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ANIMAL PRODUCTION

Fatty acid profile of slow-growing broilers supplemented with biocomplexed minerals

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ABSTRACT: *This study was conducted to evaluate the effects of dietary supplementation with biocomplexed selenium and chromium on the fatty acid profile of the breast and thigh of males and females broilers of the Label Rouge lineage. The experimental design was completely randomized arranged in a 3 x 2 factorial scheme corresponding to three diets (control; 0.40 ppm of chromium; 0.50 ppm of selenium) and two sexes. Each treatment consisted of three plots of five broilers. The fatty acid profile was evaluated in the breast and thigh samples. The addition of biocomplexed selenium in the broilers diets increased the content of long chain fatty acid of the omega 3 and 6 series (docosahexaenoic - DHA and arachidonic acids, respectively), the total of omega 6 and the stearic acid content on the breast* (pectoralis major *muscle). In addition, selenium supplementation caused a reduction in oleic acid content and in total of monounsaturated in the same muscle. Males had higher contents of linoleic and linolenic acids, and total of polyunsaturated; and lower content of oleic acid, total of monounsaturated and saturated in the thigh. The broilers supplemented with biocomplexed selenium and males presented better lipid quality in the muscle by breast and thigh, respectively.*
Key words: *docosahexaenoic acid (DHA), linolenic acid, biocomplexed chromium, omega 3, biocomplexed selenium.*

Perfil de ácidos graxos de frangos de corte de crescimento lento suplementados com minerais biocomplexados

RESUMO: *Este estudo foi conduzido com o objetivo de avaliar os efeitos da suplementação dietética com selênio e cromo biocomplexados sobre o perfil de ácidos graxos do peito e da coxa de frangos de corte machos e fêmeas da linhagem Label Rouge. O delineamento experimental foi inteiramente casualizado em esquema fatorial 3 x 2 correspondendo a três dietas (controle; 0,40 ppm de cromo; 0,50 ppm de selênio) e dois sexos. Cada tratamento foi composto por três parcelas de cinco frangos de corte. O perfil de ácidos graxos foi avaliado nas amostras de peito e coxa. A adição de selênio biocomplexado na dieta de frangos de corte aumentou o teor de ácidos graxos de cadeia longa das séries ômega 3 e 6 (ácido docosahexaenóico - DHA e araquidônico, respectivamente), o total de ômega 6 e o conteúdo de ácido esteárico no peito (músculo* pectoralis major*). Além disso, a suplementação com selênio causou redução no teor de ácido oleico e no total de monoinsaturados no mesmo músculo. Os machos apresentaram maiores teores dos ácidos linoléico e linolênico e total de poliinsaturados; e menor conteúdo de ácido oleico, total de monoinsaturados e saturados na coxa. Os frangos suplementados com selênio biocomplexado e os machos apresentaram melhor qualidade lipídica no músculo do peito e coxa, respectivamente.*
Palavras-chave: *ácido docosahexaenóico (DHA), ácido linolênico, cromo biocomplexado, ômega 3, selênio biocomplexado.*

INTRODUCTION

Lipids are essential dietary nutrients because they perform several physiological functions in the human body. In this sense, the modern consumer has been increasingly concerned with their food, paying attention to quality, nutritional composition of food and its effects on human health (GODFRAY et al., 2018). Although, the total lipid content of foods needs to be considered, its effects on human health depends on lipid quality, more specifically on their fatty acid profile (MARANGONI et al., 2020).

In general, the consumption of meat with higher levels of polyunsaturated fatty acids (PUFA), especially of the omega 3 (ω3) serie, are more indicated, as they are associated with the reduction of the plasma fraction of low density of lipoproteins (LDL and VLDL), total cholesterol

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and; consequently, the risk of cardiovascular disease (VISIOLI & POLI, 2020). Thus, broiler meat can be considered of better lipid quality because, according to RULE et al. (2002), have lower saturated fatty acid (SFA) content and higher PUFA content in muscle tissue when compared to other species, such as cattle.

However, meats with high PUFA levels are more susceptible to lipid peroxidation which occur mainly due to action of free radicals (CASTELLINI et al., 2002). This can lead to negative changes from the point of view of meat quality, such as damage to sensory characteristics, such as changes in color, odor and, especially, in flavor; and, consequently, reduced meat shelf life (HUANG & AHN, 2019). In addition, lipid peroxidation can cause changes in the nutritional quality of meat, with a reduction in the rate PUFA:SFA (PAPPAS et al., 2012). In this context, the supplementation of broiler diets with minerals of antioxidant properties may be an alternative to minimize the lipid oxidation in the meat improving, consequently, their fatty acid profile (LI et al., 2017). These minerals include chromium and selenium, which, according to PREUSS et al. (1997) and SURAI (2002), respectively, have antioxidant properties, preventing the degradation of meat lipid components, especially those with higher omega 3 concentrations.

There was a significant growth in alternative poultry farming, with the production and marketing of free-range chicken meat, not only in Brazil, but also worldwide, which aroused the interest of both producers and large companies in the poultry farming sector (TAYLOR et al., 2018). In view of this growth and seeking improvements in the performance and nutritional quality of meat, it is necessary that some food supplements, such as biocomplexed minerals, already consolidated in industrial poultry farming, be also tested in alternative poultry farming. This is because there are no current studies in the literature that evaluate supplementation with biocomplexed minerals in an alternative production system, with broilers reared in a semi-intensive system, and, more specifically, the effect of these minerals in the diet on the profile of fatty acids of these broilers, which justifies this study.

Therefore, this study evaluated the effects of dietary supplementation with biocomplexed chromium and selenium on the fatty acid profile in the breast and thigh cuts of slow-growing broilers, of both sexes, reared in an alternative system.

MATERIALS AND METHODS

The experiment was conducted at the Poultry Sector of the Department of Agrarian Sciences of the Federal Institute of Minas Gerais - Bambuí Campus (IFMG), in Bambuí, Minas Gerais, Brazil. The experimental design was completely randomized arranged in a 3 x 2 factorial scheme corresponding to three experimental diets (control diet without addition of biocomplexed minerals; diet supplemented with 0.40 ppm of biocomplexed chromium; diet supplemented with 0.50 ppm of biocomplexed selenium) and two sexes, totaling six treatments. Each treatment was evaluated in three plots of five broilers totaling 15 broiler per treatment, each plot being represented by a paddock (experimental unit).

Experimental diets were provided to broilers from 1 to 90 days of age. The control diet was formulated based on corn and soybean meal according to the nutritional recommendations of the Colonial Line Handling Manual (GLOBOAVES, 2015), specific to the Label Rouge lineage, aiming to meet the poultry' requirements in each rearing phase (Table 1). The ingredients composition were considered from the Brazilian Tables for Poultry and Swine (ROSTAGNO et al., 2011). The calculated values of the experimental feed of each phase are presented in table 2. In the diet supplemented with chromium were added 0.34g of chromium picolinate to 100kg of feed (biocomplexed chromium concentration of 12% in the product and purity of 98.64%). Already in the diet supplemented with selenium 5.10g of selenium glycinate for 100kg of feed was used (biocomplexed selenium concentration of 0.98% in the product). All diets were isonutritive and the inclusion of biocomplexed minerals in diets with biocomplexed chromium and selenium were carried out to replace kaolin (inert ingredient). The inclusion levels of biocomplexed minerals in the experimental diets were determined based on the levels evaluated by other authors (KRALIK et al., 2012; HUANG et al., 2016). In all experimental diets used the vitaminic premix with selenium in inorganic form, thus providing 0.37 ppm of inorganic selenium in the diet. In addition to the inorganic selenium present, there was extra supplementation of biocomplexed selenium and chromium in two of the experimental diets.

The broilers were reared for a period from 1 to 29 days (initial phase), in a conventional experimental shed, consisting of 24 pens with an individual area of 2.60 m^2, without access to the grazing area, receiving heating through 250W infrared lamps up to 14 days old and artificial lighting 24 hours a day. Feed and water were provided *ad libitum* in tube feeders and pendular drinkers, respectively. In

Table 1 - Compositions of experimental diets for broilers, according to the rearing phases.

Ingredient (kg)	----------Initial (1 to 29 days)----------			----------Growth I (30 to 49 days)----------		
	C†	Cr‡	Se§	C†	Cr‡	Se§
Corn grain 7%	63.85	63.85	63.85	65.94	65.94	65.94
Soybean meal 46%	31.90	31.90	31.90	29.50	29.50	29.50
Soy oil	-	-	-	0.50	0.50	0.50
Calcitic limestone	1.50	1.50	1.50	1.50	1.50	1.50
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Dicalcium phosphate	1.85	1.85	1.85	1.70	1.70	1.70
Kaolin	0.03	0.02966	0.0249	0.03	0.02966	0.02
CrPic[1]	-	0.00034	-	-	0.00034	-
Selenium glycinate[2]	-	-	0.0051	-	-	0.0051
DL-Methionine 99%	0.22	0.22	0.22	0.21	0.21	0.21
Choline Chloride 60%	0.05	0.05	0.05	0.04	0.04	0.04
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Mineral premix[4]	0.10	0.10	0.10	0.08	0.08	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ingredient (kg)	----------Growth II (50 to 77 days)----------			----------Final (78 to 90 days)----------		
	C†	Cr‡	Se§	C†	Cr‡	Se§
Corn grain 7%	69.24	69.24	69.24	71.25	71.25	71.25
Soybean meal 46%	25.60	25.60	25.60	24.10	24.10	24.10
Soy oil	1.40	1.40	1.40	1.60	1.60	1.60
Calcitic limestone	1.30	1.30	1.30	0.95	0.95	0.95
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Dicalcium phosphate	1.60	1.60	1.60	1.35	1.35	1.35
Kaolin	0.03	0.02966	0.02	0.03	0.02966	0.02
CrPic[1]	-	0.00034	-	-	0.00034	-
Selenium glycinate[2]	-	-	0.0051	-	-	0.0051
DL-Methionine 99%	0.21	0.21	0.21	0.13	0.13	0.13
Choline Chloride 60%	0.04	0.04	0.04	0.03	0.03	0.03
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Mineral premix[4]	0.08	0.08	0.08	0.06	0.06	0.06
Total	100.00	100.00	100.00	100.00	100.00	100.00

†Control diet without the addition of biocomplexed minerals; ‡diet with 0.40 ppm of biocomplexed chromium; §diet with 0.50 ppm of biocomplexed selenium; [1]Chromium picolinate with 12% concentration of biocomplexed chromium and purity of 98.64%; [2]Selenium glycinate with 0.98% concentration of biocomplexed selenium; [3]Guarantee levels per kg of vitamin premix: folic acid 900.0 mg; pantothenic acid 12,000.00 mg; biotin 77.0 mg; calcium 130.0 - 143.7g; niacin 40,000.0 mg; selenium 370.0 mg; vitamin A 8,800,000.0 IU; vitamin B1 2,500.0 mg; vitamin B12 0.04 g; antioxidant 0.02 g; Mn 75 mg; Zn 50 mg; Cu 8 mg; I 0.75 mg; Fe 50 mg; [4]Guarantee levels per kg of mineral premix: copper 7.0 g; iron 50.0 g; iodine 1.5 g; manganese 67.5 g; zinc 45.6 g.

the initial phase, the mean maximum and minimum temperatures inside the house were 32.0 and 21.4 °C, respectively. In the period from 30 to 49 days (growth phase I), from 50 to 77 days (growth phase II) and from 78 to 90 days (final phase), the broilers were raised in an experimental area for breeding free-range chickens, with access to the grazing area, with the grass Tifton 85 (*Cynodon* spp), with feed and water provided *ad libitum* in tube feeders and pendular drinkers, respectively. In these phases, the maximum and minimum temperature averages were 33.0 and 12.5 °C, respectively. In each experimental unit, with an area of 77.35 m^2, 21 broilers were housed, obtaining density around one broiler for each 3.68 m^2 of free area, discounting the coverage area of the mobile hut and thus serving the Official Notice DOI/ DIPOA nº 007/99 of 05/19/1999 (BRASIL, 1999). Each experimental unit had a mobile hut model Embrapa (AVILA et al., 2002), covered with raffia canvas and with a total area of 10 m^2.

At 90 days of age, after eight hours of fasting, broilers were stunned by electronarcosis and

Table 2 - Calculated values of experimental diets for broilers, according to the rearing phase.

Calculated Values	Initial†	Growth I‡	Growth II§	Final¶
Crude Protein (%)	19.43	18.50	17.00	16.42
Crude Fiber (%)	3.132	3.031	2.866	2.816
Calcium (%)	1.150	1.100	1.000	0.800
Total phosphor (%)	0.679	0.643	0.613	0.560
Available phosphor (%)	0.450	0.420	0.400	0.350
Sodium (%)	0.180	0.180	0.180	0.180
Chlorine (%)	0.296	0.296	0.298	0.299
Metabolizable Energy (kcal/kg)	2.889	2.950	3.050	3.100
Lysine (%)	1.030	0.967	0.866	0.828
Digestible Lysine (%)	0.940	0.882	0.788	0.753
Methionine (%)	0.508	0.486	0.469	0.380
Digestible methionine (%)	0.485	0.464	0.449	0.361
Methionine + Cystine (%)	0.825	0.790	0.753	0.657
Methionine + Digestible Cystine (%)	0.755	0.723	0.691	0.597
Digestible Tryptophan (%)	0.218	0.205	0.184	0.176
Digestible threonine (%)	0.663	0.631	0.578	0.559
Choline (mg)	1.663	1.536	1.415	1.319

†Early rearing phase (1 to 29 days old); ‡growth phase I (30 to 49 days old); §growth phase II (50 to 77 days old); ¶final phase (78 to 90 days old).

slaughtered by bleeding in the slaughterhouse of the IFMG. Subsequently, the steps of scalding, plucking, evisceration and toilet of the carcass were realized. Then, the carcasses were individually wrapped in identified plastic bags and refrigerated at 5 °C in a cold chamber for a period of 24 hours.

Subsequently, the samples for the determination of fatty acid profile were extracted from the muscle parts of the breast cuts (*pectoralis major*) and thigh (*long fibular, cranial tibial, long digital flexor, long digital extensor and gastrocnemius*), skin-free, according to the methodology of FOLCH et al. (1957). The esterification step was performed according to the methodology of HARTMAN & LAGO (1973). Posteriorly, the samples were submitted to gaseous chromatography by Shimadzu GC 2010 gas chromatograph (Agilent Technologies Inc., USA) equipped with a flame ionization detector and a split injector at 1:50 split ratio to determination of the fatty acid profile. The capillary column of fused silica of 100 m length, 0.25 mm in diameter and 0.2 µm thickness of Supelco film (SP-2560, Bellefonte, PA, US) was used. The chromatographic conditions were an initial column temperature of 140 °C/5 min, with an increase of 4 °C/min up to 240 °C and remaining at this temperature for 30 minutes for a total runtime of 60 minutes. The injector and detector temperatures were 260 °C. The carrier gas used was helium. Fatty acids were identified by comparison with retention times characteristic of chromatographic standards (Supelco 37 standard FAME Mix, Supelco Inc., USA) and were expressed as percentages of the total fatty acids identified.

The activity indices of the enzymes Δ9-desaturase^{C14}, Δ9-desaturase^{C16}, Δ9-desaturase^{C18}, elongase$^{C16\text{-}C18}$ and thioesterase$^{C16\text{-}14}$ were calculated according to the methodology of METZ et al. (2009), in which: activity index of Δ9-desaturase^{C14} = 100 [(C14:1) / (C14:1 + C14:0)]; activity index of Δ9-desaturase^{C16} = 100 [(C16:1) / (C16:1 + C16:0)]; activity index of Δ9-desaturase^{C18} = 100 [(C18:1ω9c) / (C18:1ω9c + C18:0)]; activity index of elongase$^{C16\text{-}C18}$ = 100 [(C18:0 + C18:1ω9c) / (C16:0 + C16:1 + C18:0 + C18:1ω9c)]; and activity index of thioesterase$^{C16\text{-}C14}$ = 100 [(C16:0) / (C16:0 + C14:0)]. The combined effect of the desaturase enzymes and elongase on the omega-6 metabolic pathway (Desat/elong n6) was estimated according to BRESSAN et al. (2016). Atherogenicity and thrombogenicity indices were also determined according to the methodology of ULBRICHT & SOUTHGATE (1991), where: atherogenicity index = [4 (C14:0) + C16:0] / (SFA + PUFA) and thrombogenicity index = (C14:0 + C16:0 + C18:0) / [(0.5 x MUFA) + (0.5 x Σω6) + (3 x Σω3) + (Σω3/Σω6)].

Data were analyzed with the support of the SISVAR® statistical program (FERREIRA, 2000).

Data with significant effect responses in the analysis of variance for treatments and / or interactions were submitted to Tukey average test (5% of significance).

RESULTS

Table 3 presents the fatty acid profile data of the muscle fraction of the broiler breast, and interaction between diet and sex ($P < 0.05$) was observed for the contents of stearic acid (C18:0), C17:1, linoleic acid (C18:2ω6c), C20:2, aracdonic acid (C20:4ω6) and docosahexaenoic acid - DHA (C22:6ω3).

There was influence of diet on the contents of stearic acid in the breast only for males, in which broilers fed with the control diet and with selenium presented higher values compared to those that received the diet with chromium. For broilers fed with control diets and with selenium, males presented higher contents of stearic acid and, in contrast, females presented higher value of this fatty acid for the broilers supplemented with chromium (Table 7).

Males boilers supplemented with selenium had higher content of C17:1 in the breast muscle compared to those from control treatment, which in turn had a higher average than broilers that received the diet with chromium; similar results were obtained among females. For broilers of the control treatment and with chromium, males and females presented higher contents of C17:1 in the breast, respectively. For the content of linoleic acid in the breast, there was a difference between sexes only for broilers supplemented with chromium, where males had the highest value (Table 7).

Table 3 - Fatty acid profile of breast muscle (*Pectoralis Major*) of broiler chickens of Label Rouge lineage according to diet and sex.

Variable	----------Diet (D)----------			---------Sex (S)--------		----------P* value----------			CV** (%)
	C†	Cr‡	Se§	Male	Female	D	S	DxS	
C12:0	0.16	0.04	0.05	0.06	0.11	0.353	0.536	0.712	176.17
C14:0	0.64	0.56	0.65	0.66	0.58	0.482	0.279	0.584	24.03
C15:0	0.08	0.07	0.09	0.09a	0.07b	0.060	0.011	0.417	18.77
C16:0	24.24	23.85	24.89	24.09	24.57	0.187	0.286	0.772	3.78
C17:0	0.19	0.17	0.22	0.22a	0.17b	0.169	0.018	0.361	22.41
C18:0	9.09B	8.52B	10.01A	9.40	9.01	0.001	0.125	0.004	5.46
C20:0	0.09	0.10	0.09	0.10	0.09	0.349	0.416	0.820	18.93
C21:0	0.04	0.07	0.05	0.06	0.05	0.621	0.699	0.051	115.24
C22:0	0.24	0.25	0.29	0.22b	0.31a	0.349	0.015	0.224	23.45
SFA	34.77	33.63	34.79	34.90	33.89	0.488	0.273	0.117	5.39
C14:1	0.11	0.10	0.09	0.11	0.09	0.509	0.071	0.129	19.37
C16:1	3.60	3.43	3.10	3.39	3.37	0.064	0.898	0.221	9.90
C17:1	0.55B	0.50B	0.75A	0.57b	0.63a	0.001	0.035	0.002	8.31
C18:1ω9t	0.10	0.11	0.10	0.10	0.10	0.452	0.268	0.370	10.00
C18:1ω9c	34.21AB	35.33A	32.37B	33.35	34.59	0.006	0.067	0.089	3.83
C20:1	0.22	0.24	0.22	0.23	0.23	0.306	0.757	0.951	12.54
MUFA	38.81A	39.71A	36.62B	37.75	39.01	0.007	0.078	0.080	3.61
C18:2ω6t	1.90B	1.80B	2.08A	1.87b	1.99a	0.001	0.017	0.061	4.80
C18:2ω6c	17.59	18.49	17.82	18.33	17.61	0.408	0.220	0.044	6.50
C18:3ω6	0.14	0.15	0.15	0.15	0.13	0.835	0.187	0.412	20.35
C18:3ω3	0.81	0.87	0.77	0.85	0.78	0.212	0.147	0.053	12.03
C20:2	0.21B	0.19B	0.25A	0.21	0.22	0.005	0.844	0.024	12.25
C20:3ω6	0.58B	0.51B	0.74A	0.57b	0.65a	0.001	0.029	0.059	10.84
C20:4ω6	4.67B	3.96B	6.17A	4.88	4.98	0.001	0.690	0.004	10.06
C22:2	0.05AB	0.09A	0.03B	0.04b	0.07a	0.022	0.029	0.198	57.92
C22:6ω3	0.52B	0.47B	0.67A	0.52	0.58	0.003	0.164	0.041	15.28
PUFA	26.42	26.66	28.59	27.35	27.10	0.059	0.731	0.071	5.64

*Tukey test at 5% of probability; **coefficient of variation; average followed by distinct capital letters (AB), in the line, indicate difference between diets; average followed by distinct lower case letters (ab), in the line, indicate difference between sexes; †control diet without the addition of biocomplexed minerals; ‡diet with 0.40 ppm of biocomplexed chromium; §diet with 0.50 ppm of biocomplexed selenium. SFA - total of saturated fatty acids; MUFA - total of monounsaturated fatty acids; PUFA - total of polyunsaturated fatty acids.

Broilers supplemented with selenium had higher contents of C20:2 and of aracdonic acid in the breast, among females, when compared to broilers from other treatments; between males similar results were observed. However, broilers from treatment with selenium presented similar average of these fatty acids in relation to those that received the control diet. There was difference between sexes for the contents of C20:2 and aracdonic acid in the breast for the broilers from control treatment, in which males presented the highest averages. Regarding the broilers that received the treatment with chromium, females presented higher content of aracdonic acid in the breast (Table 7).

For DHA contents in breast cuts, among males, broilers that received the control treatment and with selenium presented higher averages compared to those supplemented with chromium. Among females, broilers that received the diet with selenium had higher DHA content compared to broilers from control treatment and; however, similar to those that received treatment with chromium (Table 7).

Regarding saturated fatty acids C15:0 and C17:0 in the breast, males presented the highest contents ($P < 0.05$) and, for C22:0, females presented the highest average ($P < 0.05$). However, there was no effect of diet or sex ($P > 0.05$) to the total of saturated fatty acids (SFA) in the breast (Table 3).

There was effect of diet ($P < 0.01$) for oleic acid (C18:1ω9c) contents and for the total of monounsaturated fatty acids (MUFA) in the breast, broilers supplemented with chromium had higher values compared to those that received the diet with selenium; however, they were similar to broilers from control treatment (Table 3).

For polyunsaturated fatty acids in the breast, there was influence of diet and sex ($P<0.05$) on the contents of C18:2ω6t, C20:3ω6 and C22:2, where females had the highest averages. Broilers supplemented with selenium had higher contents of C18:2ω6t and C20:3ω6 than broilers in other treatments. For contents of C22:2, broilers that received the supplementation with chromium presented higher average when compared to broilers from treatment with selenium, being similar to those fed with the control diet. However, there was no effect of diet or sex ($P > 0.05$) for the total of polyunsaturated fatty acids (PUFA) in the breast (Table 3).

Statistical analysis revealed an interaction between diet and sex for the total of omega 6 fatty acids (Σω6) ($P < 0.05$), for estimated of the activity index of $\Delta 9\text{-desaturase}^{C18}$ enzyme ($P < 0.01$) and for the combined effect of desaturase and elongase enzymes in the omega 6 metabolic pathway (Desat/elong n6) ($P < 0.01$) in the breast (Table 4). There was influence of diet on Σω6 only among females, where broilers supplemented with selenium had the highest average compared to broilers that received the other treatments (Table 7). Regarding the estimate of the activity index of $\Delta 9\text{-desaturase}^{C18}$, among males, broilers supplemented with chromium presented higher value than the other treatments; among females, broilers that received the control diet presented higher average compared to those supplemented with selenium, being similar to broilers from treatment with chromium. Males and females had higher indexes of $\Delta 9\text{-desaturase}^{C18}$ among broilers that received the diet with chromium and control, respectively (Table 7). Among males, broilers fed with control diet and with biocomplexed selenium presented higher values of Desat/elong n6 compared to broilers fed with biocomplexed chromium; among females, diet with selenium provided higher values of this variable in relation to the other. Regarding the effect of sex, there were differences only for broilers fed with biocomplexed chromium, and females had higher average (Table 7).

There was an isolated effect of diet ($P < 0.05$) on the estimate of activity index of the enzyme $\Delta 9\text{-desaturase}^{C16}$, in which the broilers fed with control diet presented higher average compared to those supplemented with selenium, being similar to broilers from the treatment with chromium (Table 4).

Table 5 presents the fatty acid profile data of the muscle fractions of the chicken thigh, and the statistical analysis did not reveal interaction between diet and sex ($P > 0.05$), and isolated diet effect ($P > 0.05$) for any of the variables analyzed. There was influence of sex ($P < 0.05$) on the content of palmitic acid (C16:0), oleic acid (C18:1ω9c) and on the SFA and MUFA in this cut with higher average to females. For the fatty acids linoleic acid, C18:3ω6, linolenic acid (C18:3ω3), C20:2 and PUFA, males presented the highest contents ($P < 0.05$) at thigh cut (Table 5).

There was not interaction between diet and sex ($P > 0.05$) and isolated diet effect ($P > 0.05$) for the variables related to the summation (Σω3 and Σω6), relations between fatty acid (Σω6/Σω3 and PUFA/SFA), enzymatic indices and health indicators for human consumption in the muscles of thigh (Table 6). However, there was effect of sex ($P < 0.01$) for the Σω6, the PUFA/SFA and the activity index of the enzyme $\Delta 9\text{-desaturase}^{C14}$, and males presented the highest values. Regarding consumption indexes for atherogenicity and thrombogenicity, considered as health indicators and related to the risk of cardiovascular

Table 4 - Summation, relations between fatty acids, enzymatic indices and meat health indicators for consumption of the breast muscle (*Pectoralis Major*) of broiler chickens of Label Rouge lineage, according to diet and sex.

Variable	Diet (D)			Sex (S)		P* value			CV** (%)
	C†	Cr‡	Se§	Male	Female	D	S	DxS	
Summation									
Σω3	1.32	1.54	1.44	1.37	1.50	0.580	0.470	0.376	24.66
Σω6	24.85B	24.91B	26.92A	25.77	25.36	0.024	0.512	0.049	4.98
Relation									
Σω6/Σω3	18.92	17.29	18.8	18.91	17.77	0.469	0.351	0.362	13.57
PUFA/SFA	0.76	0.79	0.83	0.79	0.81	0.378	0.652	0.104	10.88
Index									
Δ9-desaturase^{C14}	14.81	15.53	12.53	14.55	14.04	0.086	0.630	0.466	15.37
Δ9-desaturase^{C16}	12.92A	12.58AB	11.09B	12.34	12.06	0.032	0.600	0.299	9.01
Δ9-desaturase^{C18}	78.97A	80.57A	76.05B	77.96	79.10	0.001	0.057	0.002	1.46
Elongase$^{C16-C18}$	60.86	61.63	59.26	60.88	60.29	0.083	0.479	0.432	2.78
Thioesterase^{C16-14}	97.42	97.72	97.45	97.36	97.71	0.583	0.200	0.539	0.56
Desat/elong n6	0.27B	0.22B	0.35A	0.27	0.28	0.001	0.583	0.006	11.92
Atherogenicity	0.44	0.43	0.43	0.43	0.44	0.915	0.322	0.396	5.72
Thrombogenicity	0.95	0.89	0.95	0.95	0.90	0.400	0.219	0.187	8.45

*Tukey test at 5% of probability; **coefficient of variation; average followed by distinct letters (AB), in the line, indicate difference between diets; †control diet without the addition of biocomplexed minerals; ‡diet with 0.40 ppm of biocomplexed chromium; §diet with 0.50 ppm of biocomplexed selenium. Σω3 - total of omega 3 fatty acids; Σω6 - total of omega 6 fatty acids; Σω6/Σω3 - relation between omega 6 and omega 3 fatty acids; PUFA/SFA - relation between polyunsaturated and saturated fatty acids; Desat/elong n6 - combined effect of desaturase and elongase enzymes on the omega 6 metabolic pathway (C20:4ω6/C18:2ω6c).

diseases in humans, the meat of male animals presented lower averages ($P < 0.05$) (Table 6).

DISCUSSION

The addition of biocomplexed selenium in broiler diets caused an increase in the content of long chain fatty acid of the omega 3 and 6 series in the broiler breast, represented by DHA and aracdonic acid, respectively. In addition, there was an increase in the Σω6 in this same cut, which may be related to the increase in aracdonic acid content. Other authors have also reported an increase in the content of eicosapentaenoic acid - EPA (C20:5ω3), docosapentaenoic acid - DPA (C22:5ω3), DHA (HAUG et al., 2007; PAPPAS et al., 2012) and omega 6, represented by aracdonic acid (KRALIK et al., 2012; PAPPAS et al., 2012), in the breast of broilers supplemented with biocomplexed selenium.

These changes may be justified due to the fact that the increase of selenium concentration in broiler diets may cause an increase in Δ5 and Δ6-desaturases and elongases activities, which catalyze, respectively, desaturation and lengthening of the fatty acid carbon chain (HAUG et al., 2007). These enzymes are responsible for the conversion of short chain fatty acids to long chain fatty acids (DAL BOSCO et al., 2012), and synthesis of long chain fatty acid of omega 3 (EPA, DPA and DHA) and omega 6 (arachidonic acid) from the essential fatty acids linolenic and linoleic, respectively. This partly explains the higher value of the Desat/elong n6; and consequently, the higher arachidonic acid content in breast muscle for broilers that received the diet supplemented with biocomplexed selenium. The Desat/elong n6 variable indicates how easily linoleic acid is converted to arachidonic acid in body tissues. Thus, increasing the selenium content in the broiler diet causes enzymatic changes in the metabolic pathway of ômega 6 fatty acids, increasing the conversion of long chain fatty acid (arachidonic acid) from its precursor (linoleic acid).

In addition, selenium consumption may slow down the degradation of long chain fatty acids by lipid oxidation processes (KRALIK et al., 2012), as this mineral acts on the body's antioxidant defense system, mainly because it acts in the activation of the enzyme glutathione peroxidase (GSH-Px) (LI et al., 2017). This may also contribute to the increase in Desat/elong n6 for broilers supplemented with selenium and increasing the arachidonic acid content.

Table 5 - Fatty acid profile of the thigh muscle groups (*long fibular, cranial tibial, long digital flexor, long digital extensor and gastrocnemius*) of broiler chickens of Label Rouge lineage, according to diet and sex.

Variable	----------Diet (D)----------			----------Sex (S)----------		----------P* value----------			CV** (%)
	C†	Cr‡	Se§	Male	Female	D	S	DxS	
C12:0	0.03	0.04	0.04	0.03	0.04	0.703	0.225	0.659	65.75
C14:0	0.51	0.50	0.52	0.51	0.51	0.289	0.571	0.896	4.28
C15:0	0.06	0.06	0.06	0.06	0.06	0.427	0.065	0.253	9.16
C16:0	24.70	24.04	24.41	24.04b	24.73a	0.256	0.043	0.196	2.67
C17:0	0.11	0.12	0.11	0.12	0.11	0.702	0.249	0.283	7.36
C18:0	6.92	6.75	6.80	6.69	6.96	0.780	0.204	0.874	6.20
C20:0	0.07	0.08	0.07	0.08	0.07	0.875	0.411	0.133	10.06
C22:0	0.10	0.11	0.10	0.09	0.12	0.834	0.199	0.676	38.18
C24:0	0.03	0.02	0.03	0.03	0.03	0.051	0.529	0.195	16.61
SFA	32.61	31.74	32.21	31.70b	32.67a	0.124	0.010	0.222	2.09
C14:1	0.14	0.14	0.14	0.14	0.13	0.944	0.096	0.845	11.90
C16:1	5.09	4.99	5.07	5.19	4.91	0.942	0.255	0.745	9.78
C18:1ω9t	0.12	0.13	0.13	0.13	0.13	0.777	0.635	0.899	8.88
C18:1ω9c	37.46	37.96	37.10	36.65b	38.37a	0.304	0.002	0.926	2.46
C20:1	0.23	0.24	0.22	0.23	0.23	0.130	0.662	0.130	5.46
MUFA	43.07	43.45	42.69	42.36b	43.78a	0.613	0.039	0.880	3.00
C18:2ω6t	1.23	1.20	1.26	1.22	1.24	0.700	0.787	0.340	9.82
C18:2ω6c	20.10	20.82	20.72	21.66a	19.44b	0.543	0.002	0.193	5.76
C18:3ω6	0.16	0.16	0.17	0.18a	0.14b	0.362	0.001	0.885	10.24
C18:3ω3	0.96	0.98	0.98	1.02a	0.93b	0.683	0.008	0.137	5.89
C20:2	0.13	0.13	0.13	0.14a	0.12b	0.971	0.018	0.660	14.38
C20:3ω6	0.22	0.22	0.23	0.22	0.22	0.819	0.931	0.630	13.80
C20:3ω3	0.02	0.02	0.01	0.01	0.02	0.098	0.329	0.867	57.39
C20:4ω6	1.44	1.43	1.50	1.48	1.44	0.942	0.819	0.955	23.96
C22:2	0.02	0.05	0.01	0.02	0.04	0.094	0.125	0.028	99.03
C22:6ω3	0.14	0.14	0.14	0.13	0.15	0.986	0.487	0.971	27.34
PUFA	24.20	24.73	24.94	25.80a	23.45b	0.694	0.007	0.647	6.24

*Tukey test at 5% of probability; **coefficient of variation; averages followed by distinct letters (ab), in the line, indicate difference between sexes; †control diet without the addition of biocomplexed minerals; ‡diet with 0.40 ppm of biocomplexed chromium; §diet with 0.50 ppm of biocomplexed selenium. SFA - total of saturated fatty acids; MUFA - total of monounsaturated fatty acids; PUFA - total of polyunsaturated fatty acids.

In the present study, the addition of biocomplexed selenium in broiler diets caused a reduction in oleic acid and MUFA content in the breast. According to HAUG et al. (2007), dietary selenium may cause the increase of Δ5 and Δ6-desaturases activity, which is possibly accompanied by a reduction in Δ9-desaturases enzymes activity. These enzymes are responsible for the addition of unsaturation in the carbonic chain of fatty acids and; consequently, for the conversion of saturated to monounsaturated fatty acids (DAL BOSCO et al., 2012). This behavior was verified in the present study, in which the broilers supplemented with biocomplexed selenium presented lower estimates of activity indexes of the enzymes Δ9-desaturase^{C16} and Δ9-desaturase^{C18} in the breast, compared to the broilers of the control treatment. This may cause a lower conversion rate of stearic acid to oleic acid, which explains the reduction and increase, respectively, in the content of oleic and stearic acid in breast meat of broilers fed with the selenium enriched by diet. However, for the SFA there was no difference between diets, regardless of the muscle fractions evaluated (breast and thigh).

Regarding broilers supplemented with chromium, no differences were observed for the content of DHA, aracdonic acid, Σω6, oleic acid, MUFA and stearic acid in the muscular portion of the breast when compared to broilers fed with the control diet. Thus, selenium was more effective in change of the lipid composition of the breast in relation to

Table 6 - Summation, relation between fatty acids, enzymatic indices and health indicators for consumption of the muscle portions of thigh cut (*long fibular, cranial tibial, long digital flexor, long digital extensor and gastrocnemius*) of broiler chickens of Label Rouge lineage, according to diet and sex.

Variable	----------Diet (D)----------			----------Sex (S)----------		----------P* value----------			CV** (%)
	C†	Cr‡	Se§	Male	Female	D	S	DxS	
----------Summation----------									
Σω3	1.11	1.14	1.13	1.16	1.09	0.727	0.068	0.353	6.80
Σω6	22.96	23.42	23.68	24.50a	22.21b	0.684	0.005	0.646	6.08
----------Relation----------									
Σω6/Σω3	20.70	20.49	21.04	21.10	20.39	0.436	0.058	0.430	3.46
PUFA/SFA	0.74	0.78	0.77	0.81a	0.72b	0.549	0.005	0.511	7.76
----------Index----------									
Δ9-desaturase^{C14}	21.16	21.37	21.04	22.10a	20.27b	0.949	0.049	0.898	8.39
Δ9-desaturase^{C16}	17.06	17.2	17.168	17.73	16.55	0.980	0.071	0.901	7.37
Δ9-desaturase^{C18}	84.40	84.89	84.5	84.56	84.64	0.652	0.862	0.856	1.12
Elongase$^{C16-C18}$	59.85	60.63	59.82	59.73	60.47	0.181	0.073	0.299	1.32
Thioesterase^{C16-14}	97.96	97.97	97.92	97.93	97.97	0.707	0.474	0.684	0.10
Desat/elong n6	0.07	0.07	0.07	0.07	0.07	0.895	0.481	0.735	23.51
Atherogenicity	0.47	0.46	0.46	0.45b	0.48a	0.642	0.021	0.480	4.16
Thrombogenicity	0.88	0.85	0.87	0.85b	0.89a	0.112	0.006	0.147	3.11

*Tukey test at 5% of probability; **coefficient of variation; averages followed by distinct letters (ab), in the line, indicate difference between sexes; †control diet without the addition of biocomplexed minerals; ‡diet with 0.40 ppm of biocomplexed chromium; §diet with 0.50 ppm of biocomplexed selenium. Σω3 - total of omega 3 fatty acids; Σω6 - total of omega 6 fatty acids; Σω6/Σω3 - relation between omega 6 and omega 3 fatty acids; PUFA/SFA - relation between polyunsaturated and saturated fatty acids; Desat/elong n6 - combined effect of desaturase and elongase enzymes on the omega 6 metabolic pathway (C20:4ω6/C18:2ω6c).

chromium. However, for the thigh cut there were no changes in the fatty acid profile between the experimental diets.

Regarding the sex effect, males presented lower content of palmitic acid and SFA in the thigh muscle groups. In the semi-intensive rearing system, males generally present greater physical activity (MADEIRA et al., 2006). According to CASTELLINI et al. (2006), the differences in poultry behavior may be related to the content of saturated fatty acids in the thigh, so that greater locomotion may cause greater use of these fatty acids as a source of energy. Thus, may occur a reduction in the content of saturated fatty acids in muscle tissue that are most required for movement.

In general, meats with lower contents of saturated fatty acids are more indicated, from the point of view of consumer health, because the fatty acids lauric (C12:0), myristic (C14:0) and palmitic, when consumed in considerable proportions, increase the plasma concentration of low density lipoproteins (LDL) and of total cholesterol, increasing the risk of cardiovascular disease. However, stearic acid has a neutral effect or even a reduction in blood cholesterol levels, which contrasts with other saturated fatty acids (SCHAEFER & BROUSEAU, 1998).

In the present study, males presented higher linoleic acid content in the thigh muscle portion. In breast cutting, similar results were obtained; however, only for broilers supplemented with chromium. This was probably due to higher feed intake by males (SANTOS et al., 2005), as the lipid composition of broiler meat is directly influenced by diet (CHERIAN et al., 2002) and the corn, as the main dietary ingredient, is rich in linoleic acid (RULE et al., 2002).

As linoleic acid was the polyunsaturated fatty acid reported in the highest concentration in the muscle portions of broilers, regardless of the cut, the increase in linoleic acid content in the male thigh was accompanied by the increase in the PUFA, in the Σω6 and in the relation PUFA/SFA in the said cut.

In general, meats with higher content of polyunsaturated fatty acids are more indicated for consumption, being associated with a reduction in the plasmatic fraction of low lipoproteins density, of total cholesterol and; consequently, in the risk of cardiovascular diseases (JUMP et al., 2012). However, the equilibrium in the content of ω6 and ω3 polyunsaturated fatty acids is fundamental for the maintenance of human health, so the increase in the ingestion of linoleic acid increases the Σω6/Σω3 relation, which represents a

Table 7 - Slicing of the means of variables with significant interaction between diet and sex.

Variable	Sex	----------Diet----------			P* value
		C†	Cr‡	Se§	Diet
C18:0	Male	9.72aA	8.02bB	10.47aA	0.001
	Female	8.45b	9.02a	9.56b	0.056
P* value	Sex	0.009	0.031	0.047	-
C17:1	Male	0.60aB	0.40bC	0.71A	0.001
	Female	0.51bB	0.59aB	0.78A	0.001
P* value	Sex	0.046	0.001	0.098	-
C18:2ω6c	Male	18.11	19.72a	17.14	0.053
	Female	17.07	17.27b	18.50	0.298
P* value	Sex	0.297	0.024	0.179	-
C20:2	Male	0.24aA	0.17B	0.24A	0.017
	Female	0.18bB	0.20B	0.27A	0.010
P* value	Sex	0.028	0.164	0.194	-
C20:4ω6	Male	5.25aA	3.33bB	6.06A	0.001
	Female	4.08bB	4.58aB	6.27A	0.001
P* value	Sex	0.014	0.010	0.623	-
C22:6ω3	Male	0.56A	0.37bB	0.64A	0.006
	Female	0.47B	0.56aAB	0.71A	0.014
P* value	Sex	0.220	0.016	0.314	-
Σω6	Male	25.96	25.33	26.00	0.773
	Female	23.75B	24.49B	27.84A	0.004
P* value	Sex	0.055	0.433	0.102	-
Δ9-desaturase^{C18}	Male	77.12bB	81.66aA	75.09B	0.001
	Female	80.83aA	79.47bAB	77.00B	0.005
P* value	Sex	0.002	0.038	0.064	-
Desat/elong n6	Male	0.29A	0.17bB	0.36A	0.001
	Female	0.24B	0.27aB	0.34A	0.008
P* value	Sex	0.082	0.005	0.549	-

*Tukey test at 5% of probability; average followed by distinct capital letters (AB), in the line, indicate difference between diets; average followed by distinct lower case letters (ab), in the column, indicate difference between sexes; †control diet without the addition of biocomplexed minerals; ‡diet with 0.40 ppm of biocomplexed chromium; §diet with 0.50 ppm of biocomplexed selenium. Σω6 - total of omega 6 fatty acids; Desat/elong n6 - combined effect of desaturase and elongase enzymes on the omega 6 metabolic pathway (C20:4ω6/C18:2ω6c).

great risk for the occurrence of some cancers and for the progress of atherogenesis (JUMP et al., 2012). Despite the higher linoleic acid content in the male thigh, there was no influence of sex on the Σω6/Σω3 relation in both cuts. According to the World Health Organization, ingestion of diet intake with relation of ω6/ω3 around 4:1 helps prevent the development of inflammatory, allergic and cardiovascular diseases (WHO, 2003). In the present study, the values of this relation ranged from 17.29 to 18.92 in the breast muscle and from 20.39 to 21.10 in the chicken thigh muscle. This shows that there is a need of ingestion from other sources, besides the chicken meat that are rich in ω3 fatty acids, to balance the ω6/ω3 relation and promote benefits to human health.

Among the monounsaturated fatty acids, oleic acid was found in higher concentration in the muscle tissue of broilers, regardless of the cut. Males had lower oleic acid content and, consequently, lower MUFA content in the thigh. This may be related to the higher content of PUFA for males in this cut, since, according to KRALIK et al. (2012), this increase is usually accompanied by a reduction in the MUFA and of the activity of Δ9-desaturases enzymes (PAPPAS et al., 2012), which are responsible for the addition of an unsaturation in the carbon chain of fatty acids. However, in the present study, there was not observed differences between sexes on the estimates of activity indexes of enzymes Δ9-desaturase^{C16} and Δ9-desaturase^{C18} in the thigh. Nevertheless, males presented higher estimates

of activity index of Δ9-desaturase^{C14} enzyme in the thigh; however, regarding to the contents of myristic acid and myristoleic acid (C14:1) in this same cut, there was no change between the sexes.

In general, monounsaturated fatty acids are shown to have effects in reducing the risk of cardiovascular disease (FELDMAN, 2002). Oleic acid can influence the composition of membranes, altering its content in phospholipids and blood cholesterol. Thus, in the human nutrition this fatty acid acts on the reduction of total serum cholesterol and low density lipoprotein (LDL) levels, without; however, decreasing the plasmatic concentration of high density lipoproteins (HDL) (SANDERS, 2001). In addition, monounsaturated fatty acids have antithrombotic and platelet aggregation inhibiting effects (FELDMAN, 2002).

Regarding health indicators, in the muscle portion of female was verified higher values for atherogenicity and thrombogenicity indexes in the thigh, which, according to ULBRICHT & SOUTHGATE (1991), are related to the risk of occurrence of coronary artery disease known as arteriosclerosis and thrombosis, respectively. The higher atherogenicity index for females may be related to the lower PUFA content in the meat of these broilers, since these parameters are inversely proportional. Regarding the thrombogenicity index, the higher value reported by females may be mainly due to their higher SFA in the muscle groups of the thigh.

CONCLUSION

The supplementation with biocomplexed selenium in broiler chicken diets improved the lipid nutritional quality of chicken breast muscle, mainly due to the increase in the content of long chain fatty acid of the omega 3 and 6 series, represented by DHA and arachidonic acids, respectively. Regarding sex, males presented better lipid profile in the muscle tissue of the thigh, which were observed, respectively, higher and lower content of polyunsaturated and saturated fatty acids. In addition, males showed lower indexes of atherogenicity and thrombogenicity in this same cut, which indicates that the meat of these broilers, when consumed, will offer a lower risk for the development of cardiovascular diseases.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. Funding sponsors had no role in the study design, collection, analysis, and data interpretation; during the writing of this manuscript, and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

All authors contributed equally to the planning and writing of the manuscript. All authors critically reviewed the manuscript and approved a final version.

BIOETHICS AND BIOSSECURITY COMMITTEE APPROVAL

All experimental procedures were approved by the Ethics Commission on Animal Use (CEUA) of José do Rosário Vellano University - UNIFENAS (Protocol Nº 29A/2016), Alfenas, Minas Gerais, Brazil.

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