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Performance, carcass yield, and meat quality of broilers supplemented with organic or inorganic zinc

[*Desempenho, rendimento e qualidade da carne de frangos de corte suplementados com zinco orgânico ou inorgânico*]

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ABSTRACT

A total of 640 one-day-old Cobb broiler chicks, half male and half female, were reared up to 49 days of age. A completely randomized 2 × 4 factorial design was used. Experimental treatments consisted of four levels of organic zinc supplementation and one control (inorganic zinc supplementation) and two levels of sex (female and male), with four replicates of 16 birds per experimental plot. Animal performance, carcass and cut yields, and meat quality were evaluated. Feed intake increased with zinc supplementation. Broilers that received the lowest level of organic zinc showed better feed conversion than those fed an equivalent level of inorganic zinc. Increased levels of organic zinc reduced the abdominal fat content in females but impaired the oxidative stability of meat. The results showed that male broilers have better performance, carcass yield, and meat quality than females and that organic zinc improves broiler feed conversion and reduces abdominal fat but increases lipid oxidation in meat.

Keywords: birds, color, lipid oxidation, oligoelement, organic minerals, meat pH

RESUMO

Foram alojados 640 pintainhos de corte, sendo metade de machos e metade de fêmeas, da linhagem Cobb, de um a 49 dias de idade. Foi adotado um delineamento inteiramente ao acaso, em esquema fatorial 2 × 4. Os tratamentos experimentais consistiram em quatro níveis de suplementação de zinco orgânico e um controle inorgânico, e diferentes sexos, com quatro repetições de 16 aves por parcela experimental. Foram avaliados o desempenho, a característica da carcaça e dos cortes, bem como a qualidade de carne dos frangos. O aumento dos níveis de zinco elevou o consumo de ração dos frangos. Os frangos que receberam zinco orgânico na exigência mínima apresentaram melhor conversão alimentar comparados àqueles que receberam ração de fonte inorgânica. O aumento nos níveis de zinco orgânico proporcionou redução no teor de gordura abdominal para fêmeas, mas níveis de zinco orgânico prejudicaram a estabilidade oxidativa da carne. Conclui-se que frangos machos apresentam melhor desempenho, carcaça e qualidade de carne em relação às fêmeas, e que o zinco orgânico melhora a conversão alimentar dos frangos, reduz a gordura abdominal, porém eleva a oxidação lipídica da carne.

Palavras-chave: aves, cor, minerais orgânicos, oxidação lipídica, oligoelemento, pH da carne

INTRODUCTION

Modern poultry farming has been characterized by the production of broilers with high growth rates and weight gain. Research on breeding, nutrition, sanitation, and management practices has been carried out to promote the development of the poultry production chain. Minerals are of great importance for bird development, acting as structural components of organs and tissues, electrolytes, and catalysts of enzymatic and hormonal processes (Maiorka and Macari, 2002). Zinc participates in the catalytic site of several enzymes, such as DNA and RNA polymerases, and binds to receptor sites in target cells. The mineral is involved in cell proliferation; protein synthesis; metabolism of carbohydrates, proteins, and lipids; and production, storage, and secretion of hormones, such as insulin, testosterone, and cortisol (González and Silva, 2006).

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The use of organic minerals has received great attention in animal nutrition because of their greater bioavailability compared with that of inorganic mineral sources (Oliveira *et al*., 2010). Absorption can take place via two ways: the mineral attaches to the brush border of the small intestine and is absorbed by the epithelial cell or, as occurs in most cases, the chelating agent is absorbed and transports the mineral through the intestinal cell wall (Kratzer and Vohra, 1996).

Zinc is a constituent of superoxide dismutase, an enzyme involved in the stabilization of structural membranes and in cell protection against lipid peroxidation (Meunier *et al*., 2005). Lipid oxidation affects the stability of meat, consequently impacting shelf life, which can be enhanced by the addition of antioxidants to animal diet (Murakami, 2009).

Some animal feed components are not antioxidants but are essential to endogenous antioxidant systems (Papas, 1999). Zinc is such a component; it has antioxidant effects and thus can increase the oxidative stability of meat. Male and female broilers present different growth curves: males have a lower growth rate than females and take longer to reach their maximum growth rate for weight gain and breast weight, but they exhibit higher fat and muscle deposition. Because of these differences, male and female broilers have different nutritional requirements (Scheuermann *et al*., 2003).

Moro *et al*. (2005) evaluated four commercial broiler strains and observed that males had better weight gain, average daily gain, feed intake, feed conversion ratio, and production efficiency index than females. Male broilers have higher muscle fiber density, a factor that can influence the quality of poultry meat (Scheuermann *et al*., 2003). Females have fewer muscle fibers, larger myofiber cross-sectional area, and, consequently, higher glycolytic potential, which can negatively affect meat quality. The aim of this study was to evaluate the performance, carcass and cut yields, and meat quality of male and female broiler chickens supplemented with different sources and levels of zinc.

MATERIAL AND METHODS

The experiment was conducted at the Bird Nutrition Research Unit and the Laboratory of Carcass Analysis of the Farm School of Londrina State University, Paraná, Brazil, and at the Laboratory of Animal Nutrition of Londrina State University, Paraná, Brazil. A total of 640 one-day-old Cobb broiler chicks, half male and half female, were used in this study. Birds were housed and received water and feed *ad libitum* during the 49-day experimental period. The period was divided into three phases: starter (1–21 days), grower (22–42 days), and finisher (43–49 days). The following production data were evaluated: feed intake, weight gain, feed conversion ratio, and livability.

Experimental diets (Table 1) met the minimum requirements for each sex, as described by Rostagno *et al*. (2005). Chicks were supplemented with inorganic or organic zinc, according to the following treatments: control, 66, 60, and 46mg/kg inorganic zinc; B, 33, 30, and 23mg/kg organic zinc; C, 66, 60, and 46mg/kg organic zinc; D, 99, 90, and 69mg/kg organic zinc; and E, 132, 120, and 92mg/kg organic zinc (starter, grower, and finisher phases, respectively). The source of inorganic zinc was zinc oxide. Bioplex® Zn was the source of organic zinc. The vitamin-mineral premix did not contain zinc in its formulation. A completely randomized 2 × 4 factorial design was used. Experimental treatments consisted of four levels of organic zinc supplementation and a control (inorganic zinc supplementation) and two levels of sex (female and male), with four replicates of 16 birds per experimental plot.

On day 50 two broilers from each plot were weighed and killed, representing the average weight of the plot, totaling 8 birds per treatment. The broilers were analyzed for carcass yield, cut yield, and meat quality. Prior to slaughter, broilers were fasted for 10h. Broilers were killed by electrical stunning using a Fluxo FX 2.0 equipment, followed by bleeding, scalding, and evisceration. Carcasses were cut into retail cuts for yield analysis. Carcass yield was obtained by weighing birds before slaughter and after evisceration and removal of the head, neck, and feet. Cut yield was determined by dividing the weight of the legs (thigh and drumstick), back, wings, and breast by the weight of the eviscerated carcass.

Table 1. Composition of experimental diets for broiler chickens during the starter, grower, and finisher periods

Ingredient (%)	Starter (1–21 days)		Grower (22–42 days)		Finisher (43–49 days)	
	Female	Male	Female	Male	Female	Male
Corn grain	63.767	59.870	64.416	61.940	69.870	69.410
Soybean meal, 45% protein	34.022	34.020	28.940	30.730	24.191	25.030
Dicalcium phosphate	1.878	1.870	3.066	3.520	2.824	3.060
Limestone	1.542	0.830	1.576	1.680	1.341	1.450
Soybean oil	0.827	1.540	0.759	0.730	0.727	0.750
L-Lysine hydrochloride	0.450	0.450	0.401	0.420	0.400	0.400
Salt	0.449	0.450	0.400	0.400	0.360	0.380
Vitamin-mineral premix[1]	0.400	0.400	0.205	0.250	0.154	0.280
DL-Methionine	0.376	0.380	0.203	0.250	0.134	0.210
L-Threonine	0.184	0.180	0.036	0.070	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000
ME[2] (Kcal/kg)	3.000	3.000	3.150	3.150	3.200	3.200
Available phosphorus	0.430	0.460	0.398	0.418	0.350	0.370
Digestible lysine	1.316	1.330	1.020	1.099	0.873	0.992
Digestible methionine and cystine	0.934	0.944	0.734	0.791	0.629	0.714
Digestible methionine	0.664	0.667	0.473	0.525	0.349	0.467
Crude protein	20.450	21.410	19.040	19.730	17.230	17.660
Sodium	0.210	0.220	0.198	0.208	0.180	0.190
Digestible threonine	0.855	0.865	0.663	0.714	0.369	0.580
Calcium	0.860	0.910	0.794	0.837	0.710	0.750

[1]Composition (per kg of premix): Starter diet, vitamin A, 2,400.000IU/g; vitamin D3, 671.667IU/g; vitamin E, 2,133.333mg; vitamin B1, 1,486.333mg; vitamin B2, 1,066.667mg; vitamin B6, 280.500mg; vitamin B12, 2,666.667mg; vitamin K3, 537.333mg; pantothenic acid, 2,153.333mg; niacin, 5,341.000mg; folic acid, 66.667mg; biotin, 3.333mg; choline, 74,666.660mg; methionine, 322,575.000mg; lysine, 122,500.000mg; iron, 7,000.000mg; copper, 1,500.000mg; manganese, 11,625.000mg; cobalt, 33.333mg; iodine, 162.500mg; selenium, 50.000mg; and antioxidant, 2,666.667mg. Grower diet, vitamin A, 2,340.000IU/g; vitamin D3, 654.875IU/g; vitamin E, 2,080.000mg; vitamin B1, 1,449.175mg; vitamin B2, 1,040.000mg; vitamin B6, 273.488mg; vitamin B12, 2,600.000mg; vitamin K3, 523.900mg; pantothenic acid, 2,099.500mg; niacin, 5,207.475mg; folic acid, 65.000mg; biotin, 3.250mg; choline, 72,800.000mg; methionine, 333,073.100mg; lysine, 98,000.000mg; iron, 6,825.000mg; copper, 1,462.500mg; manganese, 11,334.380mg; cobalt, 32.500mg; iodine, 158.438mg; selenium, 48.750mg; and antioxidant, 2,600.000mg. Finisher diet, vitamin A, 2,250.000IU/g; vitamin D3, 629.688IU/g; vitamin E, 2,000.000mg; vitamin B1, 1,393.438mg; vitamin B2, 1,000.000mg; vitamin B6, 262.969mg; vitamin B12, 2,500.000mg; vitamin K3, 503.750mg; pantothenic acid, 2,018.750mg; niacin, 5,007.188mg; folic acid, 62.500mg; biotin, 3.125mg; choline, 70,000.000mg; methionine, 297,070.300mg; lysine, 114,333.300mg; iron, 6,562.500mg; copper, 1,406.250mg; manganese, 10,898.440mg; cobalt, 31.250mg; iodine, 152.344mg; selenium, 46.875mg; and antioxidant, 2,500.000mg. [2] ME, metabolizable energy.

For meat quality analysis, chicken breasts were harvested and placed in an ice water bath at 4°C for 24h. pH was determined by insertion of a pH electrode (Testo 205 pHmeter) into the cranioventral side of the pectoralis major muscle, according to Olívo *et al*. (2001). Color was measured at three points on the ventral side of the pectoralis major using a Konica Minolta CR-10 colorimeter. Results were expressed as CIELab color parameters L* (lightness), a* (redness), and b* (yellowness). Water-holding capacity (WHC) was determined by the filter paper press method (Barbut, 1996). Briefly, a 2g sample of breast meat was placed between two filter papers and compressed with a 10kg weight for 5min. Then, the breast meat was weighed, and the amount of water released was determined by calculating the difference in weight before and after compression. WHC was expressed as the percentage of released water relative to the initial weight of the sample. Cooking loss was determined according to the method of Cason *et al*. (1997). Breast meat samples were weighed, packed, and placed in a water bath at 85°C for 30min. Then, samples were cooled to room temperature and weighed. Cooking loss was determined as the difference between the initial and final weight. Thiobarbituric acid reactive substances (TBARS) content was determined in breast samples after 90 days of storage at −20°C, according to the method described by Pikul *et al*. (1989). Briefly, samples (10g) were homogenized with 50mL of 7.5% (v/v) trichloroacetic acid solution. The supernatant was filtered, and 4mL aliquots were mixed with 5mL of thiobarbituric acid solution, placed in boiling water, cooled, and read at 538nm.

Results were submitted to analysis of variance followed by Tukey's test at the 5% significance level. Results of the different treatments were submitted to polynomial regression analysis. Comparison between treatments and the control was carried out by Dunnett's test at the 5% significance level. This research was approved by the Ethics Committee on the Use of Animals (process no. 23/10).

RESULTS AND DISCUSSION

The results of broiler performance from 1 to 49 days of age (Table 2) showed that there was no significant effect of organic zinc level on weight gain, feed conversion ratio, or livability. Furthermore, no interaction effect was found between zinc level and bird sex. Dietary supplementation with high levels of zinc, however, increased feed intake, as expressed by the linear regression equation $y= 5229.99 + 5.3787x$ with $R^2= 0.76$.

Table 2. Feed intake (FI), weight gain (WG), feed conversion ratio (FCR), and livability (L) of female and male broilers fed diets supplemented with different sources and levels of zinc from 1 to 49 days of age

Factor	FI (g)	WG (g)	FCR	L (%)
		Treatment (Zn)[1]		
A	5547.12	2956.33	1.88	97.65
B	5385.53	2889.91	1.87	98.43
C	5376.63	2990.80	1.83[2]	99.21
D	5709.18	3054.95	1.88	98.43
E	5687.71	3006.65	1.89	100.00
P-value	<0.01[3]	0.55	0.42	0.67
		Sex (S)[4]		
Female	5304.41 a	2680.48 a	1.98 a	99.61
Male	5775.12 b	3290.68 b	1.76 b	98.44
P-value	0.0016	<0.01	<0.01	0.27
F-value (Zn × S)	0.08	0.44	0.08	0.67
CV (%)	3.56	7.79	4.51	2.95

[1] Zinc sources and levels in starter, grower, and finisher diets: A (control), 66, 60, and 46mg/kg inorganic zinc; B, 33, 30, and 23mg/kg organic zinc; C, 66, 60, and 46mg/kg organic zinc; D, 99, 90, and 69mg/kg organic zinc; and E, 132, 120, and 92mg/kg organic zinc, respectively. [2] Differs significantly from the control by Dunnett's test ($P< 0.05$). [3] The relationship between zinc supplementation and FI was best described by the linear equation $y= 5229.99 + 5.3873x$ with $R^2= 0.76$. [4] Means within a column followed by different letters differ significantly by Tukey's test ($P< 0.05$).

Jahanian *et al*. (2007) obtained similar results using different organic zinc levels and sources (zinc acetate, zinc methionine, and zinc lysine). The authors observed an increase ($P< 0.01$) in feed intake with zinc supplementation and reported that zinc methionine gave the best results. Osman and Mohan (2007) reported that broilers fed a diet supplemented with 400 or 500mg/kg zinc had higher feed intake than non-supplemented birds.

According to Medeiros *et al*. (2011), increased zinc levels may influence the production of angiotensin-converting enzyme (ACE), responsible for the conversion of angiotensin I to angiotensin II, which induces vasoconstriction in the brain, kidneys, lungs, and skeletal muscles and stimulates the release of aldosterone from the adrenal gland, increasing blood pressure by enhancing sodium and water reabsorption. This metabolic response results in higher energy expenditure and increased feed intake.

Dunnett's test revealed no significant differences in feed intake, weight gain, and livability between control broilers (supplemented with inorganic zinc) and broilers supplemented with organic zinc. However, feed conversion ratio differed significantly between the groups. Broilers that received the lowest level of organic zinc showed better feed conversion than those fed an equivalent level of inorganic zinc. This result can be explained by the higher bioavailability of organic minerals compared with that of inorganic mineral sources (Oliveira *et al*., 2010), as the chelating agent is easily absorbed and transports the metal ion through the intestinal cell wall. Hess *et al*. (2001) studied female broiler diets supplemented with different zinc sources and concluded that feed conversion was improved by supplementation with zinc amino acid complexes.

Rossi *et al*. (2003), who studied the effects of five graded levels of organic zinc (0, 15, 30, 45, and 60mg/kg), and Gomes *et al*. (2008), who analyzed the effects of six graded levels of organic zinc (12, 37, 62, 87, 112, and 137mg/kg), found similar results to those of the present study: that zinc supplementation did not improve (P> 0.05) broiler weight gain.

Interestingly, male broilers showed significantly higher feed intake and weight gain and lower feed conversion ratio than female broilers. However, no differences (P> 0.05) in livability were observed between male and female birds. According to Fanatico *et al*. (2005), broiler sex influences muscle development and differences in weight between sexes increase with age. These observations are in accord with of Gonzales and Sartori (2008), who noted that androgens, hormones responsible for muscle anabolism, contribute to broiler development and are found in higher concentrations in males. Almeida and Zuber (2002), Mendes and Saldanha (2004), and Dalanezi *et al*. (2005) also evaluated broiler development by sex and reported that males perform better than females.

Carcass and cut yields (Table 3) were not influenced by organic zinc levels or sources. Dunnett's test did not reveal any significant difference in yield between organic zinc treatments and the control (P> 0.05). These results can be attributed to the lack of significant difference in weight gain between treatments, which resulted in similar carcass and cut yields. Rossi *et al*. (2007), Trindade Neto *et al*. (2010), and Medeiros *et al*. (2012) investigated the effect of different levels of organic zinc on broiler performance and concluded that carcass and cut yields were not influenced by zinc supplementation. Male broilers had higher leg yield than females (P<0.01). This result is in agreement with the data of Dalanezi *et al*. (2005).

Abdominal fat yield was higher (P<0.01) in females than in males. Similar results were obtained by Mendes *et al*. (2004) and Murakami *et al*. (2010). Females undergo specific physiological maturation processes for reproduction, including fat accumulation, which is known to increase with age (Gaiotto, 2004). As female broilers have more adipocytes than males, they have greater fat deposition capacity (Langslow and Lewis, 1974).

However, female broilers showed a reduction (P<0.01) in abdominal fat content with increasing zinc concentration. The relationship was best described by the quadratic equation $y = 6.6037 - 0.1055x + 0.0007x^2$ with $R^2 = 0.99$. The minimum value of y is given by organic zinc supplementation at 91.99mg/kg during the finisher phase.

Osman and Mohan (2007) supplemented broiler diets with 300, 400, or 500mg/kg zinc methionine and found no significant differences in carcass yield, cut yield, and abdominal fat deposition at 49 days of age. The authors did not find a decrease in abdominal fat yield in female broilers with increased levels of organic zinc, as observed in the present study (Table 4).

Table 3. Mean carcass and cut yield of 50-day old broilers fed diets containing different sources and levels of zinc

Factor	Carcass (%)	Breast (%)	Leg (%)	Wing (%)	Back (%)	Fat (%)
			Treatment (Zn)[1]			
A	74.85	37.35	30.78	10.47	18.63	2.76
B	75.06	37.16	29.87	10.60	18.96	3.41
C	74.66	37.50	30.00	10.98	18.68	2.83
D	74.06	37.72	30.30	10.46	18.78	2.76
E	74.27	37.40	30.58	10.67	18.54	2.81
P-value	0.48	0.90	0.30	0.14	0.68	0.0107
			Sex (S)[2]			
Female	74.75	37.17	29.80 a	10.73	18.62	3.63 a
Male	74.27	37.72	30.58 b	10.62	18.87	1.99 b
P-value	0.32	0.30	0.01	0.51	0.311	<0.01
F-value (Zn × S)	0.1597	0.3414	0.1278	0.8178	0.2087	0.0033
CV (%)	1.82	3.91	2.61	4.13	3.67	13.68

[1]Zinc sources and levels in starter, grower, and finisher diets: A (control), 66, 60, and 46mg/kg inorganic zinc; B, 33, 30, and 23mg/kg organic zinc; C, 66, 60, and 46mg/kg organic zinc; D, 99, 90, and 69mg/kg organic zinc; and E, 132, 120, and 92mg/kg organic zinc, respectively. [2] Means within a column followed by different letters differ significantly by Tukey's test (P< 0.05).

Table 4. Interaction effect of zinc level and broiler sex on abdominal fat content (%) of female and male broilers at 50 days of age

Treatment[1]	Female	Male
B	4.60 a	2.22 b
C	3.42 a	2.25 b
D	3.14 a	2.38 b
E	3.63 a	1.99 b
P-value	0.0002[2]	0.5861

Means within the same row followed by different letters differ significantly by Tukey's test (P< 0.05). [1] Zinc sources and levels in starter, grower, and finisher diets: B, 33, 30, and 23mg/kg organic zinc; C, 66, 60, and 46mg/kg organic zinc; D, 99, 90, and 69mg/kg organic zinc; and E, 132, 120, and 92mg/kg organic zinc, respectively. [2] The relationship between zinc supplementation and abdominal fat content in females was best described by the quadratic equation $y= 6.6037 - 0.1055x + 0.0007x^2$ with $R^2 = 0.99$.

The deiodinase type II enzyme, responsible for the peripheral deiodination of thyroxine (T4) to the active form triiodothyronine (T3), may be zinc dependent (Nishiyama *et al.*, 1994). Thus, elevated zinc levels might have promoted the conversion of T4 to T3, increasing metabolic rate, thermogenesis, and oxygen consumption. Furthermore, elevated zinc levels stimulate ACE production, which culminates in the secretion of aldosterone (Valee and Falchuk, 1993). The hormone increases blood pressure and the metabolic rate of several organs, leading to greater energy expenditure. Thus, two zinc-dependent mechanisms are able to increase feed intake and reduce abdominal fat content.

Organic zinc supplementation and broiler sex had no interaction effects on meat quality. Meat pH, color, WHC, and cooking loss were not influenced by zinc sources or levels (Table 5 and 6). Zinc level had a linear effect (P< 0.01) on lipid oxidation, according to the equation $y= 0.5403 + 0.077x$ with $R^2= 0.94$; that is, lipid oxidation increased with increasing levels of zinc.

The mechanism by which zinc supplementation might have increased lipid oxidation is related to other minerals. In excess, zinc may exert negative effects on copper homeostasis and consequently on the antioxidant system (Harris, 1992), because copper is a cofactor for the enzyme superoxide dismutase (Cu-Zn-SOD), which is an essential defense against free radicals (Signorini and Signorini, 1995). Another copper-dependent enzyme, ceruloplasmin, is a free radical scavenger. According to Schümann *et al.* (2002), chronic excessive intake of zinc interferes with the absorption and metabolism of other trace elements, such as iron and copper, which are transported and stored by ceruloplasmin. By keeping iron and copper ions bound to its structure, ceruloplasmin reduces oxidative stress by inhibiting the Fenton reaction (Gutteridge, 1985), which in turn prevents or minimizes free radical generation (Schümann *et al*., 2002) and lipid and phospholipid oxidation (Gutteridge, 1985). In short, excessive zinc intake can lead to copper deficiency, affecting iron absorption, reducing superoxide dismutase and ceruloplasmin levels, increasing free radical generation and meat oxidation. The only meat quality parameter affected by broiler sex was WHC (Table 6). Male broilers had higher (P< 0.05) WHC than females. Therefore, the meat of male broilers had greater juiciness than the meat of females.

Table 5. Meat pH and color (L*, lightness; a*, redness; and b*, yellowness) of female and male broilers supplemented with different sources and levels of zinc

Factor	pH	L*	a*	b*
		Treatment (Zn)[1]		
A	5.82	52.46	3.81	11.10
B	5.81	55.22	2.55	11.54
C	5.84	54.20	3.02	10.73
D	5.89	54.82	3.52	11.38
E	5.83	53.65	2.88	12.15
P-value	0.66	0.51	0.67	0.10
		Sex (S)		
Female	5.85	55.19	2.51	11.26
Male	5.83	53.76	3.47	11.62
P-value	0.80	0.08	0.10	0.34
F value (Zn × S)	0.4631	0.4906	0.3130	0.4745

[1]Zinc sources and levels in starter, grower, and finisher diets: A (control), 66, 60, and 46mg/kg inorganic zinc; B, 33, 30, and 23mg/kg organic zinc; C, 66, 60, and 46mg/kg organic zinc; D, 99, 90, and 69mg/kg organic zinc; and E, 132, 120, and 92mg/kg organic zinc, respectively.

Table 6. Water-holding capacity (WHC), cooking loss (CL), and lipid oxidation (thiobarbituric acid reactive substances, TBARS) in the meat of female and male broilers supplemented with different sources and levels of zinc

Factor	WHC (%)	CL (%)	TBARS (mg malondialdehyde/kg)
		Treatment (Zn)[1]	
A	71.50	22.14	0.68
B	68.68	23.17	0.68
C	69.34	22.06	0.67
D	69.19	21.05	0.88
E	69.59	21.31	0.96
P-value	0.90	0.44	0.0004[2]
		Sex (S)[3]	
Female	68.29 a	21.83	0.82 a
Male	70.10 b	21.96	0.70 b
P-value	0.0490	0.9021	0.0120
F-value (Zn × S)	0.9720	0.5687	0.8201
CV (%)	3.57	12.72	27.01

[1] Zinc sources and levels in starter, grower, and finisher diets: A (control), 66, 60, and 46mg/kg inorganic zinc; B, 33, 30, and 23mg/kg organic zinc; C, 66, 60, and 46mg/kg organic zinc; D, 99, 90, and 69mg/kg organic zinc; and E, 132, 120, and 92mg/kg organic zinc, respectively. [2] The relationship between zinc supplementation and lipid oxidation was best described by the linear equation $y= 0.5403 + 0.077x$ with $R^2= 0.94$. [3] Means within a column followed by different letters differ significantly by Tukey's test (P< 0.05).

CONCLUSION

Male broilers perform better than female broilers. Dietary supplementation with high levels of organic zinc reduces abdominal fat deposition in female broilers but shortens the shelf life of meat. Male broilers yield higher quality meat with higher WHC and, thus, improved sensorial quality.

REFERENCES

ALMEIDA, A.M.; ZUBER, U. Influência das interações estirpe-sexo e manejo-ração sobre o peso vivo e o rendimento de carcaça em frangos do tipo "campestre". *Rev. Port. Cienc. Vet.*, v.97, p.139-142, 2002.

BARBUT, S. Estimates and detection of the PSE problem in young trukey breast meat. *Can. J. Anim. Sci.*, v.76, p.455-457, 1996.

CASON, J. A. *et al*. Effect of muscle oppositon during rigor on development of broiler breast meat tenderness. *Poult. Sci.*, v.76, p. 725-787, 1997.

DALANEZI, J.A.; MENDES, A.A.; GARCIA, E.A. *et al*. Efeito da idade da matriz sobre o desempenho e rendimento de carcaça de frangos de corte. *Arq. Bras. Med. Vet. Zootec.*, v.57, p.250-260, 2005.

FANATICO, A.C.; PILLAI, P.B.; CAVITT, C.M. *et al*. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: Growth performance and carcass yield. *Poult. Sci.*, v.84, p.1321-1327, 2005.

GAIOTTO, J.B. *Determinação da energia metabolizável de gorduras e sua aplicação na formulação de dietas para frangos de corte*. 2004. 82f. Tese (Doutorado em Agronomia) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, SP.

GOMES, P.C.; RIGUEIRA, D.C.M.; ROSTAGNO, H.S. *et al*. Exigências nutricionais de zinco para frangos de corte machos e fêmeas na fase inicial. *Rev. Bras. Zootec.*, v.37, p.79-83, 2008.

GONZALES, E.; SARTORI, J.R. Crescimento e metabolismo muscular. In: MACARI, M.; FURLAN, R.L.; GONZALES, E. *Fisiologia aviária aplicada a frangos de corte*. 2.ed. Jaboticabal: UNESP/FUNEP, 2008. p.209-230.

GONZÁLEZ, F.; SILVA, S. *Introdução à bioquímica clínica veterinária*. 2.ed. Porto Alegre: Universidade Federal do Rio Grande do Sul, 2006. 30p.

GUTTERIDGE, J.M.C. Inhibition of the Fenton reaction by the protein caeruloplasmin and other copper complexes. Assessment of ferroxidase and radical scavenging activities. *Chem. Biol. Interact*., v.56, p.113-20, 1985.

HARRIS, E.D. Copper as a cofactor and regulator of copper, zinc superoxide dismutase. *J. Nutr.*, v.122, p.636-640, 1992.

HESS, J.B.; BILGILI, S.F.; PARSON, A.M.; DOWNS, K.M. Influence of complexed zinc products on live performance and carcass grade of broilers. *J. Appl. Anim. Res.*, v.19, p.49-60, 2001.

JAHANIAN, N.H.; MOGHADDAM, H.N.; POURREZA, J. Determination of chemical composition, mineral contents and protein quality of poultry byproduct meal. *Int. J. Poult. Sci.*, p.875-882, 2007.

KOURY, J.C.; DONANGELO, C.M. Homeostase do cobre e atividade física**.** *Rev. Educ. Física*, v.136, p.47-56, 2007.

KRATZER, F.H.; VOHRA, P. *Chelates in nutrition*. Boca Raton: CRC Press, 1996.

LANGSLOW, D.R.; LEWIS, R.J. Alterations with age in composition and lipolytic activity of adipose tissue from male and female chickens. *Br. Poult. Sci.*, v.15, p.267-273, 1974.

LEHNINGER, A.L. *Princípios de bioquímica*. São Paulo: Savier, 1985. p.194-195, 553.

MAIORKA, A.; MACARI, M. Absorção de minerais. In: MACARI, M., FURLAN, R. L., GONZALES, E. (Eds.). *Fisiologia aviária aplicada a frangos de corte*. Jaboticabal: FUNESP/UNESP, 2002. v.13, p.167-173.

MEDEIROS, I.M.; ELISANIE, E.N.M.; SOBRINHO, J.P.A. *et al*. Efeito do zinco orgânico sobre o rendimento de carcaça e cortes de frangos de corte criados em cama nova e reciclada. *Rev. Cient. Prod. Anim.*, v.14, p.62-64, 2012.

MEDEIROS, L.G.; ALMEIDA, M.; ALTMANN, A.H.S. Desempenho e rendimento de carcaça de frangos de corte suplementados com diferentes níveis de zinco quelatado. In: CONGRESSO BRASILEIRO DE ZOOTECNIA, 48., 2011, João Pessoa. *Anais*... João Pessoa: SBZ, 2011.

MENDES, A.A.; SALDANHA, E.S.P.B. A cadeia produtiva da carne de aves no Brasil. In: MENDES, A.A.; MACARI, M. (Eds.). *Produção de frangos de corte*. Campinas: FACTA, 2004. p.1-22.

MEUNIER, N.; O'CONNOR, J.M.; MAIANI, G. *et al*. Importance of zinc in the elderly: the Zenith study. *Eur. J. Clin. Nutr.*, v.59, p.1-4, 2005.

MORO, D.N.; ZANELLA, I.; FIGUEIREDO, E.A.P.; SILVA, J.H.S. Desempenho produtivo de quatro linhagens de frangos de corte. *Rev. Cent. Ciênc. Rural*, v.35, p.446-449, 2005.

MURAKAMI, K.T.T. *Óleo de linhaça como principal fonte lipídica na dieta de frangos de corte.* 2009. 64f. Dissertação (Mestrado em Ciência Animal) – Faculdade de Odontologia e Curso de Medicina Veterinária, Universidade Estadual Paulista, Araçatuba, SP.

MURAKAMI, K.T.T.; PINTO, M.F.; PONSANO, E.H.G.; GARCIA, N.M. Desempenho produtivo e qualidade da carne de frangos alimentados com ração contendo óleo de linhaça. *Pesqui. Agropecu. Bras.*, v.45, p.401-407, 2010.

NISHIYAMA, S.; FUTAGOISHI-SUGINOHARA, Y.; MATSUKURA, T. *et al*. Zinc supplementation alters thyroid hormone metabolism in disabled patients with zinc deficiency. *J. Am. Coll. Nutr.*, v.13, p.62, 1994.

OLIVEIRA, W.N.K.; SILVA, J.L.; LUCENA, C.A.L. *Uso do zinco orgânico na prevenção de lesões de pododermatite em aves.* Recife: UFRPE, 2010.

OLÍVO, R.; SOARES, A.L.; IDA, E.I.; SHIMOKOMAKI, M. Dietary vitamin E inhibits poultry PSE and improves meat function properties. *J. Food Biochem.*, v.25, p.271-283, 2001.

OSMAN, A.M.R.; MOHAN, S.R. *Performance and carcass characteristics of broiler chicks fed diets supplemented with commercial zinc-methionine.* 4.ed. Egypt: [s.n.] 2007.

PAPAS, A.M. Diet and antioxidant status. *Food Chem. Toxicol.*, v.37, p.999-1007, 1999.

PIKUL, J. *et al*. Evaluation of tree modified TBA methods for measuring lipid oxidation in chicken meat. *J. Agric. Food Chem.*, v.37, p.1309-1313, 1989.

ROSSI, P. *et al.* Influence of Graded Levels of Organic Zinc on Growth Performance and Carcass Traits of Broilers. *J. Appl. Poult. Res.* v.16, p.219–225, 2007.

SCHEUERMANN, G.N. *et al*. Effect of muscle oppositon during rigor on development of broiler breast meat tenderness. *Poult. Sci.*, v.82, p.1648-1658, 2003.

SCHÜMANN, K. *et al*. Hohenheim consensus workshop: copper. *Eur. J. Clin. Nutr.*, v.56, p.469-483, 2002.

SIGNORINI, J.L.; SIGNORINI, S.L. *Atividade física e radicais livres*: aspectos biológicos, químicos, fisiopatológicos e preventivos. 2.ed. São Paulo: Icone, 1995. 192p.

TRINDADE NETO, M.A.; KOBASHIGAWA, E.; NAMAZU, L.B. *et al*. Lisina digestível e zinco orgânico para frangos de corte machos na fase de 22 a 42 dias de idade. *Rev. Bras. Zootec*., v.39, p.2460-2470, 2010.

VALLEE B.L.; FALCHUK, K.H. The biochemical basis of zinc physiology. *Physiol. Rev*., v.73, p.79-118, 1993.