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NONRUMINANT NUTRITION

Effect of β-mannanase enzyme supplementation on the diet of broilers fed full-fat deactivated soy

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ABSTRACT. The objective of the present study was to evaluate the performance of broiler chickens fed a diet containing deactivated soy supplemented with the enzyme β-mannanase. A total of 1,152 broiler chickens, one day old and from the COOB 500 lineage, were used in a completely randomized design with a 4x2 factorial scheme. Four levels of β-mannanase (0, 80, 160, and 240 g ton^{-1}) and the presence or absence of deactivated soy were tested, with eight repetitions, each with 18 birds per experimental unit. On the 1st, 7th, 14th, 21st, 28th, 35th, and 42nd days of life, the birds were weighed, and the feed leftovers were measured to obtain performance variables. From days 1 to 21, weight gain, feed conversion, and average weight were significantly affected by the addition of β-mannanase to the diet. The use of deactivated soy in combination with enzyme levels in mg kg^{-1} of metabolizable energy resulted in greater gains than did the use of soybean meal combined with the same levels of metabolizable energy. The use of deactivated soy along with 240 mg of β-mannanase enzyme supplementation in broiler diets from 1--42 days of age is recommended, as this supplementation improves bird performance.

Keywords: additives; broiler farming; digestibility; exogenous enzymes.

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Introduction

Nutrition is one of the most important factors in broiler production, accounting for 60–70% of costs (Moreira et al., 2020). Broilers require specific amounts of nutrients and energy in their diet to achieve maximum performance. Under certain circumstances, it may be advantageous to seek alternative ingredients with lower costs for live weight production, necessitating adjustments in the feeding strategy as needed (Feil et al., 2019). An alternative way to reduce costs is to explore alternative food sources, such as deactivated soybean meal.

In this context, the use of deactivated soybeans could be a way to harness the benefits of the high nutritional value of grain while also reducing the costs associated with purchasing processed products from industry (Erdaw, Perez-Maldonado, & Iji, 2019). Despite having a higher energy concentration than soybean meal does, raw soybeans contain antinutritional factors such as soybean lectin, trypsin and chymotrypsin inhibitors, and urease, which may hinder animal feed utilization (Gouveia et al., 2020). Thus, grain processing, one of which involves the deactivation of these factors through heat treatment, is essential for optimal animal utilization.

The application of biotechnology to animal nutrition has enabled the development of exogenous enzymes. Enzymes are globular proteins with tertiary or quaternary structures that act as biological catalysts, increasing the speed of chemical reactions in the organism without being altered themselves in this process (Oliveira, 2019). The use of enzymes in poultry feed includes both the addition of enzymes naturally produced by the animal's digestive system, such as amylases, lipases, and proteases, and the inclusion of enzymes that are not endogenously produced, such as phytases, cellulases, xylanases, glucanases, pectinases, galactanases, and mannanases (Moura et al., 2019).

The initial commercial use of exogenous enzymes was to increase nutrient digestibility, with a focus on removing antinutritional factors from the diet, such as arabinoxylans and β-glucans, in diets based on viscous grains such as wheat, rye, barley, or triticale (Paulo et al., 2019). Other potential benefits of enzyme use include flexibility in formulating lower-cost feeds and increased food digestibility; in this regard, the enzyme β-mannanase has emerged as an efficient supplement in animal nutrition.

Hence, research on the use of β-mannanase and deactivated soybeans in broiler production is necessary due to the scarcity of information on this combination in the literature. Thus, the objective of this study was to evaluate the productivity of 1- to 42-day-old broilers fed diets containing deactivated soybeans with different levels of the β-mannanase enzyme.

Materials and methods

The experiment was conducted at the experimental broiler house of Avivar – Alimentos Company, São Sebastião do Oeste, Minas Gerais State, Brazil. A total of 1152 male broiler chickens of the COBB 500 lineage, with an initial weight of 0.043 ± 0.0012 kg, were used from days 1 to 42 of age. The animals were distributed in a completely randomized design in a 4x2 factorial scheme, with four levels of β-mannanase (0, 80, 160, 240 g ton^{-1}) and the inclusion or absence of deactivated soybeans, with eight replications and 18 birds in each experimental unit.

The animals were housed in a masonry shed, screened, covered with fibro cement tiles, subdivided into 1.0 × 1.5 m boxes with rice husk bedding, and provided with one drinker and one tubular feeder. The temperature was measured once a day (8:00 a.m.) to determine the maximum and minimum temperatures.

The diets were formulated to meet all the nutritional requirements of the birds according to Rostagno et al. (2017). The experimental treatments applied from day 1 to day 42 (according to Tables 1, 2, 3, 4, and 5) were as follows:

CON treatment: Control, without the inclusion of deactivated soybeans and with the inclusion of β-mannanase enzyme ton-1.

80 ENZ Treatment: 0 kg of deactivated soybeans and the inclusion of 80 g of β-mannanase enzyme ton^{-1}.

160 ENZ Treatment: 0 kg of deactivated soybeans and the inclusion of 160 g of β-mannanase enzyme ton^{-1}.

240 ENZ Treatment: 0 kg of deactivated soybeans and 240 g of β-mannanase enzyme ton-1.

SD0 ENZ treatment: 100 g kg^{-1} of deactivated soybeans in the starter and grower 1 phases and 200 g kg^{-1} in the grower 2 and finisher phases, all without the inclusion of β-mannanase enzyme ton^{-1}.

SD80 ENZ treatment: 100 g kg^{-1} of deactivated soybeans in the starter and grower 1 phases and 200 g kg^{-1} in the grower 2 and finisher phases, all with the inclusion of 80 g of β-mannanase enzyme ton^{-1}.

SD160 ENZ treatment: 100 g kg^{-1} of deactivated soybeans in the starter and grower 1 phases and 200 g kg^{-1} in the grower 2 and finisher phases, all with the inclusion of 160 g of β-mannanase enzyme ton^{-1}.

Finally, for the SD240 ENZ treatment, 100 g kg^{-1} of deactivated soybeans in the starter and grower 1 phase and 200 g kg^{-1} in the grower 2 and finisher phases, all with the inclusion of 240 g of β-mannanase enzyme ton^{-1}, were used.

Performance evaluation

For performance evaluation, total weight gain (TWG) (kg plot^{-1} week^{-1}), feed intake (FI) (g bird^{-1}), the feed conversion ratio (FCR), daily weight gain (DWG) (g bird^{-1} day^{-1}), and average weight (AW) were assessed. The average weight gain per bird per day was determined from weekly weights at chick arrival on the 7th, 14th, 21st, 28th, 35th, and 42nd days of age in the afternoon via a scale with a capacity of 50 kg. The average feed intake was determined by dividing the difference between the feed provided during the phase and the remaining feed weighed at the end of the phase by the number of birds in the plot.

The feed conversion ratio was calculated by dividing the average feed intake by the average weight gain of the birds in the plots studied. Mortality was monitored daily to correct feed intake and feed conversion considering the weighing of birds and feed on the day of mortality, as described by Sakomura and Rostagno (2007).

Statistical analysis

The data obtained were analyzed via the R-Studio statistical package (R Core Team, 2019). The normality of the residuals was checked via the Shapiro–Wilk test, and variances were compared via Levene's test. The data were subsequently subjected to analysis of variance to verify whether there was an interaction effect between the factors and their isolated effects.

For the evaluation of interactions, a breakdown of the sum of squares of the storage time was performed via orthogonal polynomials, and regression equations were adjusted. When evaluating the main effects, for the inclusion of SDs or not, the Tukey test was used, and for the effect of the levels of the β-mannanase enzyme, orthogonal polynomial contrasts were used, and regression equations were adjusted. For all analyses, a significance level of 5% was used.

Table 1. Calculated composition of the experimental rations for broiler chickens in the 1--7-day phase.

Ingredients	Initial (1 – 7 days)							
	CON	80ENZ	160ENZ	240ENZ	SD0ENZ	SD80ENZ	SD160ENZ	SD240ENZ
Corn grain	54.75	54.74	54.73	54.73	53.39	53.38	53.37	53.36
Soybean meal	34.86	34.86	34.86	34.86	27.99	27.99	27.99	27.99
Deactivated soybean	0.00	0.00	0.00	0.00	10.00	10.00	10.00	10.00
Meat and bone meal 46%	2.65	2.65	2.65	2.65	2.59	2.59	2.59	2.59
Viscera meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Chicken fat	1.77	1.77	1.77	1.77	0.12	0.12	0.12	0.12
Salt	0.34	0.34	0.34	0.34	0.35	0.35	0.35	0.35
Sodium sulfate	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13
Limestone	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Kaolin	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Methionine - MHA 80%	0.48	0.48	0.48	0.48	0.46	0.46	0.46	0.46
Lysine	0.46	0.46	0.46	0.46	0.44	0.44	0.44	0.44
Choline chloride	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Aluminosilicate	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Threonine 98%	0.13	0.13	0.13	0.13	0.11	0.11	0.11	0.11
L-Valine	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07
Phytase FC 10,000	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix for poultry	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mineral premix for poultry	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Antioxidant	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Prophorce	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Enramycin	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Aviax Plus	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mananase enzyme	0.00	0.008	0.0160	0.0240	0.00	0.008	0.0160	0.0240
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

EMAn values are based on the WPSA European Table of Energy Values for Poultry Feedstuffs (3rd ed., 1989). The following products were used per kilogram: Calcium (max) 210 g, Calcium (min) 170 g, Phosphorus (min) 50 g, Methionine (min) 22 g, Vitamin A (min) 120000 IU, Vitamin D3 (min) 30000 IU, Vitamin E (min) 400 IU, Thiamine (B1) (min) 35 mg, Riboflavin (B2) (min) 130 mg, Pyridoxine (B6) (min) 60 mg, Vitamin B12 (min) 300 mg, Vitamin K3 (min) 30 mg, Biotin (min) 1.6 mg, Folic Acid (min) 20 mg, Niacin (min) 680 mg, Calcium Pantothenate (min) 200 mg, Choline (min) 400 mg, Sodium (min) 26 g, Manganese (min) 1600 mg, Zinc (min) 1380 mg, Copper (min) 160 mg, Iron (min) 630 mg, Iodine (min) 20 mg, Selenium (min) 6 mg, Phytase (min) 10000 F.T.U., Avilamycin 200 mg, and Narasin+Nicarbazine.

Table 2. Calculated composition of the experimental rations for broiler chickens aged 8--21 days.

	Growth 1 (8 to 21 days)							
	CON	80ENZ	160ENZ	240ENZ	SD0ENZ	SD80ENZ	SD160ENZ	SD240ENZ
Corn grain	55.90	55.89	55.88	55.87	54.42	54.41	54.32	54.42
Soybean meal	33.26	33.26	33.26	33.26	26.39	26.39	26.39	26.39
Deactivated soybean	0.00	0.00	0.00	0.00	10.00	10.00	10.00	10.00
Meat and bone meal 46%	1.74	1.74	1.74	1.74	1.68	1.68	1.68	1.68
Viscera meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Chicken fat	3.20	3.20	3.20	3.20	1.55	1.55	1.55	1.55
Salt	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Sodium sulfate	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Limestone	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Kaolin	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Methionine - MHA 80%	0.45	0.45	0.45	0.45	0.44	0.44	0.44	0.44
Lysine	0.46	0.46	0.46	0.46	0.44	0.44	0.44	0.44
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Aluminosilicate	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Threonine 98%	0.13	0.13	0.13	0.13	0.11	0.11	0.11	0.11
L-Valine	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Phytase FC 10,000	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix for poultry	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mineral premix for poultry	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Antioxidant	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Prophorce	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Enramycin	0.01	0.01	0.01	0.01	0.10	0.10	0.10	0.10
Salinomycin 24%	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Aviax Plus	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mananase enzyme	0.00	0.008	0.0160	0.024	0.00	0.008	0.0160	0.00
Total	100.00	100.00	100.00	100.0	100.00	100.00	100.00	100.00

The EMAn values were calculated on the basis of the European Table of Energy Values for Poultry Feedstuffs (WPSA; 3rd ed., 1989). The following parameters per kg of product were used: Calcium (max) 210 g, Calcium (min) 170 g, Phosphorus (min) 50 g, Methionine (min) 22 g, Vitamin A (min) 120000 IU, Vitamin D3 (min) 30000 IU, Vitamin E (min) 400 IU, Thiamine (B1) (min) 35 mg, Riboflavin (B2) (min) 130 mg, Pyridoxine (B6) (min) 60 mg, Vitamin B12 (min) 300 mg, Vitamin K3 (min) 30 mg, Biotin (min) 1.6 mg, Folic Acid (min) 20 mg, Niacin (min) 680 mg, Calcium Pantothenate (min) 200 mg, Choline (min) 400 mg, Sodium (min) 26 g, Manganese (min) 1600 mg, Zinc (min) 1380 mg, Copper (min) 160 mg, Iron (min) 630 mg, Iodine (min) 20 mg, Selenium (min) 6 mg, Phytase (min) 10000 F.T.U., Avilamycin 200 mg and Narasin+Nicarbazine

Table 3. Calculated composition of the experimental rations for broiler chickens aged 22--35 days.

	Growth 2 (22 to 35 days)							
	CON	80ENZ	160ENZ	240ENZ	SD0ENZ	SD80ENZ	SD160ENZ	SD240ENZ
Corn grain	57.19	57.18	57.18	57.17	54.45	54.46	54.44	54.43
Soybean meal	31.78	31.78	31.78	31.78	18.03	18.02	18.03	18.03
Deactivated soybean	0.00	0.00	0.00	0.00	20.00	20.00	20.00	20.00
Meat and bone meal 46%	1.71	1.71	1.71	1.71	1.60	1.60	1.60	1.60
Viscera meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Feather meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chicken fat	4.65	4.65	4.65	4.65	1.36	1.36	1.36	1.36
Salt	0.25	0.25	0.25	0.25	0.27	0.27	0.27	0.27
Sodium sulfate	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Limestone	0.80	0.80	0.80	0.80	0.81	0.81	0.81	0.81
Kaolin	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Methionine - MHA 80%	0.41	0.41	0.41	0.41	0.38	0.38	0.38	0.38
Lysine	0.46	0.46	0.46	0.46	0.42	0.42	0.42	0.42
Choline chloride	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04
Threonine 98%	0.11	0.11	0.11	0.11	0.08	0.08	0.08	0.08
L-Valine	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Phytase FC 10,000	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin premix for poultry	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mineral premix for poultry	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Antioxidant	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Flavoring additive	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enramycin	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salinomycin 24%	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Mananase enzyme	0.00	0.01	0.02	0.02	0.00	0.01	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The EMAn values were calculated on the basis of the European Table of Energy Values for Poultry Feedstuffs (WPSA; 3rd edition, 1989). The following parameters per kg of product were used: Calcium (max) 210 g, Calcium (min) 170 g, Phosphorus (min) 50 g, Methionine (min) 22 g, Vitamin A (min) 120000 IU, Vitamin D3 (min) 30000 IU, Vitamin E (min) 400 IU, Thiamine (B1) (min) 35 mg, Riboflavin (B2) (min) 130 mg, Pyridoxine (B6) (min) 60 mg, Vitamin B12 (min) 300 mg, Vitamin K3 (min) 30 mg, Biotin (min) 1.6 mg, Folic Acid (min) 20 mg, Niacin (min) 680 mg, Calcium Pantothenate (min) 200 mg, Choline (min) 400 mg, Sodium (min) 26 g, Manganese (min) 1600 mg, Zinc (min) 1380 mg, Copper (min) 160 mg, Iron (min) 630 mg, Iodine (min) 20 mg, Selenium (min) 6 mg, Phytase (min) 10000 F.T.U., Avilamycin 200 mg and Narasin+Nicarbazine

Table 4. Calculated composition of the experimental rations for broiler chickens aged 36--42 days.

	Final (36 a 42 dias)							
	CON	80ENZ	160ENZ	240ENZ	SD0ENZ	SD80ENZ	SD160ENZ	SD240ENZ
Corn Grain	65.40	65.39	65.38	65.38	62.75	62.74	62.74	62.75
Soybean Meal	25.56	25.56	25.56	25.56	11.73	11.73	11.73	11.73
Deactivated Soybean	0.00	0.00	0.00	0.00	20.00	20.00	20.00	20.00
Meat and Bone Meal 46%	0.44	0.44	0.44	0.44	0.32	0.32	0.32	0.32
Viscera Meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Feather Meal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chicken Fat	4.09	4.09	4.09	4.09	0.78	0.78	0.78	0.78
Salt	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.24
Sodium Sulfate	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Limestone	0.82	0.82	0.82	0.82	0.83	0.83	0.83	0.83
Kaolin	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Methionine - MHA 80%	0.32	0.32	0.32	0.32	0.29	0.29	0.29	0.29
Lysine	0.46	0.46	0.46	0.46	0.42	0.42	0.42	0.42
Choline Chloride	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
Threonine 98%	0.09	0.09	0.09	0.09	0.06	0.06	0.06	0.06
L-Valine	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01
Phytase FC 10,000	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vitamin Premix for Poultry	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Mineral Premix for Poultry	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Antioxidant	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Flavoring Additive	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Enramycin	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salinomycin 24%	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Mananase Enzyme	0.00	0.01	0.02	0.02	0.00	0.01	0.02	0.02
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The EMAn values were based on the European Table of Energy Values for Poultry feedstuffs (WPSA; 3rd edition, 1989). The following parameters per kg of product were used: Calcium (max) 210 g, Calcium (min) 170 g, Phosphorus (min) 50 g, Methionine (min) 22 g, Vitamin A (min) 120000 IU, Vitamin D3 (min) 30000 IU, Vitamin E (min) 400 IU, Thiamine (B1) (min) 35 mg, Riboflavin (B2) (min) 130 mg, Pyridoxine (B6) (min) 60 mg, Vitamin B12 (min) 300 mg, Vitamin K3 (min) 30 mg, Biotin (min) 1.6 mg, Folic Acid (min) 20 mg, Niacin (min) 680 mg, Calcium Pantothenate (min) 200 mg, Choline (min) 400 mg, Sodium (min) 26 g, Manganese (min) 1600 mg, Zinc (min) 1380 mg, Copper (min) 160 mg, Iron (min) 630 mg, Iodine (min) 20 mg, Selenium (min) 6 mg, Phytase (min) 10000 F.T.U., Avilamycin 200 mg and Narasin+Nicarbazine

Table 5. Calculated nutritional composition.

Composition (%):	Starter (1 – 7 days)	Growth (8 – 21 days)	Growth 2 (22 – 35ias)	Finisher (36 – 42 days)
Crude protein	23.926	22.830	21.7562	18.826
Crude fat	5.162	6.504	7.7473	7.2747
Calcium	1.011	0.907	0.822	0.661
Available phosphorus	0.482	0.432	0.384	0.309
Metabolizable energy (Kcal/kg)	3.000	3100.00	3.200.00	3.250.00
Digestible lysine	1.364	1.306	1.235	1.067
Digestible methionine	0.702	0.670	0.6155	0.5108
Digestible methionine + cystine	1.009	0.966	0.9139	0.7789
Digestible threonine	0.900	0.862	0.8151	0.7042
Digestible tryptophan	0.246	0.235	0.2223	0.1875
Digestible leucine	1.738	1.678	1.6192	1.463
Digestible valine	1.050	1.006	0.951	0.8109
Digestible arginine	1.470	1.398	1.3247	1.1203
Choline	1900	1723	1.600	1.400
Total sodium	0.227	0.220	0.211	0.201
Chlorine	0.300	0.240	0.23	0.21
Methionine + Cystine D/Lysine D	0.740	0.740	0.74	0.73
Threonine D/Lysine D	0.660	0.660	0.66	0.66
Tryptophan D/Lysine D	0.180	0.180	0.18	0.1757
Valine D/Lysine D	0.770	0.770	0.77	0.76
Arginine D/Lysine D	1.078	1.071	1.0727	1.05

D: digestível.

Results and discussion

As shown in Table 6, during the 1- to 21-day phases, DWG (daily weight gain), FI (feed intake), and AW (average weight) had significant effects ($p < 0.05$) on the diet in response to the addition of the β-mannanase enzyme, with quadratic polynomial breakdown. There was an interaction effect of Deactivated Soy × Enzyme ($p > 0.05$) on the FCR (feed conversion ratio). The other variables did not have a significant effect ($p > 0.05$). The inclusion of 240 mg of the β-mannanase enzyme had an effect on the growth phase from 1 to 21 days, resulting in higher AW and DWG and lower FI, and the control treatment had a lower FCR. The addition of the β-mannanase enzyme had an effect on feed conversion ($p < 0.05$); the control treatment had the greatest effect on feed conversion among the tested groups, as shown in Table 6.

Table 6. Performance of broilers aged 1 to 21 days fed diets containing deactivated soybeans with the inclusion of the β–mannanase enzyme.

Variables	Protein source	B−-mannanase Enzyme Levels						p value		
		0,00	0,800	0,160	0,240	Average	SEM	PS	LME	PS x LME
DWG	Soybean Meal	29.579	30.691	28.372	27.258	28.975				
	Deactivated Soybean	29.838	29.655	28.870	27.269	28.908	0,503	0.9254	0.0269	0.8788
	Average	29.708	30.173	28.621	27.264					
FCR	Soybean Meal	1.371	1.354	1.494	1.592	1.4531				
	Deactivated Soybean	1.462	1.450	1.474	1.498	1.4715	0,0212	0.5430	0.0048	0.0838
	Average	1.416	1.402	1.484	1.545					
FI	Soybean Meal	40.652B	41.805B	43.801	44.575A	42,708				
	Deactivated Soybean	43.294A	43.059A	43.809	41.349B	42,878	0,466	0.7982	0.2467	0.0188
	Average	41.973	42.432	43.805	42.962					
AW/21 days	Soybean Meal	0.666	0.688	0.6393	0.6183	0.653				
	Deactivated Soybean	0.673	0.668	0.651	0.616	0.652	0,0106	0.9719	0.0262	0.8851
	Average	0.669	0.678	0.645	0.617					

Variable	Regression equation	R^2	Effect	p value
DWG $bird^{-1}$ day^{-1}	$Y = 29.819+0.0059x-0.000071x^2$	0.096	quadratic	$p < 0.0001$
FCR	$Y = 1.411-0.000121x+0.000003x^2$	0.085	quadratic	$p < 0.0001$
AW/21 days	$Y = 0.672+0.000108x-0.000001x^2$	0.087	quadratic	$p < 0.0001$

[a]Means followed by different uppercase letters in the column differ significantly ($p < 0.05$). FCR: feed conversion ratio; DWG: daily weight gain; AW: average weight. PS: protein source. LME: Levels of β–mananase enzyme. PS × LME: Interaction between protein source and levels of β–mananase enzyme. SEM: standard error of the mean.

According to Ribeiro, Vogt, Canal, Laganá, and Streck (2008), modern chickens have a low capacity for thermoregulation and are much more sensitive to heat than to cold. The calorific increment, which is the heat generated in the process of digestion, absorption, and metabolism of nutrients, can affect their production.

Musharaf and Latshaw (1999) reported that protein and fiber provide greater caloric increases during the digestion process than fat and starch do, which can increase the internal temperature of the animal and impair its performance.

According to Araujo, Monção, and Vieira (2017), food consumption and metabolism have a thermogenic effect that increases heat production in birds. The consumption of feed is inversely related to the ambient temperature at which the broilers are raised. The voluntary reduction in feed intake observed in birds exposed to heat occurs to avoid excessive calorific increment production (Cordeiro et al., 2010).

Thus, the greater consumption of feed by birds in the initial phase can be explained by the lower crude protein content of deactivated soybeans than of soybean meal, which therefore has a lower thermogenic effect on birds, a fact that encouraged animal consumption. Fischer et al. (2001) evaluated the inclusion of an enzymatic complex in the 1–7-day phase on the basis of proteases, amylases, and cellulases in diets based on corn and soybean meal, with normal and overestimated protein, energy, and amino acid contents.

They reported that adding the enzymatic complex did not have a significant effect, and the efficiency of the enzyme with overestimated protein, energy, and amino acid values was not proven. Research has demonstrated positive responses regarding nutrient digestibility and bird performance when fed diets based on corn and soy supplemented with enzymes such as carbohydrates, proteases, pectinases, and alpha-galactosidases (Opalinski, Maiorka, Cunha, Silva, & Borges, 2006).

Sureshkumar et al. (2023) reported that young animals have low nutritional utilization due to their intestinal enzymatic profile, which was also observed in this study, but the same authors reported that the use of exogenous enzymes in diets improved feed digestibility, compensating for the reduced size of the digestive system compared with that of older animals.

Opalinsk et al. (2006) reported that the optimal level of addition of an enzymatic complex (xylanase, α-glucanase, mannanase, pectinase, or protease) for weight gain and feed intake (1–42 days of age) is 45.94 g t^{-1} of enzyme in the feed and 49.30 g t-1 of enzyme in the feed, respectively. Exogenous enzymes increase the availability of compounds for intestinal absorption, alleviate the impact of persistent antinutritional factors after food processing, and can complement nutritional intake by degrading nonstarch polysaccharides (Jacobsen et al., 2018).

Table 7 shows the performance of the birds from 22--42 days. The inclusion of SDs had a significant interaction effect ($p < 0.05$) with FI. The inclusion of SD associated with the levels of the enzyme in mg kg-1 of FI resulted in a greater increase than the combination of soybean meal with FI. There was no difference ($p > 0.05$) in feed conversion or AW at 21 days.

The type of protein had an effect on the FCR ($p < 0.05$), which was greater in the SD treatment group. As reported by Opalinsk et al. (2011), the addition of exogenous enzymes to diets and the use of technologies aiming to alter the physical structure of ingredients aim to seek alternatives that can reduce the action of antinutritional compounds and improve food digestibility. This fact is responsible for the greater digestibility of nutrients and better zootechnical performance results, as observed in the present study.

Table 7. Performance of broiler chickens aged 22--42 days fed diets containing deactivated soybeans with elevated β–mannanase enzyme levels.

Variables	Protein source	B--mannanase Enzyme Levels					SEM	p value		
		0,00	0,800	0,160	0,240	Average		PS	LME	PS x LME
DWG bird day^{-1}	Soybean Meal	67.721B	67.330B	69.570A	67.218B	67.960	1,227	0.01652	0.9887	0.00850
	Deactivated Soybean	70.683A	71.339A	69.441A	70.135A	70.400				
	Average	69.202	69.334	69.506	68.676					
FCR	Soybean Meal	1.969	2.157	1.948	1.986	2.015	0,0482	0.9426	0.6597	0.6236
	Deactivated Soybean	2.052	2.022	2.036	1.970	2.020				
	Average	2.010	2.090	1.992	1.978					
FI	Soybean Meal	131.665	137.567	134.556	132.296	134.02B	1,370	0.0025	0.2716	0.5438
	Deactivated Soybean	142.705	142.453	138.577	136.884	140.15A				
	Average	137.185	140.010	136.566	134.590					
AW/42 days	Soybean Meal	2.088	2.124	2.109	2.042	2.091	0,028	0.3236	0.5800	0.9669
	Deactivated Soybean	2.153	2.164	2.117	2.089	2.131				
	Average	2.121	2.144	2.113	2.066					

[a]Means followed by different uppercase letters in the column differ significantly ($p < 0.05$). FCR: feed conversion ratio; DWG: daily weight gain; AW: average weight. PS: protein source. LME: Levels of β–mananase enzyme. PS × LME: Interaction between protein source and levels of β–mananase enzyme. SEM: standard error of the mean.

The composition of feed is a fundamental factor for the nutrition of production animals; the use of digestive enzymes can increase the digestibility of feed by complementing endogenous enzymes and increasing the rate of degradation and absorption of the nutrients present in the diet (Dalólio et al., 2015). According to Silva et al. (2016), the increased intestinal viscosity caused by the presence of naturally occurring proteins in poultry feed acts as a barrier between endogenous enzymes, the substrate, and the digestion products, influencing food digestibility. Thus, the use of exogenous enzymes such as β-mannanase can be efficient in digesting these nutrients.

This fact may have led to the better performance of birds even when fed diets supplemented with deactivated soybeans, which are an ingredient that contains a greater quantity of no starch polysaccharides, resulting in a greater AW with the addition of the β-mannanase enzyme. As reported by Barbosa et al. (2014), the use of enzymes assists in the breakdown of specific molecules contained in feed, favoring the utilization of phosphorus, calcium, amino acids, and energy, resulting in better productive performance and cost savings in the final production, in addition to benefiting the environment.

According to Ludke, Lima, Lanznaster, and Ardigó (2007), raw soybeans contain substances that inhibit the utilization of proteins and other nutrients in the diet of monogastric animals. Among these antinutritional factors, hemagglutinins, biogenic factors, saponins, lectins, and trypsin inhibitors stand out. The thermal processing of soybeans favors the inactivation of these factors, which can impair nutrient absorption by birds, resulting in better digestion and absorption and consequently improved animal performance, as demonstrated in the present study, where the results related to treatments with the inclusion of deactivated soybeans were superior to those with regular soybean meal.

The better performance results regarding the use of deactivated soybeans are directly related to the processing of the product, which ensures greater nutrient availability, especially amino acids composing the proteins present in soy, making them more bioavailable and better utilized by the animal. Rocha et al. (2014) reported that processing increases the efficiency of providing protein to feed, improving its digestibility, considering that heat can interfere with this percentage.

Another point to be evaluated is regarding the substrate for enzymatic action, as reported by Nunes, Broch, Polese, Eyng, and Pozza (2015). Deactivated soybeans are a raw material of high organoleptic quality, with amino acids and energy of better availability for the animal, and the interaction between deactivated soybeans and the β-mannanase enzyme occurs through this beneficial use of the substrate with the enzyme.

Table 8 shows the performance of broilers from days 1 to 35. There was an interaction effect ($p < 0.05$) for the factors Deactivated Soy versus FI regarding DWG and an isolated effect ($p < 0.05$) for the variable FCR concerning the type of soy used, with the treatment with deactivated soy having a greater FCR.

Improvements in the activity of enzymes are important for the digestibility of polysaccharides; thus, the addition of the β-mannanase enzyme to feed improves nutrient digestion in the initial part of the digestive tract, resulting in better energy and amino acid utilization. In contrast to Costa, Figueirêdo, Moreira Filho, Ribeiro, and Lima (2015), who conducted a trial with processed soybeans (extruded whole soybeans and semiextruded whole soybeans) and degummed soybean oil, in the growth and finishing phase, Costa et al. (2015) reported that diet only affected feed conversion in birds.

According to Barbosa et al. (2014), the effects of adding enzymes and enzymatic complexes on production and metabolism variables may be due to a series of factors, with the main factors being the type of diet and the form of enzyme supplementation. In general, the superior performance of deactivated soy compared with the control treatment (without deactivated soy) is due to the nutritional characteristics of this ingredient, along with the supplementation of the β-mannanase enzyme, which increases the availability of nutrients for animal absorption.

Table 8. Performance of broiler chickens aged 1 to 42 days fed diets containing deactivated soybeans with elevated β–mannanase enzyme levels.

Variables	Protein source	B–-mannanase Enzyme Levels						p value		
		0,00	0,800	0,160	0,240	Average	SEM	PS	LME	PS x LME
DWG bird day^{-1}	Soybean Meal	48.650B	49.010B	48.971B	47.238B	48.467	0,701	0.0236	0.6062	0.0415
	Deactivated Soybean	50.261A	50.497A	49.155A	48.702A	49.654				
FCR	Soybean Meal	1.670	1.756	1.721	1.789	1.734	0,0258	0.7470	0.8249	0.5436
	Deactivated Soybean	1.757	1.736	1.755	1.734	1.746				
	Average	1.713	1.746	1.738	1.761					
FI	Soybean Meal	86.159 A	89.686	89.178	88.436	88.365B	0,789	0.0066	0.4710	0.2506
	Deactivated Soybean	93.00B	92.756	91.193	89.116	91.516A				
	Average	89.579	91.221	90.185	88.776					

[a]Means followed by different uppercase letters in the column differ significantly ($p < 0.05$). FCR: feed conversion ratio; DWG: daily weight gain; AW: average weight. PS: protein source. LME: Levels of β–mananase enzyme. PS × LME: Interaction between protein source and levels of β–mananase enzyme. SEM: standard error of the mean.

Cowieson, Aureli, Guggenbuhl, and Fru-Nji (2014) reported that protein digestibility in response to enzymes depends on their interaction with the provided food; that is, the efficacy of the protein reflects the quantity of substrate and enzymes present in the intestine, whether of endogenous or exogenous origin, a finding that corroborates what happened in this study regarding the interaction of the β-mannanase enzyme and deactivated soy included in the diet, interfering with improvements in animal performance.

As highlighted by Nunes et al. (2015), whole soybeans, owing to their high protein and energy contents, present themselves as raw materials with economic advantages in the manufacture of poultry feed. The processing of this feedstuff increases the coefficient of amino acid digestibility, meeting the nutritional requirements of poultry, improving performance, and reducing feed costs.

Conclusion

The use of deactivated soybeans combined with the supplementation of 240 mg of β-mannanase enzyme in the diet of broiler chickens from 1--42 days of age is recommended, as it favors the productive performance of the birds.

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