R. Bras. Zootec., 51:e20210203, 2022
https://doi.org/10.37496/rbz5120210203

Non-ruminants
Full-length research article

Revista Brasileira de Zootecnia

Brazilian Journal of Animal Science
e-ISSN 1806-9290
www.rbz.org.br

Effects of *Moringa oleifera* leaf meal on performance and carcass yield of broilers

Gabriel Miranda Macambira[1], Carlos Bôa-Viagem Rabello[1], Manuel Isidoro Valdivie Navarro[2], Cláudia da Costa Lopes[3]*, Elainy Cristina Lopes[1], Guilherme Rodrigues do Nascimento[4], Helia Sharlane de Holanda Oliveira[1], Jaqueline de Cássia Ramos da Silva[1]

[1] Universidade Federal Rural de Pernambuco, Departamento de Zootecnia, Programa de Pós-Graduação em Zootecnia, Recife, PE, Brasil.
[2] Instituto de Ciencia Animal, San Jose de las Lajas, Mayabeque, Cuba.
[3] Universidade Federal do Rio Grande do Norte, Unidade Acadêmica Especializada em Ciências Agrárias, Programa de Pós-Graduação em Produção Animal, Macaíba, RN, Brasil.
[4] Instituto Federal Baiano, Campus Santa Inês, Santa Inês, BA, Brasil.

***Corresponding author:**
cclway@yahoo.com.br

Received: November 4, 2021
Accepted: April 1, 2022

How to cite: Macambira, G. M.; Rabello, C. B. V.; Navarro, M. I. V.; Lopes, C. C.; Lopes, E. C.; Nascimento, G. R.; Oliveira, H. S. H. and Silva, J. C. R. 2022. Effects of *Moringa oleifera* leaf meal on performance and carcass yield of broilers. Revista Brasileira de Zootecnia 51:e20210203. https://doi.org/10.37496/rbz5120210203

ABSTRACT - This study evaluated the effects of including *Moringa oleifera* (moringa) leaf meal on performance, carcass yield and characteristics, and relative organ weights of broilers from 10 to 42 days of age. We distributed 420 male Cobb 500 chicks in a completely randomized design with five treatments and six replicates with 14 birds each. Treatments consisted of five experimental diets in which the moringa leaf meal was included at 0, 1.5, 3.0, 4.5, and 6.0% in the diets. The following performance variables were evaluated: weight gain, feed intake, and feed conversion; weights and yields of carcass, carcass traits, organs, and abdominal fat; and feet color. Significant differences between the treatment means were analyzed by Dunnett's test. The meal inclusion levels did not affect performance, carcass characteristics and yield, or organs weight. However, feet pigmentation increased linearly, and abdominal fat was greater only at the 1.5% level when compared with the control group. Moringa leaf meal can be included in the diet of broilers from 10 to 42 days of age, up to the level of 6%, without compromising performance or carcass yield of these birds.

Keywords: broiler, carcass traits, carotenoids, performance

1. Introduction

At present, Brazil is the third largest broiler producer in the world, ranking only after the USA and China. It is also the biggest exporter of poultry, having exported 4,214,000 t in 2019 (ABPA, 2020). The growing globalization and adoption of new technologies, alongside improvements in biosafety, facilities, and equipment and the competence of professionals in the area, has led the Brazilian poultry farming activity to these great achievements (Amorim et al., 2015).

As an important part of animal production, the diet represents the component of highest cost of the sector, surpassing 70% of total costs. However, these costs are closely related to the availability of ingredients commonly used in the formulation of diets. In this regard, corn and soybean meal together can account for approximately 90% of the total volume of a diet, but because they are commodities, these products are subject to price fluctuations in the market. Bearing that in mind, researchers in the nutrition field have looked into alternative feedstuffs aiming to reduce production costs without compromising animal production performance (Ribeiro et al., 2010; Amorim et al., 2015; Ayaşan et al., 2020; Ülger et al., 2020a; Ülger et al., 2020b).

The prohibition of the use of antibiotics in poultry production in several countries around the world has led nutritionists nowadays to seek foods, mostly plants, which, in addition to having good nutritional profiles, also promote growth effects in birds (Anwar et al., 2017; Ulger et al., 2017; Cheng et al., 2019; Ekizoğlu et al., 2020). Several plants known for their beneficial effects on human nutrition have been researched as alternative ingredients in animal feeding. *Moringa oleifera* (herein referred to as "moringa"), a plant belonging to the family Moringaceae, has great potential for use in poultry feeding, given its high levels of important compounds such as essential amino acids, antioxidants, and lipids (Makkar and Becker, 1997; Mbikay, 2012). Studies have proved its nutritional and pharmacological potential in humans (Nkukwana et al., 2014), and some have confirmed its high ability to potentiate growth, weight gain, and carcass yield of broilers (Zanu et al., 2012; Nkukwana et al., 2014).

The present study evaluated the effects of feeding broilers from 10 to 42 days of age a diet including *Moringa oleifera* leaf meal on performance, carcass yield and characteristics, and relative organ weight of these birds.

2. Material and Methods

This experiment was conducted according to the recommendations of the local Committee of Ethics in Animal Use (License no. 23082.000497/2015), in Recife, PE, Brazil (latitude 8°04'03" S, longitude 34°55'00" W, and 4 m above sea level) localized in the physiographic micro region of Litoral Mata, belonging to the Metropolitan Region of Recife.

A total of 420 male Cobb 500 chicks in the period from 10 to 42 days of age, with an average initial weight of 256 g (10 day old), were housed in a prefabricated shed divided into cages, at a density of 10 birds/m^2. Cages were equipped with nipple drinkers and trough feeders and lined with sugarcane bagasse bedding. During the entire experimental period, a constant illumination program (24 h) was adopted.

During the first 10 days, the animals received a standard diet based on corn and soybean meal and were subsequently distributed in the experimental treatments. The feeding program consisted of three diets, as follows: starter (10 to 21 days of age), grower (21 to 35 days of age), and finisher (35 to 42 days of age). Feed and water were provided *ad libitum*. Temperature and relative humidity were recorded throughout the entire experimental period, using a data logger; mean values for these variables were 29.7 °C and 70.1%, respectively.

The broilers were distributed in a completely randomized design composed of five treatments and six replicates with 14 birds per experimental unit. Treatments consisted of five experimental diets in which the moringa leaf meal was included in the proportions of 0, 1.5, 3.0, 4.5, and 6.0% (as-fed basis) (Tables 1, 2, and 3).

The nutritional values of the feedstuffs used in the formulation of the experimental diets were obtained from feed composition tables proposed by Rostagno et al. (2011), whereas the nutritional content of the moringa leaf meal used in this experiment (Table 4) was obtained from chemical analyses following methods described by Silva and Queiroz (2002). The metabolizable energy value of *Moringa oleifera* used for the formulation of feed was that found by Macambira et al. (2018).

To obtain the *Moringa oleifera* leaf meal, moringa leaves and petioles were collected with an interval of 45 days between cuts, aiming to combine the great production of green matter and nutritional value of the leaves. The plants were cut at a height of approximately 60 cm from the ground. After cutting, the entire production was ground in forage and the material was housed in a shed to dry until weight stabilized. The material was then ground in a vertical mill to obtain leaf bran.

Table 1 - Centesimal composition and nutritional values of starter diets from 10 to 21 days of age

Ingredient	Moringa leaf meal inclusion level (%)				
	0	1.5	3.0	4.5	6.0
Corn	56.87	55.89	54.92	53.94	52.96
Moringa leaf meal	0.00	1.50	3.00	4.50	6.00
Soybean meal	35.93	35.28	35.62	33.96	33.31
Calcitic limestone	0.950	0.940	0.940	0.940	0.940
Soybean oil	3.290	3.390	3.480	3.570	3.670
Dicalcium phosphate	1.560	1.570	1.580	1.590	1.600
Mineral-vitamin premix[1]	0.200	0.200	0.200	0.200	0.200
Salt (NaCl)	0.400	0.400	0.400	0.400	0.400
L-Lysine HCl 78.8	0.240	0.250	0.260	0.271	0.281
DL-Methionine 99	0.311	0.316	0.320	0.324	0.329
L-Threonine 98.5	0.121	0.125	0.129	0.134	0.138
Sodium bicarbonate	0.081	0.092	0.103	0.115	0.126
Anticoccidian	0.050	0.050	0.050	0.050	0.050
Total	100.00	100.00	100.00	100.00	100.00
Energetic and nutritional composition (calculated values)					
Apparent metabolizable energy (MJ/kg)	12.76	12.76	12.76	12.76	12.76
Crude protein (%)	21.20	21.20	21.20	21.20	21.20
Crude fiber[2] (%)	2.89	2.97	3.03	3.08	3.15
Calcium (%)	0.841	0.841	0.841	0.841	0.841
Available phosphorus (%)	0.401	0.401	0.401	0.401	0.401
Sodium (%)	0.210	0.210	0.210	0.210	0.210
Chlorine (%)	0.190	0.190	0.190	0.190	0.190
Potassium (%)	0.585	0.585	0.585	0.585	0.585
Digestible amino acids (%)					
Lysine	1.217	1.217	1.217	1.217	1.217
Methionine + cystine	0.876	0.876	0.876	0.876	0.876
Methionine	0.475	0.475	0.475	0.475	0.475
Threonine	0.791	0.791	0.791	0.791	0.791
Tryptophan	0.207	0.207	0.207	0.207	0.207

[1] Quantity per kg of product: folic acid, 150 mg; pantothenic acid, 13,500 mg; biotin, 40 mg; copper, 1400 mg; iron, 6000 mg; iodine, 915 mg; manganese, 17 g; zinc, 38 g; niacina, 13 g; selenium, 300 mg; vitamin A, 5,000,000 IU; vitamin D3, 1,600,000 IU; vitamin E, 4000 UI; vitamin K3, 1000 mg; vitamin B6, 250 mg; vitamin B12, 6500 mg.
[2] Calculated from the values of crude fiber obtained by Oliveira (2019).

Broilers and feed leftovers were weighed weekly to determine the performance parameters: feed intake, weight gain, and feed conversion.

At the end of the experimental period, two birds with the average weight of each experimental unit were fasted for 12 h and then weighed, stunned, slaughtered, and evaluated for the yields of carcass and cuts (drumstick, thigh, breast, wing, and back); abdominal fat, edible viscera (heart, liver, and gizzard), non-edible viscera (intestines and proventriculus); weight of organs from the immune system (bursa and spleen), and feet color (using a DSM color fan).

For feet color, there were three evaluations in each broiler and, after that, mean values were calculated. With the help of a measuring tape, the length of the small intestine and large intestine were measured. The small intestine was separated where the duodenum emerges from the cloaca and at the beginning of cecum. The large intestine length was obtained from sum of the lengths of the colon, rectum, and ceca.

Table 2 - Centesimal composition and nutritional values of starter diets from 22 to 35 days of age

Ingredient	Moringa leaf meal inclusion level (%)				
	0	1.5	3.0	4.5	6.0
Corn	59.85	59.03	58.21	57.39	56.57
Moringa leaf meal	0.00	1.50	3.00	4.50	6.00
Soybean meal	32.35	31.69	31.03	30.36	29.70
Calcitic limestone	0.890	0.810	0.740	0.660	0.580
Soybean oil	4.220	4.260	4.300	4.330	4.370
Dicalcium phosphate	1.330	1.340	1.340	1.340	1.350
Mineral-vitamin premix[1]	0.180	0.180	0.180	0.180	0.180
Salt (NaCl)	0.321	0.322	0.323	0.323	0.324
L-Lysine HCl 78.8	0.240	0.250	0.260	0.270	0.280
DL-Methionine 99	0.293	0.297	0.301	0.304	0.308
L-Threonine 98.5	0.072	0.077	0.082	0.086	0.091
Sodium bicarbonate	0.200	0.200	0.200	0.200	0.200
Anticoccidian	0.050	0.050	0.050	0.050	0.050
Total	100.00	100.00	100.00	100.00	100.00
Energetic and nutritional composition (calculated values)					
Apparent metabolizable energy (MJ/kg)	13.19	13.19	13.19	13.19	13.19
Crude protein (%)	19.80	19.80	19.80	19.80	19.80
Crude fiber[2] (%)	3.75	3.84	3.98	4.05	4.10
Calcium (%)	0.578	0.578	0.578	0.578	0.578
Available phosphorus (%)	0.354	0.354	0.354	0.354	0.354
Sodium (%)	0.200	0.200	0.200	0.200	0.200
Chlorine (%)	0.180	0.180	0.180	0.180	0.180
Potassium (%)	0.580	0.580	0.580	0.580	0.580
Digestible amino acids (%)					
Lysine	1.131	1.131	1.131	1.131	1.131
Methionine + cystine	0.826	0.826	0.826	0.826	0.826
Methionine	0.452	0.452	0.452	0.452	0.452
Threonine	0.735	0.735	0.735	0.735	0.735
Tryptophan	0.204	0.204	0.204	0.204	0.204

[1] Quantity per kg of product: folic acid, 150 mg; pantothenic acid, 13,500 mg; biotin, 40 mg; copper, 1400 mg; iron, 6000 mg; iodine, 915 mg; manganese, 17 g; zinc, 38 g; niacina, 13 g; selenium, 300 mg; vitamin A, 5,000,000 IU; vitamin D3, 1,600,000 IU; vitamin E, 4000 IU; vitamin K3, 1000 mg; vitamin B6, 250 mg; vitamin B12, 6500 mg.
[2] Calculated from the values of crude fiber obtained by Oliveira (2019).

Carcass yield was calculated as the ratio between carcass weight without viscera and feet and live weight after fasting. Organ yield was determined as the weight of an organ divided by the live weight of the animal after fasting. Lastly, yield of prime cuts was calculated as the relationship between the type of cut and the carcass weight (without viscera and feet).

The results obtained for all variables were subjected to the regression analysis. Data also were subjected to analysis of variance and, in case of significant differences, the means were compared by Dunnett's test. Data were considered significant at the 5% probability level.

The following statistical model was used:

$$Y_{ij} = \mu + T_i + e_{ij},$$

Table 3 - Centesimal composition and nutritional values of starter diets from 36 to 42 days of age

Ingredient	Moringa leaf meal inclusion level (%)				
	0	1.5	3.0	4.5	6.0
Corn	64.11	63.29	62.47	61.65	60.23
Moringa leaf meal	0.00	1.50	3.00	4.50	6.00
Soybean meal	28.48	27.81	27.15	26.46	25.82
Calcitic limestone	0.800	0.720	0.640	0.570	0.490
Soybean oil	4.140	4.180	4.220	4.260	4.300
Dicalcium phosphate	1.120	1.130	1.130	1.130	1.140
Mineral-vitamin premix[1]	0.180	0.180	0.180	0.180	0.180
Salt (NaCl)	0.309	0.309	0.310	0.311	0.312
L-Lysine HCl 78.8	0.267	0.277	0.287	0.297	0.307
DL-Methionine 99	0.272	0.276	0.279	0.283	0.287
L-Threonine 98.5	0.076	0.080	0.085	0.090	0.095
Sodium bicarbonate	0.200	0.200	0.200	0.200	0.200
Anticoccidian	0.050	0.050	0.050	0.050	0.050
Total	100.00	100.00	100.00	100.00	100.00
Energetic and nutritional composition (calculated values)					
Apparent metabolizable energy (MJ/kg)	13.40	13.40	13.40	13.40	13.40
Crude protein (%)	18.40	18.40	18.40	18.40	18.40
Crude fiber[2] (%)	3.80	3.91	4.02	4.08	4.16
Calcium (%)	0.663	0.663	0.663	0.663	0.663
Available phosphorus (%)	0.309	0.309	0.309	0.309	0.309
Sodium (%)	0.195	0.195	0.195	0.195	0.195
Chlorine (%)	0.170	0.170	0.170	0.170	0.170
Potassium (%)	0.580	0.580	0.580	0.580	0.580
Digestible amino acids (%)					
Lysine	1.060	1.060	1.060	1.060	1.060
Methionine + cystine	0.774	0.774	0.774	0.774	0.774
Methionine	0.424	0.424	0.424	0.424	0.424
Threonine	0.689	0.689	0.689	0.689	0.689
Tryptophan	0.191	0.191	0.191	0.191	0.191

[1] Quantity per kg of product: folic acid, 150 mg; pantothenic acid, 13,500 mg; biotin, 40 mg; copper, 1400 mg; iron, 6000 mg; iodine, 915 mg; manganese, 17 g; zinc, 38 g; niacin, 13 g; selenium, 300 mg; vitamin A, 5,000,000 IU; vitamin D3, 1,600,000 IU; vitamin E, 4000 IU; vitamin K3, 1000 mg; vitamin B6, 250 mg; vitamin B12, 6500 mg.
[2] Calculated from the values of crude fiber obtained by Oliveira (2019).

in which Y_{ij} = value observed for the response variable Y in treatment i and its repetition j; μ = general average of all observations; T_i = treatment effect (0, 1.5, 3.0, 4.5, and 6.0% of moringa leaf meal/kg); and e_{ij} = experimental error associated with the observed value Y_{ij}.

3. Results

Moringa leaf meal levels in the diets had no significant effects the performance variables (weight gain, feed intake, or feed conversion) in any of the phases evaluated (Table 5).

No significant effects of moringa leaf meal levels were detected on live weight; weights of carcass, breast, drumstick + thigh, wing, back, and organs (heart, liver, gizzard, proventriculus, weight and length of the small and large intestines, bursa, and spleen); or their yields (Table 6).

Table 4 - Chemical composition of moringa leaf meal (dry matter basis)

Nutrient		Total amino acids (%)[1]	
Dry matter (%)	90.13	Methionine	0.372
Crude protein (%)[2]	25.87	Cystine	0.300
Neutral detergent fiber (%)	40.32	Methionine + cystine	0.671
Acid detergent fiber (%)	20.10	Lysine	1.162
Mineral matter (%)	15.94	Threonine	0.945
Ether extract (%)	6.31	Tryptophan	-
Metabolizable energy (MJ/kg)[3]	11.91	Arginine	1.131
		Isoleucine	0.932
		Leucine	1.709
		Valine	1.170
		Histidine	0.465
		Phenylalanine	1.319
		Glycine	1.264
		Serina	0.966
		Proline	0.969
		Alanine	1.279
		Aspartic acid	2.003
		Glutamic acid	2.914

[1] Values determined by the company Evonik by high-performance liquid chromatography (HPLC).
[2] Value determined by Kjeldahl method.
[3] Value determined by Macambira et al. (2018).

Table 5 - Performance of broilers from 10 to 42 days of age fed moringa leaf meal

Variable	Moringa leaf meal inclusion level (%)					RE	SD	P	CV (%)
	0	1.5	3.0	4.5	6.0				
					10 to 21 days old				
WG (g/bird)	618	620	616	577	589	NS	43	0.298	6.95
FI (g/bird)	908	954	912	915	912	NS	44	0.589	5.95
FC (g/g)	1.473	1.540	1.482	1.593	1.560	NS	0.124	0.417	8.12
					10 to 35 days old				
WG (g/bird)	1808	1816	1896	1809	1807	NS	902	0.735	7.29
FI (g/bird)	2881	3013	3073	3028	3057	NS	138	0.112	4.27
FC (g/g)	1.597	1.663	1.627	1.678	1.693	NS	0.061	0.148	4.22
					10 to 42 days old				
WG (g/bird)	2148	2116	2085	2053	2021	NS	177	0.744	8.82
FI (g/bird)	3440	3448	3455	3463	3471	NS	259	0.903	5.99
FC (g/g)	1.605	1.633	1.681	1.689	1.717	NS	0.105	0.144	13.78

WG - weight gain; FI - feed intake; FC - feed conversion; NS - not significantly different; RE - regression equation; P - probability; SD - standard deviation; CV - coefficient of variation.

Abdominal fat did not have a significant effect on the regression equations; however, when the test of means was performed, we observed that only at the 1.5% inclusion level of the moringa did it increase abdominal fat when compared with the control group.

Feet color values increased linearly as the levels of moringa leaf meal in broiler diets were increased (Figure 1).

Table 6 - Weights and yields of carcass and organs of broilers fed moringa leaf meal

Variable	Moringa leaf meal inclusion level (%)					RE	SD	P	CV (%)
	0	1.5	3.0	4.5	6.0				
Final weight (g)	2522	2478	2478	2478	2497	NS	188.57	0.974	7.81
Carcass (g)	1.855	1.853	1.850	1.854	1.909	NS	0.13	0.781	7.17
Breast (g)	636	643	648	658	682	NS	0.68	0.521	10.45
Drumstick + thigh (g)	570	546	563	554	570	NS	0.47	0.678	8.51
Wings (g)	185	187	179	185	191	NS	0.15	0.436	7.99
Back (g)	323	337	315	329	318	NS	0.31	0.444	9.54
Heart (g)	13.16	13.10	14.33	14.49	13.75	NS	2.26	0.436	16.46
Gizzard (g)	36.57	37.90	36.30	40.41	38.27	NS	6.41	0.444	15.38
Liver (g)	54.00	49.23	56.88	52.62	54.04	NS	7.98	0.142	13.22
Proventriculus (g)	8.860	8.778	8.738	9.308	8.808	NS	1.29	0.826	14.86
Small intestine (g)	83.10	82.94	79.30	83.72	75.86	NS	14.97	0.676	18.76
Large intestine (g)	20.68	18.38	20.47	22.94	19.75	NS	5.93	0.449	29.09
Small intestine (cm)	169.13	170.13	170.71	174.96	167.58	NS	19.63	0.924	11.83
Large intestine (cm)	24.71	24.71	27.13	25.54	25.04	NS	3.50	0.416	13.76
Abdominal fat (g)	37.59a	49.96b	40.43a	35.80a	39.23a	NS	11.73	0.026	27.11
Spleen (g)	2.869	3.463	3.581	3.380	3.046	NS	0.96	0.392	29.14
Bursa of Fabricius (g)	2.404	2.608	2.473	2.461	2.088	NS	0.95	0.754	40.33
					Yield (%)				
Carcass	74.67	74.81	74.69	74.88	75.48	NS	2.98	0.747	2.10
Breast	34.28	34.70	35.08	35.48	35.64	NS	2.16	0.542	6.22
Drumstick + thigh	30.77	29.44	30.41	29.94	29.98	NS	1.48	0.228	4.84
Wings	9.90	10.10	9.72	10.06	10.02	NS	0.60	0.545	6.07
Back	17.41	18.13	17.09	17.80	16.69	NS	1.17	0.019	6.28
Heart	0.523	0.530	0.580	0.585	0.553	NS	0.09	0.391	16.05
Gizzard	1.447	1.532	1.465	1.632	1.545	NS	0.23	0.208	13.52
Liver	2.143	1.981	2.300	2.128	2.178	NS	0.29	0.067	11.85
Abdominal fat	1.496a	2.013b	1.633a	1.431a	1.574a	NS*	0.46	0.013	25.93

NS - not significantly different; RE - regression equation; P - probability; SD - standard deviation; CV - coefficient of variation.
a-b - Means with the same letters are not significantly different by Dunett's test (P>0.05).
* P = 0.0502.

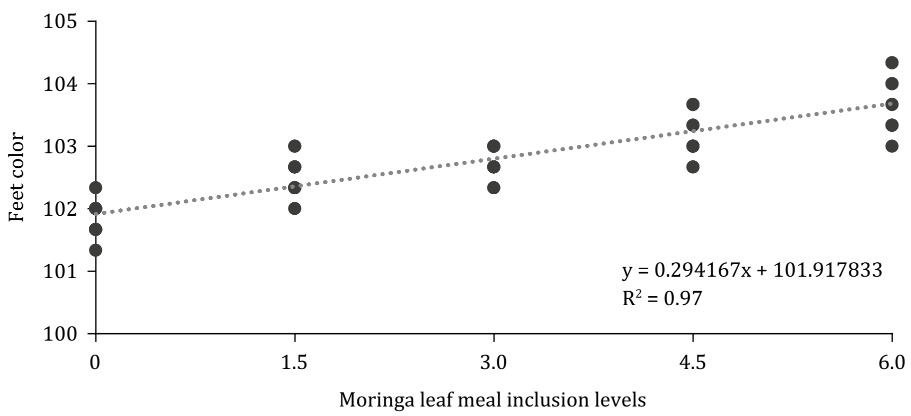

Figure 1 - Feet color of broilers fed moringa leaf meal.

4. Discussion

The use of forage plants in the feeding of non-ruminants has always been restricted due to their negative effects on animal performance. These feedstuffs are known for having a large amount of fiber, worsening feed conversion, having in some cases high concentrations of anti-nutritional factors, and reducing the nutrient usage potential by the animal (Xiao et al., 2012). By contrast, studies have shown that inclusion of small amounts of forage species may benefit the animal performance because of their growth-promoting properties (Banjo, 2012; Nkukwana et al., 2014; Nkukwana et al., 2015; Cui et al., 2018).

Most studies use estimated metabolizable energy (ME) values using ingredient composition or feeds with similar composition, such as alfalfa, or simply do not report how the values were determined (Olugbemi et al., 2010; Ayssiwede et al., 2011; Nkukwana et al., 2014; Nkukwana et al., 2015; Kaijage et al., 2015), which may explain part of the wide variation in results found between different studies. Taking this into account, in a previous work by our research group, developed by Macambira et al. (2018), we determined the ME values of *Moringa oleifera in vivo* in a metabolism assay, and the value found (11.91 MJ/kg) was used for the formulation of rations. Thus, the results of this study characterize a new approach to the use of this plant in the feeding of fast-growing broilers.

The literature is highly controversial with respect to the use of moringa in poultry feeding. Nkukwana et al. (2014) worked with diets containing moringa levels ranging from 1 to 5% and observed that on the 35th day of life of the birds, the groups fed diets containing the highest levels had a higher final weight and worse feed conversion than the control group. These authors used moringa with an ME content of 2,723 kcal/kg and 26.76% crude protein, which is a similar composition to that used in the present study (Table 4), but our results indicated the opposite response at 35 days of age, in which performance variables were not affected.

The present findings are similar to those found by Atuahene et al. (2008), who did not also observe differences in feed intake or weight gain. However, the authors reported worse feed conversion in broilers fed diets containing moringa at the levels of 0, 2.5, 5, and 7.5% when compared with control group. Other studies have also shown similar results (Elbashier and Ahmed, 2016).

Zanu et al. (2012) worked with moringa leaf meal inclusion levels of 5, 10, and 15% and observed a reduction of weight gain with inclusion of 15% of the meal, and worse feed conversion. Likewise, Olugbemi et al. (2010) included different proportions of moringa leaf meal (5 and 10%) in cassava chip-based diets and obtained lower weight gain, higher feed intake, and worse feed conversion in broilers.

According to Ash et al. (1992), inclusion of moringa leaf meal in broiler diets at levels greater than 10% lead to an increase in feed conversion and feed intake, besides a reduction in weight gain and final weight of animals. The variations in broiler performance found in the literature as a function of moringa inclusion in the diet may stem from differences observed in the chemical composition of this ingredient, especially in terms of fiber. Several factors are known to interfere with the nutritional composition of a forage plant, e.g., age, soil-climatic conditions of the area where the plant was grown, and part of the plant used (leaves, stems, or both) (Carvalho and Pires, 2008; Arruda et al., 2010).

According to the quality of the fiber or proportion of its components, soluble fibers can decrease the intestinal transit, improving the use of nutrients to a certain degree (Montagne et al., 2003; Owusu-Asiedu et al., 2006). This fiber category, where the hemicellulose and pectin fractions are located, is known for having the ability to retain water molecules, increasing the viscosity of the diet (Johnston et al., 2003).

The fibrous fraction classified as insoluble, in turn, whose main component is cellulose, provides an increase in the rate of passage through the gastrointestinal tract. This increased rate of passage reduces the time of residence of the digesta in the stomach and intestine, consequently reducing the use of the nutrients ingested by the animals (Montagne et al., 2003).

Oliveira (2019), working with material from the same harvest site as the present study, found crude fiber values of 8.22% for Moringa. Consequently, when the plant was included in the diets, the content of crude fiber in the diets was also increased. However, these increases were not sufficient to cause adverse effects on the performance of the chickens that maintained their constant production indexes in all treatments. This demonstrates that moringa leaf meal can be included at levels of up to 6.0%, without compromising the growth performance of birds.

Evaluating the chemical composition of the moringa leaf meal used in this study (Table 4), we can observe that the neutral detergent fiber content was approximately 40.32%, and this fraction includes cellulose, hemicellulose, and lignin. Acid detergent fiber, where cellulose and lignin are found, was at a concentration of around 20.10%. However, a large part of the fiber in this meal consisted of potentially soluble fraction.

With the increasing levels of moringa leaf meal in the diets, the amounts of soluble fiber were also elevated. This fact, associated with the significant crude protein (25.86%), ether extract (6.31%), and ash (15.94%) contents, led to improved use of the material, because of the effects this type of fiber has on intestinal transit and nutrient use. This interaction might have provided the obtained results, in which no effects of meal inclusion were detected on animal performance from 10 to 42 days of age.

Banjo (2012) worked with moringa in broiler diets at the inclusion levels of 0, 1, 2, 3, and 4%, and stated that animals receiving up to 3% of the ingredient had greater weight gain; from that point onwards, this parameter decreased. The author also reported that this result was likely due to the high crude fiber content present in the material, which, at greater levels, compromised the use of the diet by the animal.

The low inclusion level of moringa leaf meal in the diets and the use of only leaves, which, according to a study by Makkar and Becker (1997), have low concentration of antinutritional factors, also ensured that the animal performance would not be compromised.

According to González-Alvarado et al. (2010), the adequate development of the gizzard is a factor of extreme importance for broilers, as it works as a regulator of the gastrointestinal tract motility, and its improper development may compromise the nutrient digestibility and performance of these animals. However, in the present study, no differences were found in the weight or yields of the gizzard.

Nkukwana et al. (2014) did not find differences in carcass yield and relative weights and/or yields of gizzard, pancreas, heart, liver, and spleen of 35-day-old broilers fed diets containing moringa. These results were similar to those found in this study, in which no differences were observed at the inclusion levels tested for weight and yield of digestive organs.

Results for weight and yields of carcass and organs obtained in this study were similar to those reported by Zanu et al. (2012), who did not find significant differences for any of the yields of cuts and digestive organs of broilers fed diets containing increasing levels of moringa meal (5, 10, and 15%). Likewise, Nkukwana et al. (2015) worked with diets containing 1, 3, and 5% moringa leaf meal for broilers aged up to 35 days and did not detect any effect on weight of organs.

Zanu et al. (2012) observed a linear increase in the fat content in the carcass when they increased the moringa levels (5, 10, and 15%) in the diets. However, in this study only the 1.5% level differed from the control group.

The pigmentation in the feet of the broilers fed diets containing higher moringa levels (4.5 and 6%) increased linearly, which may be a consequence of the presence of carotenoids in diets with higher levels of this ingredient. These compounds, also known as xantophils, are important precursors of vitamin A, and, when present in a diet, have the ability to be deposited in the meat, making carcasses yellower (Pérez-Vendrell et al., 2001).

The so-called natural pigments, e.g., carotenoids, are important molecules, because, in addition to providing a distinguished color to the end products for the consumer, they often also have antioxidant activity. The use of natural pigments is preferable to artificial pigments due to the risks that these can cause to health, in addition to having higher costs (Nunes Junior et al., 2019). *Moringa oleifera* has carotenes and xanthophylls (lutein, zeaxanthin, canthaxanthin, citranaxanthin, and capsanthin) in its composition, these being the yellow and red pigments present in many plants, capable of intensifying the color of poultry products (Olugbemi et al., 2010; Moyo et al., 2011). Chicken meat color is a parameter of great importance, as it is one of the first features considered by the consumer at the time of purchase (Venturini et al., 2007).

Finally, the inclusion of moringa resulted, on average, in a reduction of 6 and 9% in the use of corn and soybean meal, respectively, in the formulation of diets without harm to performance, carcass yield, and skin pigmentation of broilers. With the increase in the price of the ingredients used in feed formulation, mainly due to the pandemic of the coronavirus, the search for foods that can reduce the percentage of these in the formulation of diets becomes important for the industry and small producers, because of the potential to reduce production costs.

5. Conclusions

Moringa oleifera has potential for use in diets of broilers from 10 to 42 days of age, at up to 6% inclusion, without compromising the performance or carcass yield of these animals.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: G.M. Macambira, C.B.V. Rabello, M.I.V. Navarro, C.C. Lopes, G.R. Nascimento and J.C.R. Silva. Data curation: G.M. Macambira and G.R. Nascimento. Formal analysis: G.M. Macambira, C.B.V. Rabello, C.C. Lopes, E.C. Lopes, H.S.H. Oliveira and J.C.R. Silva. Funding acquisition: G.M. Macambira and C.B.V. Rabello. Investigation: G.M. Macambira, C.B.V. Rabello and E.C. Lopes. Methodology: G.M. Macambira, C.B.V. Rabello, M.I.V. Navarro, C.C. Lopes, E.C. Lopes, G.R. Nascimento, H.S.H. Oliveira and J.C.R. Silva. Project administration: C.B.V. Rabello. Resources: G.M. Macambira, C.B.V. Rabello, G.R. Nascimento, H.S.H. Oliveira and J.C.R. Silva. Software: C.B.V. Rabello, C.C. Lopes, G.R. Nascimento and J.C.R. Silva. Supervision: C.B.V. Rabello, M.I.V. Navarro, C.C. Lopes, G.R. Nascimento and J.C.R. Silva. Validation: C.B.V. Rabello and E.C. Lopes. Visualization: G.M. Macambira. Writing-original draft: G.M. Macambira, G.R. Nascimento and H.S.H. Oliveira. Writing-review & editing: C.B.V. Rabello, M.I.V. Navarro, C.C. Lopes, E.C. Lopes and J.C.R. Silva.

Acknowledgments

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco (FACEPE) for financing this research.

References

Amorim, A. F.; Siqueira, J. C.; Rodrigues, K. F.; Vaz, R. G. M. V.; Barbosa, S. M.; Santos, H. D.; Rosa, F. C.; Sousa, J. P. L.; Silva, E. G.; Moufarreg, I. M. M. O.; Perente, I. P. and Soares, J. A. R. 2015. Níveis de inclusão do bagaço de mandioca na ração de frangos de crescimento lento: características físico-químicas da carne. Semina: Ciências Agrárias 36:1685-1700. https://doi.org/10.5433/1679-0359.2015v36n3p1685

ABPA - Associação Brasileira de Proteína Animal. 2020. Relatório anual 2020. Available at: <https://abpa-br.org/wp-content/uploads/2020/05/abpa_relatorio_anual_2020_portugues_web.pdf>. Accessed on: Mar. 29, 2021.

Atuahene, C. C.; Attoh-Kotoku, V.; Foso, K. D.; Amissah, S. E.; Sarfo, F. K. and Mensah, J. J. 2008. Preliminary study of the effect of feeding *Moringa oleifera* leaf meal as a feed ingredient on the growth performance of broiler chickens. p.72-75. In: Proceedings of the 28th and 29th Ghana Animal Science Association held at the University of Education, Winneba, Mmpong Campus.

Anwar, M. I.; Muhammad, F.; Awais, M. M. and Akhtar, M. 2017. A review of β-glucans as a growth promoter and antibiotic alternative against enteric pathogens in poultry. World's Poultry Science Journal 73:651-661. https://doi.org/10.1017/S0043933917000241

Arruda, A. M. V.; Filgueira, T. M. B.; Fernandes, R. T. V.; Melo, A. S.; Souza, D. H. and Oliveira, J. F. 2010. Avaliação nutricional do feno de mata pasto com aves caipiras. Acta Veterinaria Brasilica 4:193-198.

Ash, A. J.; Petaia, L. and Ako, H. 1992. Nutritional value of *Sesbania grandiflora* leaves for monogastrics and ruminants. Tropical Agriculture 69:223-228.

Ayssiwede, S. B.; Zanmenou, J. C.; Issa, Y.; Hane, M. B.; Dieng, A.; Chrysostome, C. A. A. M.; Houinato, M. R.; Hornick, J. L. and Missohou, A. 2011. Nutrient composition of some unconventional and local feed resources available in Senegal and recoverable in indigenous chickens or animal feeding. Pakistan Journal of Nutrition 10:707-717. https://doi.org/10.3923/pjn.2011.707.717

Ayaşan, T.; Sucu, E.; Ülger, I.; Hızlı, H.; Cubukcu, P. and Özcan, B. D. 2020. Determination of in vitro rumen digestibility and potential feed value of tiger nut varieties. South African Journal of Animal Science 50:738-744. https://doi.org/10.4314/sajas.v50i5.12

Banjo, O. S. 2012. Growth and performance as affected by inclusion of *Moringa oleifera* leaf meal in broiler chicks diet. Journal of Biology, Agriculture and Healthcare 2:35-38.

Carvalho, G. G. P. and Pires, A. J. V. 2008. Organização dos tecidos de plantas forrageiras e suas implicações para os ruminantes. Archivos de Zootecnia 57:13-28.

Cheng, Y.; Chen, Y.; Li, J.; Qu, H.; Zhao, Y.; Wen, C. and Zhou, Y. 2019. Dietary β-sitosterol improves growth performance, meat quality, antioxidant status, and mitochondrial biogenesis of breast muscle in broilers. Animals 9:71. https://doi.org/10.3390/ani9030071

Cui, Y. M.; Wang, J.; Lu, W.; Zhang, H. J.; Wu, S. G. and Qi, G. H. 2018. Effect of dietary supplementation with *Moringa oleifera* leaf on performance, meat quality, and oxidative stability of meat in broilers. Poultry Science 97:2836-2844. https://doi.org/10.3382/ps/pey122

Elbashier, O. M. and Ahmed, H. E. 2016. The effect of feeding different levels of *Moringa oleifera* leaf meal on the performance and some blood parameters of broilers. International Journal of Science and Research 5:632-635.

Ekizoğlu, H.; Ülger, İ.; Kaliber, M. and Ayaşan, T. 2020. Effects of Spirulina (Algae) supplementation to Japanese quail (*Coturnix coturnix Japonica*) diets on growth performance and carcass traits. Indian Journal of Animal Sciences 90:923-927.

González-Alvarado, J. M.; Jiménez-Moreno, E.; González-Sánchez, D.; Lázaro, R. and Mateos, G. G. 2010. Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. Animal Feed Science and Technology 162:37-46. https://doi.org/10.1016/j.anifeedsci.2010.08.010

Johnston, L. J.; Noll, S.; Renteria, A. and Shurson, J. 2003. Feeding by-products high in concentration of fiber to nonruminants. p.169-186. In: 3rd National Symposium on Alternative Feeds for Livestock and Poultry, Kansas City.

Kaijage, J. T.; Mutayoba, S. K. and Katule, A. 2015. *Moringa oleifera* leaf meal and molasses as additives in grain sorghum based diets for layer chickens. Livestock Research for Rural Development 27:22.

Macambira, G. M.; Rabello, C. B. V.; Navarro, M. I. V.; Ludke, M. C. M. M.; Silva, J. C. R.; Lopes, E. C.; Nascimento, G. R.; Lopes, C. C.; Bandeira, J. M. and Silva, D. A. 2018. Caracterização nutricional das folhas de *Moringa oleifera* (MOL) para frangos de corte. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 70:570-578. https://doi.org/10.1590/1678-4162-9522

Makkar, H. P. S. and Becker, K. 1997. Nutrients and antiquality factors in different morphological parts of the *Moringa oleifera* tree. Journal of Agricultural Science 128:311-322. https://doi.org/10.1017/S0021859697004292

Mbikay, M. 2012. Therapeutic potential of *Moringa oleifera* leaves in chronic hyperglycemia and dyslipidemia: a review. Frontiers in Pharmacology 3:24. https://doi.org/10.3389/fphar.2012.00024

Montagne, L.; Pluske, J. R. and Hampson, D. J. 2003. A review of interactions between dietary fibre and the intestinal mucosa, and their consequences on digestive health in young non-ruminant animals. Animal Feed Science and Technology 108:95-117. https://doi.org/10.1016/S0377-8401(03)00163-9

Moyo, B.; Masika, P. J.; Hugo, A. and Muchenje, V. 2011. Nutritional characterization of Moringa (*Moringa oleifera* Lam.) leaves. African Journal of Biotechnology 10:12925-12933. https://doi.org/10.5897/AJB10.1599

Nkukwana, T. T.; Muchenje, V.; Pieterse, E.; Masika, P. J.; Mabusela, T. P.; Hoffman, L. C. and Dzama, K. 2014. Effect of *Moringa oleifera* leaf meal on growth performance, apparent digestibility, digestive organ size and carcass yield in broiler chickens. Livestock Science 161:139-146. https://doi.org/10.1016/j.livsci.2014.01.001

Nkukwana, T. T.; Muchenje, V.; Masika, P. J. and Mushonga, B. 2015. Intestinal morphology, digestive organ size and digesta pH of broiler chickens fed diets supplemented with or without *Moringa oleifera* leaf meal. South African Journal of Animal Science 45:362-370. https://doi.org/10.4314/sajas.v45i4.2

Nunes Junior, D. A.; Lima, H. J. D.; Souza, L. A. Z.; Silva, N. E. M.; Martins, A. C. S.; Valentim, J. K. and Bittencourt, T. M. 2019. Pigmentantes em dietas a base de milho e sorgo para aves comerciais. Revista Brasileira de Nutrição Animal 13:1-9.

Oliveira, H. S. H. 2019. Avaliação nutricional das folhas da *Moringa oleifera* para aves. Dissertação (M.Sc). Universidade Federal Rural de Pernambuco, Recife.

Olugbemi, T. S.; Mutayoba, S. K. and Lekule, F. P. 2010. Effect of Moringa (*Moringa oleifera*) inclusion in cassava based diets fed to broiler chickens. International Journal Poultry Science 9:363-367. https://doi.org/10.3923/ijps.2010.363.367

Owusu-Asiedu, A.; Patience, J. F.; Laarveld, B.; Van Kessel, A. G.; Simmins, P. H. and Zijlstra, R. T. 2006. Effects of guar gum and cellulose on digesta passage rate, ileal microbial populations, energy and protein digestibility, and performance of grower pigs. Journal of Animal Science 84:843-852. https://doi.org/10.2527/2006.844843x

Pérez-Vendrell, A. M.; Hernández, J. M.; Llauradó, L.; Schierle, J. and Brufau, J. 2001. Influence of source and ratio of xanthophyll pigments on broiler chicken pigmentation and performance. Poultry Science 80:320-326. https://doi.org/10.1093/ps/80.3.320

Ribeiro, A. M. L.; Henn, J. D. and Silva, G. L. 2010. Alimentos alternativos para suínos em crescimento e terminação. Acta Scientiae Veterinariae 38:61-71.

Rostagno, H. S.; Albino, L. F. T.; Donzele J. L.; Gomes, P. C.; Oliveira, R. F.; Lopes, D. C.; Ferreira, A. S.; Barreto, S. L. T. and Euclides, R. F. 2011. Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. 3.ed. Viçosa, MG.

Silva, D. J. and Queiroz, A. C. 2002. Análise de alimentos: Métodos químicos e biológicos. Imprensa Universitária, Viçosa, MG.

Ülger, İ.; Beyzi, S. B.; Kaliber, M. and Konca, Y. 2020a. Chemical, nutritive, fermentation profile and gas production of citrus pulp silages, alone or combined with maize silage. South African Journal of Animal Science 50:161-169. https://doi.org/10.4314/sajas.v50i1.17

Ülger, İ.; Kaliber, M.; Beyzi, S. B. and Konca, Y. 2020b. Possible ensiling of pumpkin (*Cucurbita pepo*) residues. Turkish Journal of Veterinary and Animal Sciences 44:853-859. https://doi.org/10.3906/vet-2002-81

Ulger, I.; Onmaz, A. C. and Ayaşan, T. 2017. Effects of silymarin (*Silybum marianum*) supplementation on milk and blood parameters of dairy cattle. South African Journal of Animal Science 47:758-765. https://doi.org/10520/EJC-adf124503

Venturini, K. S.; Sarcinelli, M. F. and Silva, L. C. 2007. Características da carne de frango. Boletim Técnico - PIE-UFES:01307.

Xiao, Z.; Lester, G. E.; Luo, Y. and Wang, Q. 2012. Assessment of vitamin and carotenoid concentrations of emerging food products: edible microgreens. Journal of Agricultural and Food Chemistry 60:7644-7651. https://doi.org/10.1021/jf300459b

Zanu, H. K.; Asiedu, P.; Tampuori, M.; Abada, M. and Asante, I. 2012. Possibilities of using Moringa (*Moringa oleifera*) leaf meal as a partial substitute for fishmeal in broiler chickens diets. Online Journal of Animal and Feed Research 2:70-75.