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Effect of condensed tannin from *Acacia mearnsii* on the productive and reproductive performance of meat-type quail breeders

[Efeito do tanino condensado da Acácia mearnsii sobre o desempenho produtivo e reprodutivo de matrizes de codornas de corte]

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Abstract: This study evaluated the effects of condensed tannins from *Acacia mearnsii* on the productive and reproductive performance of broiler quail breeders over three 28-day cycles. In total, 140 *Coturnix coturnix* breeders were used, distributed in a completely randomized design in a split-plot arrangement, consisting of 4 treatments with 7 replicates of 5 birds per experimental unit, totaling 28 plots. The treatments were: T1, basal diet (negative control) without additives;T2, basal diet + zinc bacitracin at 22 ppm/ton (positive control); T3, basal diet + condensed tannin at 1.000 g/ton; and T4, basal diet + condensed tannin at 750 g/ton. Feed intake, egg production and mass, egg weight, feed conversion ratio per dozen eggs, hatchability, chick weight, and nitrogen excretion were evaluated. Performance varied among cycles, with higher feed intake and egg mass in the second cycle and better feed conversion in the third ($p < 0.05$). Supplementation with 750 g/ton of tannin promoted higher egg production and mass and (CA/dz), whereas 1.000 g/ton did not provide additional benefits ($p > 0.05$). Hatchability was higher in diets without additives ($p < 0.05$). Excreta nitrogen content was reduced by dietary treatments ($p < 0.05$), and an interaction between diet and cycle was observed for dry matter ($p < 0.05$). No effect was observed on mineral matter ($p > 0.05$). It can be concluded that moderate inclusion of condensed tannins from *A. mearnsii* (750 g/ton) (CA/dz), nutrient utilization, and reproductive performance, particularly in later cycles, in addition to reducing nitrogen excretion. These results indicate the potential of tannins as sustainable phytogenic additives and natural alternatives to antibiotic growth promoters.

Keywords: antimicrobial; environmental sustainability; feed efficiency; metabolism; phytogenic additive.

Resumo: O estudo avaliou os efeitos do tanino condensado de *Acacia mearnsii* sobre o desempenho produtivo e reprodutivo de matrizes de codornas de corte ao longo de três ciclos de 28 dias. Foram utilizadas 140 matrizes *Coturnix coturnix*, distribuídas em delineamento inteiramente casualizado, em esquema de parcelas subdivididas, composto por quatro tratamentos, com sete repetições de cinco aves em cada unidade experimental, totalizando 28 parcelas. Os tratamentos foram: T1: Dieta basal (controle negativo) sem adição de aditivos; T2: Dieta basal + antibiótico bacitracina de zinco em 22

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ppm/ton (controle positivo); T3: Dieta basal + tanino condensado em 1.000 g/ton e T4: Dieta basal + tanino condensado 750 g/ton. Foram analisados consumo de ração (CR), produção e massa de ovos (TPO e MO), peso dos ovos (POI), conversão alimentar por dúzia de ovos (CA/dz), taxa de eclosão (TE), peso dos pintinhos (PP) e excreção de nitrogênio. O desempenho variou entre os ciclos, com CR e MO no segundo ciclo e melhor CA/dz no terceiro ($p<0,05$). A suplementação com 750 g/ton de tanino promoveu maior TPO e MO e melhor CA/dz, enquanto 1.000 g/ton não apresentou benefícios adicionais ($p>0,05$). A TE foi superior nas dietas sem aditivos ($p<0,05$). O teor de nitrogênio das excretas foi reduzido por influência das dietas ($p<0,05$), e observou-se interação entre dieta e ciclo para matéria seca ($p<0,05$). Nenhum efeito foi constatado na matéria mineral ($p>0,05$). Conclui-se que a inclusão moderada de taninos condensados de *Acacia mearnsii* (750 g/ton) melhora a CA/dz, a utilização de nutrientes e o desempenho reprodutivo, especialmente em ciclos mais avançados, além de reduzir a excreção de nitrogênio. Esses resultados indicam o potencial dos taninos como aditivos fitogênicos sustentáveis e substitutos naturais aos antibióticos promotores de crescimento.

Palavras-chave: aditivo fitogênico; antimicrobiano; eficiência alimentar; metabolismo e sustentabilidade ambiental.

1. Introduction

In industrial poultry production, feed efficiency is essential for maintaining productive performance and is often enhanced by the inclusion of dietary additives. These compounds can promote intestinal and immune health, improve product quality, and support the use of alternative feed ingredients [1]. However, growing restrictions on antibiotic use have intensified the search for natural alternatives that ensure performance while safeguarding animal and public health [2].

Phytogenic additives, particularly polyphenols such as condensed tannins, have emerged as promising substitutes for antibiotic growth promoters. Once considered antinutritional, tannins are now recognized for their antimicrobial, antioxidant, and gut-modulating properties [3, 4]. Extracts from *Acacia mearnsii* have been associated with improved intestinal microbiota balance, reduced oxidative processes, and better nutrient utilization [5].

In poultry, dietary tannins have shown beneficial effects on performance and product quality. Studies in laying hens report improvements in egg quality, lipid stability, and gut health [6], while research in broilers demonstrates positive effects on weight gain, feed conversion, and resilience to health challenges [7, 8]. These findings suggest that tannins may act as multifunctional additives capable of partially or fully replacing antibiotics in poultry diets.

Despite these advances, information on meat-type quail breeders remains scarce. Considering the species' reproductive importance and potential differences in response to dietary tannins, further studies are needed to define appropriate supplementation levels. Thus, the present study aimed to evaluate the effects of dietary inclusion of condensed tannins from *A. mearnsii* (750 and 1.000 g/ton) on the productive and reproductive performance of meat-type quail, compared with zinc bacitracin as a conventional performance promoter.

2. Material and methods

2.1 Animals and experimental diets

The experiment was conducted at the Monogastric Animal Research Laboratory of the Department of Animal Science, Federal University of the Jequitinhonha and Mucuri Valleys (UFVJM), JK Campus, located at MGT 367 – Km 583, nº 5000, Alto da Jacuba district, Diamantina, Minas Gerais, Brazil (18°12′S, 43°34′W; approximately 1,250 m above sea level).

Meat-type quail breeders (*Coturnix coturnix*) of the LF2 strain were obtained from a specialized hatchery associated with an animal breeding program. The research was carried out over three experimental cycles of 28 days each, corresponding to: cycle I (62–90 days of age), cycle II (91–118 days of age), and cycle III (119–146 days of age). The project was submitted, reviewed, and approved by the Ethics Committee for Animal Use (CEUA) under protocol number 3920240323.

A completely randomized design in a split-plot arrangement was used, with three production cycles as the main plots and four dietary treatments as subplots. Each treatment had seven replicates with five birds per experimental unit, totaling 140 quail.

The experimental treatments were as follows: T1 – basal diet (negative control, NC) without additives; T2 – basal diet supplemented with 22 ppm/ton of zinc bacitracin (positive control, PC); T3 – basal diet supplemented with 1000 g/ton of condensed tannin; and T4 – basal diet supplemented with 750 g/ton of condensed tannin. The diets experimental were formulated to be isoenergetic and isoproteic, meeting the nutritional recommendations for meat-type quails described by Silva et al. [9], and were provided from 62 to 146 days of age (Table 1). The diets intended exclusively for breeders, were formulated based on corn and soybean meal (Table 2).

2.2 Experimental conditions and facilities

During the first 34 days of age, the birds were kept on a concrete floor covered with wood-shaving bedding, equipped with automatic feeders and pressure cup drinkers, and received commercial feed formulated to meet the nutritional requirements of the initial phase.

At 35 days of age, the birds were sexed, weighed, and placed in stacked metal cages (60 × 60 × 35 cm), at a density of 720 cm²/bird, containing trough feeders, pressure drinkers, and a textured floor. Metal trays lined with plastic were placed below the cages to collect excreta. From that point on, the birds began receiving experimental diets. Water and feed were provided *ad libitum*, and the males were housed in individual cages.

Table 1. Percentage and calculated composition of diets for meat-type quail breeders during the laying phase (62–146 days of age).

Ingredients	T1	T2	T3	T4
Corn meal (7.92 %)	44.426	44.426	44.426	44.426
Soybean meal (45 %)	38.998	38.998	38.998	38.998
Soybean oil	4.550	4.550	4.550	4.550
Salt	0.531	0.531	0.531	0.531
L-Threonine (98.5 %)	0.100	0.100	0.100	0.100
L-Lysine HCl (98.5 %)	0.088	0.088	0.088	0.088
DL-Methionine (99 %)	0.278	0.278	0.278	0.278
L-Valine (100 %)	0.187	0.187	0.187	0.187
Mineral premix[1]	0.050	0.050	0.050	0.050
Vitamin premix[2]	0.100	0.100	0.100	0.100
Bicalcium phosphate	1.637	1.637	1.637	1.637
Calcitic Limestone	7.940	7.940	7.940	7.940
Corn starch	1.000	1.003	1.100	1.200
Zinc bacitracin	0.000	0.147	0.000	0.000
Condensed tannin (*Acacia mearnsii*)	0.000	0.000	0.100	0.075
Inert[3]	0.300	0.150	0.100	0.025
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated composition				
Metabolizable energy (Kcal/kg)	2787	2787	2790	2794
Crude protein (%)	21.47	21.47	21.47	21.47
Available phosphorus (%)	0.42	0.42	0.42	0.42
Calcium (%)	3.50	3.50	3.50	3.50
Sodium (%)	0.23	0.23	0.23	0.23
Digestible Met + Cys (%)	0.84	0.84	0.84	0.84
Digestible Lys (%)	1.15	1.15	1.15	1.15
Digestible Thr (%)	0.81	0.81	0.81	0.81
Digestible Trp (%)	0.303	0.331	0.360	0.389
Digestible Val (%)	1.280	1.380	1.480	1.575

[1]Mineral premix (amount per kg of diet): manganese – 80.0 mg; iron – 50.0 mg; zinc – 50.0 mg; copper – 10.0 mg; iodine – 1.0 mg; selenium – 0.300 mg; cobalt – 1.0 mg. [2]Vitamin premix (amount per kg of diet): vitamin A – 12,000 IU; vitamin D_3 – 2,500 IU; vitamin E – 30.0 IU; vitamin B_1 – 2.0 mg; vitamin B_6 – 3.00 mg; pantothenic acid – 10.0 mg; biotin – 0.07 mg; vitamin K_3 – 3.0 mg; folic acid – 1.0 mg; nicotinic acid – 35.0 mg; vitamin B_{12} – 15 µg; choline chloride (60 %) – 100.0 mg. [3]Washed sand.

Table 2. Percentage composition of diets for male meat-type quail (breeders) during the growth/final phase (35–146 days).

Ingredients	Grower/Finisher
Corn (7.92 %)	54.745
Soybean meal (45 %)	38.435
Soybean oil	4.023
Limestone	1.058
Dicalcium phosphate	0.794
Salt	0.323
Mineral premix[1]	0.100
Vitamin premix[2]	0.200
DL-Methionine (98 %)	0.213
L-Threonine (99 %)	0.049
Antioxidant[3]	0.010
Coccidiostat[4]	0.050
Total	**100.000**

[1]Per kilogram of product: copper – 2500.00 mg; choline – 27.00 mg; iron – 12.5 mg; iodine – 250.00 mg; manganese – 7.5 mg; methionine – 130.00 g; selenium – 20.00 mg; sodium – 120.00 g; zinc – 4500.00 mg. [2]Per kilogram of product: folic acid – 175.00 mg; nicotinic acid – 28000.00 mg; pantothenic acid – 2500.00 mg; zinc bacitracin – 5100.00 mg; BHA – 500.00 mg; BHT – 500.00 mg; biotin – 12.50 mg; vitamin A – 500,000.00 IU; vitamin B_1 – 150.00 mg; vitamin B_{12} – 2500.00 mg; vitamin B_2 – 800.00 mg; vitamin B_6 – 250.00 mg; vitamin D_3 – 170,000.00 IU; vitamin E – 2100.00 IU; vitamin K_3 – 400.00 mg; salinomycin – 12500.00 mg/kg. [3]Butylated hydroxytoluene. [4]Coxistac.

2.3 Sanitary challenge

To promote an immunological challenge, only the breeding female quails were subjected to specific sanitary management conditions, without regular cleaning of the drinkers and collection trays. The drinkers were cleaned three times per week, and the trays were cleaned only once per week. Additionally, these birds received water contaminated with poultry litter, prepared by diluting 1,000 g of poultry litter in 5 L of water, which was provided in the drinkers and consumed over 5 days in each experimental period. The males were not subjected to this immunological challenge.

2.4 Reproductive management

Reproductive management was performed in each experimental period, allocating one male for every five females, distributed across 28 experimental cages. Males were introduced into the cages at 64 days of age and remained with the females for 8 consecutive days. Of these, the first 3 days were designated for male adaptation to the female group, with no collection of hatching eggs, while the subsequent 5 days were used for collecting eggs intended for incubation. During this phase, the eggs produced were collected, weighed, identified, stored, and later sent to a specialized incubation facility. At the end of the mating cycle, the males were returned to individual housing.

Hatching eggs were kept in a biochemical oxygen demand incubator at temperatures between 20°C and 25°C to avoid microbial deterioration until incubation. Incubation was programmed and carried out in a COPEMARQ incubator (model Labo 13), with a capacity for 4,000 eggs and equipped with automatic temperature, humidity, and egg-turning control. The eggs remained in incubation for 15 days and were transferred to the hatcher on day 16, where they remained until day 19 (estimated hatching day).

At the time of transfer to the hatcher, the eggs were placed in properly identified woven fabric bags for control and analysis of the chicks. After hatching, the chicks were weighed individually.

2.5 Performance and reproductive traits

The performance variables evaluated between 62 and 146 days of age included feed intake (FI, g/bird), egg mass (EM, g), egg weight (EW, g), egg production rate (EPR, %/bird/day), feed conversion ratio per dozen eggs (FCR/dz, g/dz), feed conversion ratio per egg mass (FCR/EM, g/g), hatchability rate (HR, %), hatching egg weight (HEW, g), and chick weight (CW, g). FI was corrected based on mortality data, as described by Sakomura and Rostagno [10], also considering the days during which males remained with the breeders. Mortality was recorded daily and used to adjust FI calculations.

2.6 Excreta analysis

At the end of each cycle, the dry matter (DM, %), mineral matter (MM, %), and nitrogen (N, %) contents of the excreta were analyzed according to the methodology described by Silva and Queiroz [11]. The excreta were collected twice per week at 8:00 a.m. to avoid fermentation and nutrient loss. The samples were stored in identified plastic bags and kept in a freezer at −20°C. After the end of the collection cycle, the samples were thawed and homogenized, and an aliquot was removed for analysis.

2.7 Statistical analysis

The data were analyzed using R software [12], adopting a 5 % significance level. Initially, the assumptions of residual normality and homogeneity of variances were verified using the Shapiro–Wilk test and Levene's test, respectively. Prior to the analyses, observations identified as outliers through exploratory data analysis were removed when considered inconsistent with the biological pattern of the dataset. DM data, expressed as percentages, were subjected to an arcsine square-root transformation to meet the assumptions of analysis of variance. Statistical analyses were conducted using the transformed data; however, for clarity and ease of interpretation, the results are presented as means on the original percentage scale.

The statistical model included the fixed effects of cycle, treatment, and their interaction (cycle × treatment). When the interaction was not significant, the main effects were interpreted. When significant effects were detected, means were compared using Tukey's test at the 5 % probability level. The analyses were performed using the ExpDes.pt package [11] in R.

3. Results

3.1 Environmental conditions

The average temperatures recorded during the first period (62–90 days) were 27.9°C (maximum) and 16.5°C (minimum), with a relative humidity of 79.1 %. In the second period (91–118 days), the average temperatures were 28.6°C (maximum) and 16.5°C (minimum), with a relative humidity of 79.7 %. In the third period (119–146 days), the maximum and minimum temperatures were 29.8°C and 16.5°C, respectively, and the relative humidity was 81.4 %.

3.2 Production performance

There was a significant effect of the production cycle on FI, FCR/dz, FCR/EM, EW, EM, and CW ($p < 0.05$) (Tables 3 and 4). Diets influenced EPR, FCR/dz, FCR/EM, and HR ($p < 0.05$). No significant interaction between diet and cycle was observed for any of the variables evaluated.

FI varied among production cycles ($p < 0.05$), with higher intake in the second cycle (35.61 g/bird) than in the first (30.24 g/bird) and third cycles (24.08 g/bird). However, FI was not affected by dietary treatments ($p > 0.05$). FCR/dz was affected by both cycle and diet ($p < 0.01$). Birds in the second cycle exhibited poorer feed conversion (0.474 g/dz) than birds in the third cycle (0.347 kg/dz). Among diets, the inclusion of condensed tannin at 1000 g/ton resulted in worse FCR/dz (0.446 g/dz) than did the inclusion of zinc bacitracin (0.386 g/dz).

Similarly, FCR/EM was influenced by both factors ($p < 0.05$). The highest values were observed in the second production cycle and in birds fed 1.000g/tonelada condensed tannin (2.65 g/g), while those receiving 750 g/ton tannin showed better conversion efficiency (2.26 g/g). EW differed among production cycles ($p = 0.019$), with higher averages recorded in the second cycle (14.52 g) and lower in the third (13.37 g). No dietary effect was detected on EW ($p > 0.05$). EM also varied according to cycle ($p = 0.021$), with higher means observed during the first (12.61 g) and second cycles (13.13 g) than during the third (11.39 g). Diets did not significantly affect EM ($p > 0.05$).

3.4 Excreta composition

No significant effect was observed on the MM content of the excreta ($p > 0.05$). However, N content was influenced by the evaluated diets ($p < 0.05$). Regarding DM of the excreta, there was a significant interaction between diet and production cycle ($p < 0.05$), in addition to significant main effects of both factors (Table 5).

Table 3. Means ± standard deviation for feed intake, egg production rate, feed conversion per dozen eggs, feed conversion per egg mass, egg weight, and egg mass of meat-type quail breeders during the laying phase (62–146 days of age).

		Diets					p-value		
Variables	Cycles	T1: Basal Diet	T2: Basal + Bzn	T3: Basal + CT (1,000 g/ton)	T4: Basal + CT (750 g)	Mean	Cycle	Diet	Diet × Cycle
FI (g/bird)	I	29.62 ± 2.38	29.98 ± 3.59	31.55 ± 3.32	29.82 ± 1.63	30.24b			
	II	35.50 ± 1.81	36.32 ± 2.81	34.62 ± 0.60	36.00 ± 1.84	35.61a	<0.0001	0.800	0.340
	III	25.18 ± 2.13	22.88 ± 3.67	25.03 ± 3.11	23.23 ± 3.29	24.08c			
Mean		30.10	29.73	30.40	29.68				
EPR (%)	I	90.20 ± 8.88	91.33 ± 12.67	82.32 ± 6.88	87.27 ± 8.75	87.78			
	II	91.38 ± 9.67	96.10 ± 13.27	84.64 ± 5.11	91.48 ± 6.50	90.90	0.35	0.016	0.874
	III	80.48 ± 10.42	93.24 ± 25.44	80.08 ± 11.65	87.15 ± 8.85	85.24			
Mean		87.35AB	93.55A	82.35B	88.63AB				
FCR/dz (g/dz)	I	0.399 ± 0.07	0.396 ± 0.03	0.465 ± 0.08	0.412 ± 0.03	0.418b			
	II	0.471 ± 0.05	0.457 ± 0.04	0.492 ± 0.02	0.474 ± 0.03	0.474a	<0.001	0.003	0.318
	III	0.383 ± 0.08	0.304 ± 0.05	0.382 ± 0.07	0.318 ± 0.05	0.347c			
Mean		0.418AB	0.386B	0.446A	0.401B				
FCR/EM (g/g)	I	2.28 ± 0.38	2.40 ± 0.21	2.74 ± 0.47	2.30 ± 0.28	2.38b			
	II	2.76 ± 0.42	2.65 ± 0.22	2.80 ± 0.25	2.51 ± 0.59	2.68a	0.003	0.030	0.920
	III	2.09 ± 0.68	2.06 ± 0.45	2.40 ± 0.61	1.98 ± 0.38	2.13c			
Mean		2.38AB	2.37AB	2.65A	2.26B				
EW (g)	I	13.85 ± 0.68	13.98 ± 1.19	14.28 ± 1.41	13.05 ± 1.18	13.79ab			
	II	14.29 ± 0.76	14.42 ± 1.02	14.74 ± 1.16	14.62 ± 0.42	14.52a	0.019	0.282	0.169
	III	13.93 ± 0.74	12.45 ± 1.63	13.57 ± 1.80	13.53 ± 1.03	13.37b			
Mean		14.02	13.62	14.20	13.73				
EM (g)	I	13.15 ± 0.68	12.52 ± 1.19	11.60 ± 1.41	13.18 ± 1.18	12.61a			
	II	13.07 ± 0.76	13.75 ± 1.02	12.47 ± 1.16	13.22 ± 0.42	13.13ab	0.021	0.164	0.892
	III	11.18 ± 0.74	11.65 ± 1.63	10.98 ± 1.80	11.76 ± 1.03	11.39b			
Mean		12.47	12.64	11.68	12.72				

FI, feed intake (g/bird); EPR, egg production rate (%/bird/day); FCR/dz, feed conversion ratio per dozen eggs (g/dozen); FCR/EM, feed conversion ratio per egg mass (g/g); EW, egg weight (g); EM, egg mass (g). T1, basal diet (negative control); T2, basal diet + zinc bacitracin (positive control); T3, basal diet + condensed tannin (1,000 g/ton); T4, basal diet + condensed tannin (750 g/ton). Cycle I, 62–90 days of age; Cycle II, 91–118 days of age; Cycle III, 119–146 days of age. Means followed by different lowercase letters within rows and uppercase letters within columns differ by Tukey's test ($p < 0.05$).

Table 4. Means ± standard deviation for hatchability rate, hatching egg weight, and chick weight of meat-type quail breeders during the laying phase (62–146 days of age).

		Diets					p-value		
Variables	Cycles	T1: Diet Basal	T2: Basal +Bzn	T3: Basal + CT (1,000g/ton)	T4: Basal+ CT (750g)	Mean	Cycle	Diets	Diets * Cycle
HE (%)	I	59.38±17.04a	20.77±17.73b	28.19±17.92	33.89±17.93	35.56b	0.188	0.0015	0.193
	II	45.06±19.02a	19.80±13.84b	29.66±25.24	32.32±23.52	31.71b			
	III	43.25±13.31b	39.82±23.34a	29.81±24.98	53.40±14.67	41.57a			
Mean		49.23A	26.80B	29.22B	39.87AB				
HEW (g)	I	13.85±0.68	13.98±1.19	14.28±1.41	13.05±1.18	13.79	0.106	0.731	0.051
	II	14.11±1.00	13.57±0.80	13.73±0.86	14.11±1.26	13.88			
	III	14.41±0.70	13.95±0.67	14.20±0.58	15.02±0.39	14.39			
Mean		14.12	13.83	14.07	14.06				
CW (g)	I	9.64 ± 0.93	9.34 ± 0.91	9.34 ± 0.91	9.47 ± 0.92	9.72a	<0.001	0.091	0.699
	II	9.64 ± 0.93	9.34 ± 0.91	9.34 ± 0.91	9.47 ± 0.92	9.54a			
	III	9.64 ± 0.93	9.34 ± 0.91	9.34 ± 0.91	9.47 ± 0.92	9.21b			
Mean		9.49	9.40	9.29					

HR, hatchability rate (%); HEW, hatching egg weight (g); CW, chick weight (g). T1, basal diet (negative control); T2, basal diet + zinc bacitracin (positive control); T3, basal diet + condensed tannin (1,000 g/ton); T4, basal diet + condensed tannin (750 g/ton). Cycle I, 62–90 days of age; Cycle II, 91–118 days of age; Cycle III, 119–146 days of age. Means followed by different lowercase letters within rows and uppercase letters within columns differ by Tukey's test ($p < 0.05$).

Table 5 – Means ± standard deviation for dry matter, mineral matter, and nitrogen content in the excreta of meat-type quail breeders during the laying phase (62–146 days of age).

		Diets				p-value			
Variables	Cycles	T1: Diet Basal	T2: Basal +Bzn	T3: Basal + CT (1,000g/ton)	T4: Basal+ CT (750g)	Mean	Cycle	Diets	Diets * Cycle
MM (%)	I	29.29±4.13	28.00±1.84	28.87±1.01	29.98±6.73	29.03			
	II	31.00±0.98	29.27±3.32	28.39±0.55	30.74±5.56	29.85	0.075	0.124	0.059
	III	28.26±9.46	29.39±3.60	26.13±3.18	22.77±1.81	26.64			
	Mean	31.69	29.01	28.27	27.83				
N (%)	I	6.23±1.00	5.93±0.72	5.19±1.38	6.80±0.71	6.04			
	II	6.43±0.66	6.26±0.64	5.27±0.62	6.48±0.73	6.11	ns	0.032	ns
	III	6.27±1.46	6.34±1.19	5.92±0.64	6.68±0.54	6.30			
	Mean	6.31A	6.17AB	5.46B	6.65A				
DM (%)	I	94.6±2.41a	93.4±0.56a	93.5±0.78a	92.5±2.24a	93.5			
	II	89.7±2.49b	89.1±1.59b	87.9±1.73b	90.2±2.01b	89.2	0.0066	<0.001	<0.001
	III	93.5±3.19a	89.3±6.36b	83.6±5.82c	78.6±6.97c	86.3			
	Mean	92.60	90.60	88.30	87.10				

DM, dry matter (%); MM, mineral matter (%); N, nitrogen (%). T1, basal diet (negative control); T2, basal diet + zinc bacitracin (positive control); T3, basal diet + condensed tannin (1,000 g/ton); T4, basal diet + condensed tannin (750 g/ton). Cycle I, 62–90 days of age; Cycle II, 91–118 days of age; Cycle III, 119–146 days of age. Means followed by different lowercase letters within rows and uppercase letters within columns differ by Tukey's test ($p < 0.05$).

4. Discussion

4.1 FI and FCR

FI is a key factor influencing both productive and reproductive performance in birds because it directly affects the intake of nutrients essential for maintenance and egg production [13]. In the present study, FI remained stable across production cycles, indicating adequate adaptation of the breeders to the experimental diets. The best FCR/dz was observed during the third cycle, coinciding with a slight reduction in FI. Although this lower intake may have partially limited reproductive output, it resulted in improved feed conversion ratio, reflecting a more balanced use of nutrients for egg formation and laying. Breeders fed 750 g/ton of condensed tannins from *A. mearnsii*, as well as those receiving the positive control diet (zinc bacitracin), achieved the best FCR/dz values, indicating that moderate tannin inclusion favors feed conversion ratio associated with egg production.

These findings suggest that controlled tannin inclusion enhances nutrient utilization directed toward egg production without compromising overall productivity. Previous studies have also reported that optimized levels of *A. mearnsii* tannins improve nutrient digestibility and utilization, leading to better zootechnical performance [14–16]. Furthermore, Liu et al. [3] demonstrated that tannins from this species stimulate the growth of *Lactobacillus* and improve intestinal absorption, which may explain the enhanced feed conversion ratio observed in this study, particularly at the 750 g/ton inclusion level.

4.2 Reproductive performance and egg quality

EW was highest in the second production cycle, coinciding with greater FI. According to Guimarães et al. [17], reduced FI may restrict the supply of essential nutrients, especially amino acids and proteins, potentially compromising muscle deposition and increasing susceptibility to heat stress. In the current study, EW values remained within the expected range reported by Albino and Barreto [18]. Adequate EW is crucial for embryonic development because CW at hatch represents approximately 70 % of the initial EW [19]. Consequently, the higher EW during the second cycle likely contributed to improved embryo mass.

EPR remained consistently high across all treatments, exceeding the 80 %–85 % range described by Albino and Barreto [18] for European quails, even under thermal stress conditions that typically reduce FI [20]. Birds receiving the positive control (zinc bacitracin) diet achieved the highest EPR, indicating that antibiotic replacement with moderate tannin inclusion can maintain comparable production performance.

HR was highest in the second cycle, particularly in birds receiving the negative control diet. High tannin inclusion levels (1.000 g/ton) appeared to compromise embryonic development, likely due to the complexation of tannins with dietary proteins and carbohydrates and the inhibition of digestive enzymes [21]. Such interactions may reduce nutrient bioavailability and impair embryogenesis, emphasizing the importance of optimizing tannin dosage to balance antimicrobial effects with nutrient utilization.

4.3 Nitrogen metabolism and environmental sustainability

An important finding of this study was the significant reduction in N excretion at 1.000 g/ton of condensed tannin. This suggests improved amino acid retention and reduced protein catabolism, which may decrease the energy costs associated with excretion. Tannins can modulate the intestinal microbiota and reduce urease activity, thereby diminishing ammonia formation

and promoting more efficient N utilization [22]. Similarly, Choi and Kim [23] reported that tannin supplementation lowered urea levels and ammonia emissions in poultry, contributing to improved gut health and reduced environmental pollution.

From an environmental perspective, the reduction in N excretion achieved with tannin inclusion represents a strategic advantage in intensive poultry systems. Lower ammonia emissions improve air quality and animal welfare while reducing the ecological footprint of production [24]. Thus, tannin supplementation aligns with current sustainability goals in animal agriculture.

5. Conclusion

Under the experimental conditions of this study, the inclusion of 750 g/ton of condensed tannins from *A. mearnsii* in the diet of meat-type quail breeders improved eggs production ratio, feed conversion, and hatchability, particularly during the second and third production cycles. This moderate inclusion level enhanced nutrient utilization and reproductive performance without impairing productivity. Moreover, the reduction in N excretion observed with tannin supplementation highlights its potential contribution to environmental sustainability in intensive poultry systems. Overall, *A. mearnsii* condensed tannins represent a promising natural alternative to antibiotic growth promoters in breeder quail nutrition.

Conflict of interest statement

The authors declare no competing interests.

Data availability statement

The datasets generated and analyzed during the current study are not publicly available because of confidentiality agreements with the private institution involved in the research. However, anonymized data containing only independent and dependent variables can be made available from the corresponding author upon reasonable request.

Author contributions

Conceptualization: Custódio, D. K., Dalólio, F. S., Magalhães, A. F. B., Poletti, B., Pinheiro, S. R. F.; Data curation: Custódio, D. K., Magalhães, A. F. B.; Formal analysis: Magalhães, A. F. B., Pinheiro, S. R. F.; Investigation: Custódio, D. K., Souza, K. O.; Methodology: Custódio, D. K., Dalólio, F. S., Magalhães, A. F. B., Poletti, B., Pinheiro, S. R. F.; Funding acquisition: Dalólio, F. S., Poletti, B., Pinheiro, S. R. F.; Resources: Dalólio, F. S., Poletti, B., Pinheiro, S. R. F.; Project administration: Custódio, D. K., Pinheiro, S. R. F.; Visualization: Custódio, D. K., Ferreira, R. S., Pinheiro, S. R. F.; Supervision: Dalólio, F. S., Poletti, B., Pinheiro, S. R. F.; Writing – original draft: Custódio, D. K., Ferreira, R. S., Pinheiro, S. R. F.; Writing – review & editing: Custódio, D. K., Ferreira, R. S., Magalhães, A. F. B.

Generative AI use statement

The authors did not use generative artificial intelligence tools or technologies in the creation or editing of any part of this manuscript.

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