits. The treatments consisted of two experimental diets (Table 1): a Control Diet (CD), composed of a commercial pelleted rabbit feed (Supra®), and a Silage Diet (SD), consisting of silage prepared from a mixture of fresh whole fodder radish (*Raphanus sativus* L.) plants and the same commercial pelleted rabbit feed used in the CD (Supra®), ensiled at a 1:1 ratio on an as-fed basis.

Table 1
Bromatological composition of the Control Diet (CD) and Silage Diet (SD) on a dry matter basis

Diet	DM, g kg^{-1}	EE, g kg^{-1}	CP, g kg^{-1}	NDF, g kg^{-1}	ADF g kg^{-1}	MM, g kg^{-1}	NFC*, g kg^{-1}	DE**, kcal kg^{-1}
CD***	880.0	30.0	130.0	370.0	243.0	130.0	340.0	2574
SD****	463.5	41.7	154.1	428.2	246.8	110.0	214.2	2485

DM: dry matter; EE: ether extract; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; MM: mineral matter; NFC: non-fibrous carbohydrates;
*Estimated using the equation: NFC (g/kg) = 1000 – (NDF + CP + EE + MM), according to Andriguetto (2002).
**Estimated using the prediction equation: DE (J) = (0.013 × CP) + (0.036 × EE) + (0.017 × NFC) + (0.006 × NDF) (Villamide et al., 2009). The estimated values were converted to kcal.
***Supra® Coelho Agro commercial pelleted rabbit feed (manufacturer's label information).
****Silage prepared from a 1:1 mixture (as-fed basis) of Supra® Coelho Agro commercial pelleted rabbit feed and fodder radish, ensiled for 70 days. Chemical composition was determined at the Animal Nutrition Laboratory, Federal University of Paraná (UFPR).

The fodder radish silage was prepared using fresh whole plants chopped into approximately 20-mm particles with an electric forage chopper. Mixtures containing 25 kg of chopped fodder radish and 25 kg of commercial pelleted rabbit feed (Supra®) were prepared without the addition of silage inoculants. The mixture was compacted into 20-L plastic buckets lined with black plastic bags using wooden tampers. The bags and bucket lids were sealed with adhesive tape, and the buckets were stored in a dry, shaded area. The silos were opened after 70 days of fermentation, and the pH of the silage was 4.52. The silage resembled a moistened mash feed because of pellet disintegration, with visible fodder radish particles.

The bromatological composition of the silage was determined at the Laboratory of Animal Nutrition at UFPR. Samples collected from different silos were combined to obtain a composite sample, which was then frozen for subsequent analysis. The sample was thawed at room temperature, homogenized, weighed, placed in trays, and pre-dried in a forced-air oven at 55°C for 72 h. It was then reweighed and ground in a Wiley mill fitted with a 1-mm screen. Dry matter (DM), crude protein (CP), mineral matter (MM), and ether extract (EE) were determined according to Detmann et al. (2012). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to Van Soest et al. (1991). Non-fibrous carbohydrates (NFC) were calculated as: NFC (g/kg) = 1000 − (NDF + CP + EE + Ash) (Andriguetto et al., 2002). Digestible energy (DE) was estimated using the prediction equation: DE (J) = (0.013 × CP) + (0.036 × EE) + (0.017 × NFC) + (0.006 × NDF) (Villamide et al., 2009), and the resulting values were converted to kcal.

At the beginning of the experiment, rabbits were blocked according to age, initial body weight, and sex and housed in pairs (one male and one female) in battery cages (60 × 80 × 45 cm) from 35 to 75 days of age. Both diets were offered *ad libitum* twice daily at 09:00 and 15:00. Rabbits were weighed weekly to determine average daily gain (ADG), calculated as (final body weight − initial body weight)/(number of experimental days). Feed refusals were also weighed daily to determine dry matter intake and adjust feed allowance, maintaining approximately 10% refusals. Animals were also monitored daily for fecal consistency.

At 75 days of age, after a 12-h fast, 11 rabbits from each treatment (one rabbit per experimental unit) were weighed and slaughtered. Rabbits were stunned by electronarcosis, followed by exsanguination through severing of the jugular veins and carotid arteries (Conselho Nacional de Controle de Experimentação Animal [CONCEA], 2018). After skinning and evisceration, carcasses were identified and weighed to determine hot carcass weight (HCW). Hot carcass yield (HCY) was calculated as: HCY = (HCW/SBW) × 100, where SBW is slaughter body weight. Carcasses were then chilled at 4°C for 24 h and reweighed to determine cold carcass weight (CCW) and calculate cold carcass yield (CCY) as: CCY = (CCW/SBW) × 100.

The carcasses were subsequently divided into commercial cuts consisting of forelegs with shoulders, hindlegs, loins, and ribs. Each cut was weighed individually to calculate cut yield. The loin was deboned, and the right and left *Longissimus lumborum* muscles were collected, packaged in plastic bags, and frozen until analysis.

Meat quality analyses were performed at the UFPR Meat Evaluation Laboratory. Only the right and left *Longissimus lumborum* muscles were used. Samples were thawed for 12 h at 10°C before determining pH, color, water-holding capacity (WHC), cooking loss (CL), and shear force (SF).

Muscle pH was measured using a digital penetration pH meter (Testo 206-pH2), with readings taken at both ends and the center of each sample. Meat color was measured after 30 min of exposure to ambient air using a CM600d spectrophotometer (Konica Minolta) equipped with a D65 illuminant, an 8-mm aperture, and a 10° standard observer. The L* (lightness), a* (redness), and b* (yellowness) values were recorded (King et al., 2023).

WHC was determined using a 0.5-g sample placed between acrylic plates on filter paper and compressed under a 10-kg weight for 5 min. WHC was calculated from the difference between the initial sample weight and the water lost and expressed as a percentage (Ramos & Gomide, 2009).

CL was determined by weighing raw samples before cooking them on an electric grill (Large Stone Electric Grill PGR03P, Philco, Brazil), turning the samples to ensure even grilling on both sides. Cooking continued until the internal temperature reached 70°C, as measured with a digital probe thermometer. Samples were cooled at room temperature on the bench until the following day and then reweighed. CL was calculated as: CL (%) = [(initial weight − final weight)/initial weight] × 100.

For SF determination, cooked meat samples were cut into 1.27-cm-diameter cylindrical cores parallel to the muscle fibers and sheared perpendicular to the fiber direction (three replicates per sample) using a Texture Analyzer (TA.XT Plus; 5-kg load cell) equipped with a Warner–Bratzler blade. The blade speed was 3.33 mm/s, the cutting distance was 30 mm, and results were expressed in Newtons (N) (American Meat Science Association [AMSA], 2016).

Data were subjected to the Shapiro–Wilk test for normality and Levene's test for homogeneity of variances. Data were then analyzed using generalized linear models including cage, sex, and treatment as fixed effects and initial body weight as a covariate. Means were compared using Student's *t*-test at the 5% significance level. Muscle pH was analyzed using the nonparametric Friedman test. Statistical analyses were performed using Minitab software, version 18.1.

Results and Discussion

Throughout the experimental period, all rabbits remained healthy, showed no signs of gastrointestinal disorders, and readily accepted both diets.

During the adaptation period, animals fed the SD exhibited a dry matter intake (DMI) 25% lower than that of the CD group (CD: 122 g; SD: 92 g). However, over the entire experimental period, only a trend ($P = 0.078$; Table 1) toward higher DMI was observed in the CD group.

Furthermore, the CD group exhibited greater average daily gain (ADG) and better feed conversion ratio (FCR) ($P < 0.05$), which can be attributed to the higher digestible energy (DE) content of this diet (Table 2). Although both diets contained DE levels within the range recommended by Xiccato and Trocino (2020) for growing rabbits (2400–2510 kcal kg^{-1}), the average DE intake was 340 kcal kg^{-1} for the CD group and 298 kcal kg^{-1} for the SD group. Consequently, rabbits fed the experimental diet consumed less DE than the amount recommended by the same authors for rabbits between 32 and 72 days of age (316 kcal kg^{-1}), which likely contributed to their poorer performance.

Table 2

Dry matter intake (DMI), average daily gain (ADG), and feed conversion ratio (FCR) of rabbits fed the Control Diet (CD) and Silage Diet (SD)

Variable	CD	DE	Standard error (SE)	P-value
DMI, g	132	120	4.98	0.078
ADG, g	32.85	25.62	2.20	0.003
FCR	3.92	4.47	0.26	0.03

Means were analyzed using a generalized linear model, with treatment, sex, and cage as fixed effects and initial body weight as a covariate. Means were compared using Student's t-test ($P < 0.05$).

Before the experiment, the composition of the silage diet was formulated based on the chemical composition of fodder radish harvested at a height of 80 cm to ensure that both diets were isoenergetic and isonitrogenous. However, variations in plant cutting heights at harvest resulted in differences in the chemical composition of the ensiled material before and during fermentation, leading to compositional imbalances between the two experimental diets, including the lower energy content of the silage diet. The higher neutral detergent fiber (NDF) content of the experimental diet (Table 2) may also have contributed to its lower energy density, negatively affecting ADG and FCR. Farías-Kovac et al. (2020) demonstrated that diets with lower NDF levels and lower NDF-to-soluble fiber ratios resulted in better feed conversion. Similarly, Christopher et al. (2022) reported that replacing concentrate with increasing levels of forage reduced the performance of New Zealand White and Chinchilla rabbits, negatively affecting ADG, FCR, and slaughter body weight.

The present findings are also consistent with those of Birolo et al. (2022), who evaluated diets differing in digestible energy (2600 vs. 2200 kcal kg^{-1}) and crude protein (CP; 159 vs. 144 g kg^{-1}) concentrations for growing rabbits. Those authors found that rabbits fed diets with higher DE levels exhibited greater ADG and better FCR, regardless of dietary CP level.

Regarding the quantitative carcass traits (Table 3), no difference ($P > 0.05$) was observed in slaughter body weight. However, rabbits in the CD group had greater ($P \leq 0.05$) hot and cold carcass weights, which can be attributed to their superior growth performance, as discussed previously. In contrast, no significant differences ($P > 0.05$) were observed for hot carcass yield or cold carcass yield (Table 3).

Table 3

Slaughter body weight (SBW), hot carcass weight (HCW), cold carcass weight (CCW), hot carcass yield (HCY), cold carcass yield (CCY), and cut yields of rabbits fed the Control Diet (CD) and Silage Diet (SD)

Variable	CD	DE	Standard error (SE)	P-value
SBW (kg)	2.096	1.816	0.065	0.25
HCW (kg)	1.033	0.856	0.041	0.016
CCW (kg)	1.037	0.860	0.040	0.017
HCY (%)	49.31	47.05	0.62	0.078
CCY (%)	49.52	47.23	0.63	0.104
Cut Yields				
Forelegs and Shoulders (%)	15.22	16.12	0.43	0.67
Ribs (%)	21.87	20.16	0.48	0.21
Loin (%)	24.64	23.78	0.32	0.59
Hindlegs (%)	34.83	35.51	1.10	0.78

Means were analyzed using a generalized linear model, with treatment, sex, and cage as fixed effects and initial body weight as a covariate. Means were compared using Student's t-test ($P < 0.05$).

The values obtained for the CD group were similar to those reported by Souza et al. (2022) for New Zealand White rabbits fed exclusively pelleted feed and slaughtered at 70 days of age (slaughter body weight: 2.154 kg; hot carcass weight: 1.030 kg; cold carcass weight: 1.012 kg). The lower dietary DE concentration of the experimental diet compared with that reported by Souza et al. (2022) reinforces the importance of dietary energy density for body growth in growing rabbits. Likewise, no significant differences ($P > 0.05$) were detected among diets for cut yields (Table 3).

Rabbit meat pH typically ranges from 5.62 to 5.88 (Mancini et al., 2005; Paci et al., 2012), and the values obtained in the present study fell within this range (Table 4).

Table 4
Meat pH, lightness (L*), redness (a*), yellowness (b*), water-holding capacity (WHC), cooking loss (CL), and shear force (SF) of rabbits fed the Control Diet (CD) and Silage Diet (SD)

Variable	CD	DE	Standard error	P-value
pH	5.85 (± 0.02)	5.80 (± 0.024)	0.02	0.13
L*	57.55 (± 1.106)	60.02 (± 1.206)	1.15	0.06
a*	8.54 (± 0.443)	9.21 (± 0.56)	0.51	0.37
b*	12.82 (± 0.46)	14.24 (± 0.41)	0.44	0.034
WHC (%)	64.56 (± 2.73)	65.82 (± 1.65)	2.19	0.70
CL (%)	29.15 (± 3.208)	24.06 (± 2.058)	2.63	0.25
SF (N)	19.08 (± 1.022)	28.49 (± 1.123)	1.09	<0.001

Means were analyzed using a generalized linear model, with treatment, sex, and cage as fixed effects and initial weight as a covariate. Means were compared using Student's t-test (P < 0.05). The pH values were analyzed using the Friedman test (P < 0.05).

The L* values also fell within the range reported for rabbit meat (Kumar et al., 2023). However, the a* and b* values were higher than those previously reported in the literature (Kumar et al., 2023), indicating greater redness and yellowness in the meat from both treatments. Meat pH is one of the primary factors affecting color, and a high ultimate pH (above 6.0–6.2) is characteristic of dark, firm, and dry (DFD) meat (Gomide et al., 2013). This was not observed in the present study, as the pH values ranged from 5.80 to 5.85. Moreover, DFD meat is a characteristic primarily associated with red meats characterized by oxidative muscle metabolism (Gomide et al., 2013).

Fodder radish contains β-carotene, a carotenoid that serves as a precursor of vitamin A (Barros & Jardine, 2021), which may have contributed to the greater yellowness observed in the meat of rabbits fed the SD (Table 4).

Shear force is strongly influenced by water-holding capacity and cooking loss. However, although no differences (P > 0.05) were observed between treatments for WHC or CL, SF differed significantly (P < 0.001). Meat pH also influences SF; however, as previously discussed, pH values remained within the normal range for the species. Despite the observed difference, SF values fell within the range typically reported for rabbit meat, which, according to Combes et al. (2001), varies from 2 to 4 kgf (19.6–39.2 N), indicating that the meat from both treatments was tender.

Overall, fodder radish silage was readily accepted by the rabbits, indicating its potential as an alternative feed source for small-scale production systems. This strategy may help reduce feeding costs, particularly on farms with limited access to commercial feeds and seasonal forage availability.

A simplified feed cost analysis based on the cost of feed required to produce one kilogram of live weight produced (feed cost = feed conversion ratio × diet cost) indicated an approximately 43% reduction in feed cost for the SD compared with the CD. Assuming a commercial feed price of R$ 3.00 kg^{-1} and excluding fodder radish production costs, the feed cost to produce one kilogram of live rabbit weight was estimated at R$ 11.76 for the CD and R$ 6.71 for the SD.

Despite this economic advantage, the diet containing fodder radish silage resulted in lower growth performance, with reductions in both weight gain and carcass weight. These findings indicate that further adjustments to the formulation of the ensiled total diet, particularly its energy density, are needed to improve productive performance and increase its potential as an effective and sustainable alternative for rabbit production systems with lower technological inputs.

Conclusions

The growth performance and quantitative carcass characteristics of New Zealand White rabbits were negatively affected, primarily because of the lower energy content of the fodder radish silage diet. However, meat quality was not compromised, remaining within the normal range reported for the species.

These findings indicate that, despite its negative effect on growth performance, fodder radish silage may represent a viable alternative for small-scale rabbit production systems, particularly where fodder radish is readily available and commercial feed is costly or scarce.

Further research should evaluate the inclusion of higher proportions of concentrate in fodder radish silage to optimize dietary energy, protein, and fiber concentrations, as well as its effects on growth performance and nutrient digestibility. Additional studies should also investigate the use of silages produced from other forage crops in rabbit diets.

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