The effects of functional oils on broiler diets of varying energy levels

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Primary Audience: Nutritionists, Researchers, Broiler Integrators

SUMMARY

Some plant oils have been labeled "functional oils" because they have biological activities beyond their energy value. Recently, it has been shown that the effects of some functional oils on broiler performance are similar to the effects of antibiotic growth promoters. A commercial mixture of functional oils (containing castor oil and cashew nut shell liquid as the active ingredients) in diets with 3 ME levels (industry standard, industry standard minus 100 kcal/kg, and industry standard minus 200 kcal/kg) was used to study the effects on the performance of 2,250 broiler chicks from 1 to 42 d of age. In addition, the effects of supplementing the functional oils in the low-energy diets were studied in chicks from 21 to 42 d of age and from 35 to 42 d of age. Therefore, at the end of the experiment, there were 10 treatments, with 9 floor pens per treatment. Adding functional oils to the feed not only improved the BW gains and FCR of the birds compared with diets with the same ME, but it also allowed for a decrease in ME of 100 kcal/kg without negatively affecting performance parameters. These improvements in performance might be related to the antimicrobial and anti-inflammatory activities of the functional oils.

Key words: broiler, functional oil, metabolizable energy

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DESCRIPTION OF PROBLEM

Under the current production systems, broiler chickens are exposed to various pathogenic microorganisms. The problems caused by these pathogenic microorganisms have traditionally been prevented by the use of vaccines and antibiotics. However, new regulations and negative consumer perceptions concerning the use of antibiotics in animal production have led to the development of products that consumers consider "natural." With varying degrees of success, several natural alternatives have been developed as substitutes for antibiotics: prebiotics [1], direct-fed microbials (probiotics) [2], yeast cell wall derivatives [3], organic acids [4], and plant oils and extracts [5].

Plant oils and extracts have usually been associated with essential oils. However, some of the oils used as antibiotic substitutes cannot be classified as essential oils because the oils are not derived from either essences or spices. Instead, these oils are referred to as "functional oils" [6] because they have functions beyond their energy value. Castor oil and cashew nut shell liquid (**CNSL**) are considered functional

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oils because both have been shown to have antimicrobial activity [7, 8], but they are neither spices nor essences. Castor oil has also been shown to have anti-inflammatory activity [9]. Unfortunately, because castor oil is a laxative when taken orally, its oral use is precluded. However, when combined with CNSL, castor oil is biologically active at lower dosages than when it acts as a laxative, thus making it safe for oral use. A commercial product composed of castor oil and CNSL [10] was previously shown to increase the AME of supplemented broiler diets by 4% [6]. It was hypothesized, based on these data, that it would be possible to decrease the ME density of the diet and still maintain bird performance when the birds received supplements with the castor oil-CNSL mixture. The objective of this study was to evaluate the effects of the castor oil-CNSL mixture in diets with varying levels of ME.

MATERIALS AND METHODS

Birds and Housing

A total of 2,250 one-day-old male broiler chicks (Cobb × Cobb 500) were purchased from a commercial hatchery [11], sorted by BW, and then randomized among 90 floor pens, with 25 birds per pen. The initial average chick BW for all pens was 48 g. The chickens were reared in a conventional poultry house with side curtains, and the litter consisted of new rice straw.

Experimental Design

This research was conducted at the Experimental Agronomic Station of the Federal University of Rio Grande do Sul, Brazil, with the approval of the Institutional Animal Care and Use Committee, which oversees research with animals and poultry at university facilities.

The experiment included diets at 3 energy levels. The baseline energy level followed typical Brazilian industry standards. For the other energy levels, the ME was decreased by 100 and 200 kcal/kg. All the other nutrients were kept constant in all 3 diets. The feeding program consisted of a prestarter diet (1 to 7 d), a starter diet (8 to 21 d), a grower diet (22 to 35 d), and a finisher diet (36 to 42 d; Tables 1 and 2). The effects of the castor oil-CNSL mixture (0.15% inclusion rate) were studied at the 3 energy levels and at different points during the feeding program in the low-energy diets. From 0 to 21 d of age, there were 6 treatments: 1) industry energy levels without supplementation of the castor oil-CNSL mixture (**C-Ind**), 2) industry energy levels with the castor oil-CNSL mixture (**E-Ind**), 3) −100 kcal/kg without the castor oil-CNSL mixture (**C-100**), 4) −100 kcal/kg with the castor oil-CNSL mixture (**E-100**), 5) −200 kcal/kg without the castor oil-CNSL mixture (**C-200**), and 6) −200 kcal/kg with the castor oil-CNSL mixture (**E-200**). From 21 to 35 d of age, 9 pens from each of the C-100 and C-200 treatments were used to add 2 treatments: 7) −100 kcal/kg with supplementation of the castor oil-CNSL mixture in the grower and the finisher phases (**Egf-100**), and 8) −200 kcal/kg with the castor oil-CNSL mixture in the grower and the finisher phases (**Egf-200**). Finally, from 35 to 42 d of age, 2 more treatments were included in the experiment, again using 9 pens each from the C-100 and C-200 treatments: 9) −100 kcal/kg with supplementation of the castor oil-CNSL mixture only in the finisher phase (**Ef-100**), and 10) −200 kcal/kg with supplementation of the castor oil-CNSL mixture only in the finisher phase (**Ef-200**). Therefore, there were 10 treatments (9 pens per treatment) at the end of the experiment (Table 3). To avoid any carryover effects, the pen assignments for new treatments at 21 and 35 d of age were made by equalizing the average BW between the new and existing treatments. Because the castor oil-CNSL mixture has been shown to have coccidiostatic activity [6], no coccidiostats were used during the phases when the castor oil-CNSL mixture was fed to the birds. When the castor oil-CNSL mixture was not present in the diet, monensin (125 ppm) was included in the formulations of all prestarter, starter, and grower diets. All finisher diets were devoid of any coccidiostat.

Measurements

The BW and feed intakes of the birds were determined weekly. Mortality and its cause were recorded daily, and the FCR was calculated after correcting for mortality. At 42 d of age, 6 birds were randomly selected from each pen,

Table 1. Ingredients in the experimental diets at varying ME levels (industry standard, industry standard − 100 kcal/kg, and industry standard − 200 kcal/kg)

	Prestarter			Starter			Grower			Finisher		
Ingredient	Standard	−100	−200	Standard	−100	−200	Standard	−100	−200	Standard	−100	−200
Corn	50.07	52.40	54.72	55.44	58.18	60.92	59.54	61.86	64.18	59.94	62.26	64.59
Soybean meal (45% CP)	41.23	40.83	40.43	35.26	34.79	34.32	31.76	31.36	30.97	30.21	29.82	29.42
Soybean oil	3.98	2.04	0.11	4.81	2.53	0.25	4.54	2.61	0.68	5.95	4.01	2.08
Dicalcium phosphate	2.10	2.09	2.09	2.00	1.99	1.99	1.88	1.88	1.87	1.76	1.75	1.75
Limestone	0.88	0.89	0.89	0.86	0.87	0.88	0.85	0.85	0.86	0.81	0.82	0.82
Sodium chloride	0.34	0.33	0.33	0.37	0.36	0.36	0.30	0.30	0.29	0.25	0.24	0.24
Sodium bicarbonate	0.29	0.30	0.30	0.21	0.21	0.21	0.21	0.21	0.21	0.24	0.25	0.25
Kaolin	0.21	0.21	0.21	0.20	0.21	0.22	0.19	0.19	0.20	0.21	0.21	0.21
Lysine hydrochloride (78%)	0.17	0.18	0.18	0.18	0.19	0.20	0.16	0.17	0.17	0.15	0.15	0.16
Vitamin premix[1]	0.12	0.12	0.12	0.10	0.10	0.10	0.08	0.08	0.08	0.05	0.05	0.05
L-Threonine (98.5%)	0.06	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.05	0.05	0.05
Mineral premix[2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride (60%)	0.04	0.04	0.04	0.05	0.05	0.06	0.03	0.03	0.03	0.02	0.02	0.03
Methionine hydroxy analog	0.47	0.46	0.46	0.40	0.40	0.40	0.34	0.34	0.33	0.31	0.31	0.30

[1]Composition per kilogram of feed: vitamin A, 9,000 IU; vitamin D_3, 2,500 IU; vitamin E, 20 IU; vitamin K_3, 2.5 mg; vitamin B_1, 1.5 mg; vitamin B_2, 6 mg; vitamin B_6, 3 mg; pantothenic acid, 1.2 mg; biotin, 0.060 mg; folic acid, 0.8 mg, niacin, 25 mg, vitamin B_{12}, 12 µg.

[2]Composition per kilogram of feed: iodine, 2 mg; selenium, 0.25 mg; copper, 20 mg; manganese, 160 mg; zinc, 100 mg; iron, 100 mg.

Table 2. Calculated nutrient values of the baseline diet according to Brazilian industry standards

Nutrient	Prestarter	Starter	Grower	Finisher
CP, %	22.97	20.66	19.32	18.61
Ca, %	1.00	0.95	0.90	0.85
Available P, %	0.50	0.47	0.45	0.42
Na, %	0.23	0.22	0.19	0.18
Dietary electrolyte balance, mEq/kg	250	215	200	200
ME, kcal/kg	3,000	3,080	3,150	3,250
Choline, mg/kg	1,700	1,600	1,600	1,500
Digestible amino acids, %				
Arginine	1.49	1.31	1.21	1.17
Isoleucine	0.91	0.81	0.75	0.73
Lysine	1.28	1.15	1.05	1.00
Methionine	0.66	0.59	0.53	0.50
Methionine + cysteine	0.96	0.86	0.79	0.75
Threonine	0.83	0.75	0.68	0.65
Tryptophan	0.26	0.23	0.21	0.21
Valine	0.96	0.86	0.81	0.78
Leucine	1.78	1.64	1.56	1.52
Histidine	0.59	0.54	0.51	0.50
Phenylalanine	1.05	0.95	0.89	0.85
Phenylalanine + tyrosine	1.78	1.59	1.49	1.44

identified, fasted for 8 h, and then individually weighed for on-line processing. The birds were killed after electrical stunning at 45 V for 3 s. After the jugular vein was cut, the birds were exsanguinated (3 min) and scalded at 60°C for 45 s, and their feathers were mechanically plucked. The broilers were manually eviscerated, and the carcasses were chilled through immersion in slush ice for 3 h. The carcasses, which included the abdominal fat, lungs, and kidneys but excluded the viscera with adjacent fat, and the feet, neck, and head, were then weighed. The abdominal fat was removed from the carcasses and weighed. The carcasses were cut into the following commercial parts and then weighed: the deboned breast meat with the attached skin (pectoralis major plus and pectoralis minor muscles), the leg plus the thigh and the wings. After removal of the gastrointestinal tract, the intestine was sectioned immediately distal to the gizzard, the pancreas was removed, and the weight of the empty intestine was determined (duodenum, jejunum, and ileum) with a precision scale [12].

Statistical Analyses

A 2 × 3 full factorial design was used to examine the effects of the type of additive and the energy levels for the data from 1 to 21 d of age. The remaining data were analyzed following a completely randomized block design. To improve normality, the percentage data were arcsine-transformed before analysis [13].

RESULTS AND DISCUSSION

Prestarter and Starter Phases (1 to 21 d of age)

The BW gains at 7 d of age ranged from 0.138 kg for birds receiving the C-200 treatment to 0.147 kg for birds receiving the E-100 treatment. At 7 and 21 d of age, decreasing the energy density of the diets resulted in lighter birds ($P < 0.0001$) and higher FCR ($P < 0.0001$). However, the intake was significantly increased only at 21 d ($P < 0.0001$).

Supplementation of the castor oil-CNSL mixture increased BW gains at both 7 and 21 d of age ($P < 0.001$) and improved FCR at 21 d of age ($P < 0.0001$) when compared with monensin supplementation. The performance parameters of chickens fed the E-100 diet were similar to those of chickens fed the C-Ind diet. For chickens fed the E-100 vs. C-Ind diet, the BW gain was 0.864 vs. 0.832 kg, and the FCR was 1.402 vs. 1.400, respectively. In addition, the performance parameters of the chickens fed the E-200 diet were similar to those of chickens fed the

Table 3. Metabolizable energy levels (kcal/kg), the additive supplemented [monensin at 125 ppm or the castor oil-cashew nut shell liquid (CNSL) mixture at 1,500 ppm[1]], and the number of pens at each treatment and phase

Treatment	Prestarter			Starter			Grower			Finisher		
	ME	Additive	Pens, no.	ME	Additive	Pens, no.	ME	Additive	Pens, no.	ME	Additive	Pens, no.
1	3,000	Monensin	9	3,080	Monensin	9	3,150	Monensin	9	3,250	None	9
2	3,000	Castor oil-CNSL	9	3,080	Castor oil-CNSL	9	3,150	Castor oil-CNSL	9	3250	Castor oil-CNSL	9
3	2,900	Monensin	27	2,980	Monensin	27	3,050	Monensin	18	3,150	None	9
4	2,900	Castor oil-CNSL	9	2,980	Castor oil-CNSL	9	3,050	Castor oil-CNSL	9	3,150	Castor oil-CNSL	9
5	2,800	Monensin	27	2,880	Monensin	27	2,950	Monensin	18	3,050	None	9
6	2,800	Castor oil-CNSL	9	2,880	Castor oil-CNSL	9	2,950	Castor oil-CNSL	9	3,050	Castor oil-CNSL	9
7	2,900	Monensin	0	2,980	Monensin	0	3,050	Castor oil-CNSL	9	3,150	Castor oil-CNSL	9
8	2,800	Monensin	0	2,880	Monensin	0	2,950	Castor oil-CNSL	9	3,050	Castor oil-CNSL	9
9	2,900	Monensin	0	2,980	Monensin	0	3,050	Monensin	0	3,150	Castor oil-CNSL	9
10	2,800	Monensin	0	2,880	Monensin	0	2,950	Monensin	0	3,050	Castor oil-CNSL	9

[1]Essential (patent pending; Oligo Basics Ind. Ltda., Cascavel, Paraná, Brazil).

C-100 diet, with a BW gain of 0.838 vs. 0.834 kg and an FCR of 1.457 vs. 1.442, respectively. Therefore, supplementation with the castor oil-CNSL mixture allowed for a decrease in ME of 100 kcal/kg without negatively affecting performance parameters (Table 4).

Grower Phase (21 to 35 d of age)

The birds in treatments E-Ind and E-100 gained 1.497 and 1.499 kg, respectively, and were heavier than birds in the other treatments ($P < 0.05$). The birds in treatments C-Ind, E-Ind, Egf-100, and E-100 had lower FCR (1.672, 1.656, 1.673, and 1.672, respectively; $P < 0.05$) than those in the rest of the treatments. As in the previous phase, it was found that supplementing the feed with the castor oil-CNSL mixture supported BW gain and FCR similar to the BW gain and FCR achieved by diets that were 100 kcal/kg higher in ME and supplemented with monensin (Table 5).

Finisher Phase (35 to 42 d of age)

In the finisher phase, the BW gains were very similar, averaging 0.757 kg across all treatments, and BW gains were different ($P < 0.05$) only between the Egf-100 and C-200 treatments (0.782 and 0.734 kg, respectively). The FCR were also very similar, with a 2.055 average across all the treatments (Table 6). The birds in treatment E-100 yielded the best FCR (1.990), which was significantly lower ($P < 0.05$) than that of birds in treatments C-200 and Ef-200 (2.112 and 2.113, respectively).

All Phases (1 to 42 d of age)

The average mortality rate across all the treatments was 5.27%, and the rate did not vary among treatments. The birds fed the E-Ind, Egf-100, and E-100 diets were approximately 100 g heavier ($P < 0.05$) than those fed diets C-Ind, C-100, and Ef-100 at 42 d (Table 7). Decreasing the ME and supplementation with the castor oil-CNSL mixture led to increased intake. Therefore, decreasing the dietary ME level by 100 kcal/kg did not negatively affect the BW and FCR of the birds when their diets were supplemented with the castor oil-CNSL mixture.

Table 4. Performance at 7 and 21 d of age for birds supplemented with either monensin (125 ppm) or the castor oil-cashew nut shell liquid (CNSL) mixture[1] (0.15%) at 3 different energy levels

		Grower phase					
		1 to 7 d			1 to 21 d		
Item	Additive type	BW gain, kg	FCR	Intake, kg	BW gain, kg	FCR	Intake, kg
Energy level							
Industry	Monensin	0.142	1.127	0.160	0.832	1.400	1.166
Industry	Castor oil-CNSL	0.146	1.119	0.163	0.884	1.338	1.182
Industry − 100 kcal/kg	Monensin	0.144	1.135	0.163	0.834	1.442	1.202
Industry − 100 kcal/kg	Castor oil-CNSL	0.147	1.123	0.165	0.864	1.402	1.210
Industry − 200 kcal/kg	Monensin	0.138	1.177	0.163	0.823	1.482	1.219
Industry − 200 kcal/kg	Castor oil-CNSL	0.142	1.155	0.164	0.838	1.457	1.221
SEM		0.0005	0.0004	0.0006	0.002	0.004	0.003
		P-value					
Effect							
Energy level		0.001	0.001	0.302	0.0001	0.0001	0.0001
Additive type		0.003	0.154	0.112	0.0001	0.0001	0.145
Energy level × additive type		0.963	0.816	0.724	0.027	0.256	0.645

[1]Essential (patent pending; Oligo Basics Ind. Ltda., Cascavel, Paraná, Brazil).

Table 5. Performance parameters from 21 to 35 d of age for birds supplemented with either monensin (125 ppm) or the castor oil-cashew nut shell liquid (CNSL) mixture[1] (0.15%) at 3 different energy levels

	Additive supplemented		Performance parameter		
Item	1 to 21 d	21 to 35 d	BW gain, kg	FCR	Intake, kg
Energy level					
Industry	Monensin	Monensin	1.441[b]	1.672[c]	2.409[c]
Industry	Castor oil-CNSL	Castor oil-CNSL	1.497[a]	1.656[c]	2.478[ab]
Industry − 100 kcal/kg	Monensin	Monensin	1.407[b]	1.741[b]	2.448[b]
Industry − 100 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	1.499[a]	1.672[c]	2.505[a]
Industry − 200 kcal/kg	Monensin	Monensin	1.363[c]	1.823[a]	2.485[ab]
Industry − 200 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	1.442[b]	1.764[b]	2.542[a]
Industry − 100 kcal/kg	Monensin	Castor oil-CNSL	1.495[a]	1.673[c]	2.502[ab]
Industry − 200 kcal/kg	Monensin	Castor oil-CNSL	1.409[b]	1.791[ab]	2.522[a]
SEM			0.035	0.044	0.042

[a–c]Values in the same column with different superscripts are significantly different ($P < 0.05$).

[1]Essential (patent pending; Oligo Basics Ind. Ltda., Cascavel, Paraná, Brazil).

Chickens whose diets were supplemented with the castor oil-CNSL mixture at different points during their growth were heavier and had better FCR ($P < 0.05$). The longer the birds were supplemented with the castor oil-CNSL mixture, the greater were the differences. Based on the FCR, corrected at 2.5 kg of BW [14], it was possible to decrease the ME by 100 kcal/kg and still attain the same FCR when birds were supplemented with the castor oil-CNSL mixture (Table 7).

When comparing diets with the same ME density, the intake of birds supplemented with the castor oil-CNSL mixture was sometimes higher than that of nonsupplemented birds. Hence, the amount of energy used for maintenance as a percentage of the total energy used (maintenance + growth) was lower for birds supplemented with the castor oil-CNSL mixture. Therefore, part of the improvement observed with supplementation of the castor oil-CNSL mixture could be attributed to the dilution of the maintenance requirements because, percentagewise, more of the energy ingested by birds supplemented with the castor oil-CNSL mixture was directed toward growth. However, when the calculated average ME daily intakes for birds supplemented with the castor oil-CNSL mixture from 1 to 42 d of age (E-Ind, E-100, and E-200) were plotted against their BW at 42 d of age, and its regression equation was compared with that of birds that were not supplemented with the castor oil-CNSL mixture (C-Ind, C-100, and C-200), it was apparent that supplementation of the castor oil-CNSL mixture increased the BW of the birds when they ingested the same amount of ME (Figure 1). Based on an analysis of the regression lines, slopes were similar but with different intercepts ($P < 0.001$). Therefore, the castor oil-CNSL mixture increased the ME of the diet, and the improved performance was not simply due to higher feed intakes.

Carcass Characteristics

The carcass and wing yields, as well as the amount of abdominal fat, did not differ among the birds in the various treatments (Table 8). The birds fed the C-Ind and E-200 diets had greater ($P < 0.05$) breast yields than those fed the Ef-100 diet. The leg and thigh yields were greater for birds fed the C-100 diet than for those fed the E-200 diet. Supplementation with the castor oil-CNSL mixture decreased intestinal weights only in the low-energy diets ($P < 0.05$).

Although the dosage of monensin used in this trial is common in Brazil, it is well above approved levels in other countries. Therefore, because the birds supplemented with monensin were used as controls, it could be argued that, rather than the functional oils increasing the performance of the birds, monensin was actually decreasing it. However, it was reported previously that 120 ppm of monensin did not affect broiler FCR [15, 16]. In addition, diets high in oil, such as the ones used in this study, have been shown to counteract the negative effects of monensin toxicity [16]. Finally, monensin toxicity affects protein utilization, but it does not

Table 6. Performance parameters from 35 to 42 d of age for birds supplemented with either monensin (125 ppm) or the castor oil-cashew nut shell liquid (CNSL) mixture[1] (0.15%) at 3 different energy levels

	Additive supplemented			Performance parameter		
Item	1 to 21 d	21 to 35 d	35 to 42 d	BW gain, kg	FCR	Intake, kg
Energy level						
Industry	Monensin	Monensin	None	0.771^{ab}	2.006^{ab}	1.545
Industry	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	0.778^{ab}	1.990^{b}	1.545
Industry − 100 kcal/kg	Monensin	Monensin	None	0.756^{ab}	2.051^{ab}	1.550
Industry − 100 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	0.771^{ab}	2.018^{ab}	1.554
Industry − 200 kcal/kg	Monensin	Monensin	None	0.734^{b}	2.122^{a}	1.557
Industry − 200 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	0.738^{ab}	2.113^{ab}	1.558
Industry − 100 kcal/kg	Monensin	Castor oil-CNSL	Castor oil-CNSL	0.782^{a}	1.989^{b}	1.555
Industry − 200 kcal/kg	Monensin	Castor oil-CNSL	Castor oil-CNSL	0.739^{ab}	2.112^{ab}	1.560
Industry − 100 kcal/kg	Monensin	Monensin	Castor oil-CNSL	0.764^{ab}	2.031^{ab}	1.549
Industry − 200 kcal/kg	Monensin	Monensin	Castor oil-CNSL	0.737^{ab}	2.116^{a}	1.557
SEM				0.029	0.078	0.040

[a,b]Values in the same column with different superscripts are significantly different ($P < 0.05$).

[1]Essential (patent pending; Oligo Basics Ind. Ltda., Cascavel, Paraná, Brazil).

Table 7. Body weight, intake, FCR, and corrected FCR at 2.5 kg of BW [FCR at 2.5 kg = (2.5 − BW)/3.5 + FCR] from 1 to 42 d of age for birds supplemented with either monensin (125 ppm) or the castor oil-cashew nut shell liquid (CNSL) mixture[1] (0.15%) at 3 different energy levels

	Type of additive			Performance parameter			
Item	1 to 21 d	21 to 35 d	35 to 42 d	BW, kg	Intake, kg	FCR	FCR at 2.5 kg
Energy level							
Industry	Monensin	Monensin	None	3.093^{b}	5.120^{c}	1.682^{d}	1.512^{d}
Industry	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	3.207^{a}	5.206^{bc}	1.648^{d}	1.446^{d}
Industry − 100 kcal/kg	Monensin	Monensin	None	3.046^{b}	5.198^{c}	1.734^{c}	1.578^{b}
Industry − 100 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	3.182^{a}	5.269^{ab}	1.681^{d}	1.487^{cd}
Industry − 200 kcal/kg	Monensin	Monensin	None	2.968^{c}	5.260^{ab}	1.801^{a}	1.667^{a}
Industry − 200 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	3.066^{b}	5.322^{a}	1.763^{bc}	1.601^{b}
Industry − 100 kcal/kg	Monensin	Castor oil-CNSL	Castor oil-CNSL	3.160^{a}	5.260^{ab}	1.690^{d}	1.502^{b}
Industry − 200 kcal/kg	Monensin	Castor oil-CNSL	Castor oil-CNSL	3.018^{bc}	5.301^{ab}	1.785^{ab}	1.637^{a}
Industry − 100 kcal/kg	Monensin	Monensin	Castor oil-CNSL	3.054^{b}	5.200^{c}	1.731^{c}	1.572^{c}
Industry − 200 kcal/kg	Monensin	Monensin	Castor oil-CNSL	2.971^{c}	5.262^{ab}	1.800^{a}	1.666^{ab}
SEM				0.037	0.067	0.022	0.029

[a–d]Values in the same column with different superscripts are significantly different ($P < 0.05$).

[1]Essential (patent pending; Oligo Basics Ind. Ltda., Cascavel, Paraná, Brazil).

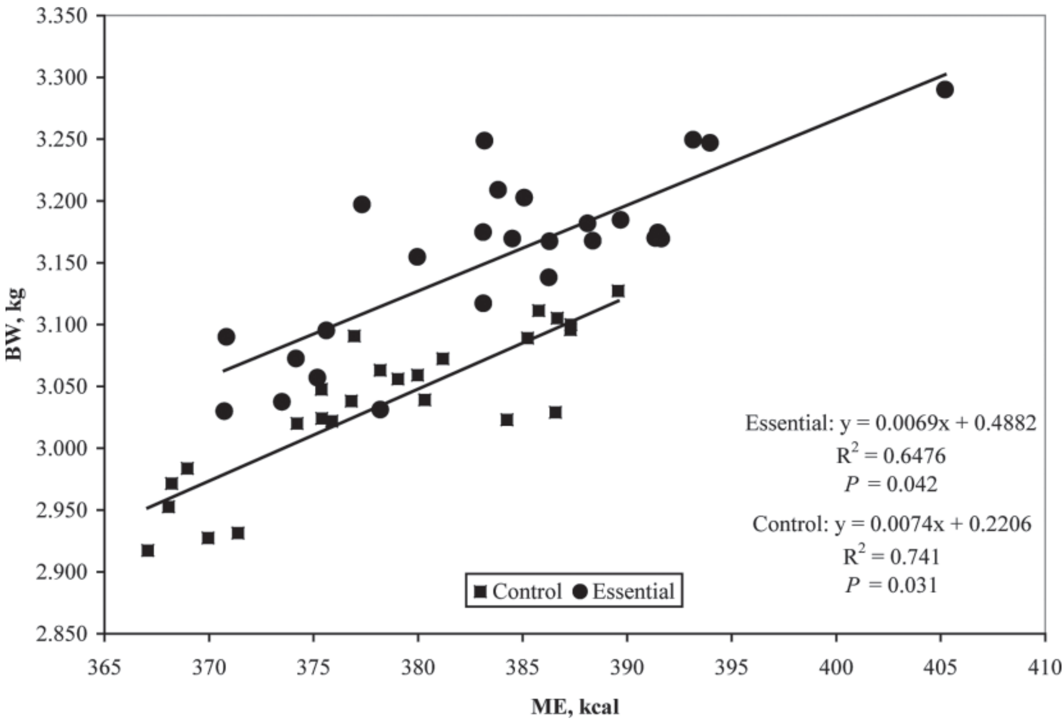

Figure 1. Regression equations of the calculated average daily ME intakes vs. the BW at d 42 for the treatments with and without the castor oil-cashew nut shell liquid (CNSL) mixture [10] from 1 to 42 d of age.

affect dietary ME content [16]. Therefore, if monensin toxicity had affected protein rather than energy utilization, the carcass data should have shown decreases in meat yields for the birds supplemented with monensin. However, meat yields were not affected by monensin supplementation. Therefore, it can be concluded that monensin did not decrease performance.

Little published literature is available that might explain the improved performance of the birds supplemented with these functional oils. However, one could speculate that the antimicrobial activity of castor oil and CNSL [7, 8] decreased the microbial challenge, which resulted in improved performance. These functional oils might work in a similar fashion as antibiotic growth promoters, which modify the intestinal wall thickness by eliminating some types of bacteria [17, 18] and change the physical structure of the intestine [19]. This decrease in the intestinal mass could have a nutrient-sparing effect, which might result in nutrient economy [20]. In this study, this effect was partially observed because the birds supplemented with the castor oil-CNSL mixture (other than at industry energy levels) had smaller intestines than the birds fed diets containing monensin or diets lacking an additive. Moreover, when comparing treatments with low-ME values, the longer the birds were fed the castor oil-CNSL mixture, the lighter were their intestines.

The improved performance of the birds could also be attributed to the reported anti-inflammatory activities of components of the functional oil mixture. Ricinoleic acid, a natural component of castor oil, has been shown to have anti-inflammatory properties [9]. The CNSL contains the resorcinolic lipid cardol, and resorcinolic lipids have been shown to inhibit both cyclooxygenases [21] and lipoxygenases [22], which are involved in the inflammatory response. Finally, both cardanol, (another CNSL component) and cardol are known antioxidants [23]. Inflammation is a pro-oxidative process, and increasing the levels of antioxidants might limit inflammatory responses. Therefore, birds supplemented with the castor oil-CNSL mixture might not respond as strongly to inflammatory challenges. Prolonged inflammation is known to cause metabolic inefficiency [24], and birds

Table 8. Carcass characteristics of broilers fed different levels of ME with and without the castor oil-cashew nut shell liquid (CNSL) mixture supplement[1]

	Type of additive			Carcass characteristic, % of BW					
Item	1 to 21 d	21 to 35 d	35 to 42 d	Carcass	Abdominal fat	Breasts	Legs + thighs	Wings	Intestines
Energy level									
Industry	Monensin	Monensin	None	77.68	2.21	29.61[a]	32.16[ab]	10.10	3.72[a]
Industry	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	77.81	2.05	28.66[ab]	32.19[ab]	10.15	3.70[a]
Industry − 100 kcal/kg	Monensin	Monensin	None	78.65	1.93	29.69[a]	32.21[ab]	10.11	3.72[a]
Industry − 100 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	78.46	1.94	28.74[ab]	32.83[ab]	10.15	3.31[c]
Industry − 200 kcal/kg	Monensin	Monensin	None	78.49	2.00	29.36[ab]	32.04[ab]	10.39	3.71[a]
Industry − 200 kcal/kg	Castor oil-CNSL	Castor oil-CNSL	Castor oil-CNSL	78.53	1.96	29.76[a]	32.00[b]	10.38	3.42[b]
Industry − 100 kcal/kg	Monensin	Castor oil-CNSL	Castor oil-CNSL	77.62	1.98	28.36[ab]	32.75[ab]	10.22	3.66[ab]
Industry − 200 kcal/kg	Monensin	Castor oil-CNSL	Castor oil-CNSL	78.89	2.05	28.75[ab]	33.08[ab]	10.20	3.49[ab]
Industry − 100 kcal/kg	Monensin	Monensin	Castor oil-CNSL	77.90	1.86	28.15[b]	33.23[a]	10.23	3.67[a]
Industry − 200 kcal/kg	Monensin	Monensin	Castor oil-CNSL	78.22	1.97	29.21[ab]	32.35[ab]	10.11	3.67[ab]
SEM				0.95	0.30	0.010	0.89	0.86	0.01

[a–c]Values in the same column with different superscripts are significantly different ($P < 0.05$).

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supplemented with the castor oil-CNSL mixture might be more metabolically efficient because of their smaller inflammatory responses.

CONCLUSIONS AND APPLICATIONS

1. Supplementing the diets of chickens with the castor oil-CNSL mixture improved performance parameters of the birds when dietary ME levels were equal.
2. Addition of the castor oil-CNSL mixture to the feed allowed for a reduction in ME of 100 kcal/kg without a negative effect on performance parameters.
3. The improvement in performance of birds supplemented with the castor oil-CNSL mixture might be related to the antimicrobial and anti-inflammatory effects of the functional oils.

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