COMPARISON OF THE EFFECT OF COPPER ORGANIC AND INORGANIC SALTS IN CU-DEFICIENT DIET ON BONE GEOMETRIC AND STRUCTURAL PARAMETERS AS WELL AS MATERIAL CHARACTERISTICS IN BROILER CHICKEN

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Femoral mechanical and histomorphometrical traits were investigated for growing male Ross 308 broiler chickens fed on diets with copper (Cu) from organic or inorganic sources at lowered level of 25 % of daily demand. The control group was fed with basal diet supplemented with the premix which provided Cu as a sulphate in 100% of daily demand (8 mg·kg^{-1}). The experimental diets were formulated by supplementing a corn-wheat-soyabean meal mixture with lowered levels (25 % of the total daily recommended amount for Ross 308 broiler, 4 mg·kg^{-1}) of Cu from Gly-Cu or Cu-S. Mechanical and geometric properties such as the cross-section area (A), mean relative wall thickness (MRWT), and cortical index (CI) were estimated. The relative bone volume (BV/TV), trabecular thickness (Tb.Th), trabecular separation (Tb.Sp), and trabecular number (Tb.N) were aslo measured. The intake of Cu in the Cu-Gly or Cu-S form at the concentration of 25% of daily demand decreased the bone weight and did not influence of the length. As the result, the chickens fed Cu-poor diet irrespective of the form had decreased cross section area compared to the control chickens. However, mean relative wall thickness decreased in the Cu-Gly group as well as cortical index. While, mean relative wall thickness increased in the Cu-S group and cortical index decreased compared to the control group. The addition of Cu-S in Cu-poor diet resulted in an decrease in the yield strength. However, the values of ultimate strength was not changes. Microscopic assessment of cancellous bone showed a significant decrease in the real bone volume (BV/TV), mean (Tb.Th mean) and maximal (Tb.Th max) trabecular thickness in both experimental groups. An increase in mean (Tb.Sp mean) and maximal (Tb.Sp max) trabecular space in the Cu-Gly group compared to the control group and the Cu-S was observed. Moreover, in the Cu-Gly group the decrease in the trabeculea number (Tb.N) was observed when compared to other groups. The changes in femoral trabecular bone suggest that the diet supplemented with Cu only in 25 % of the total requirement of the component recommended for Ross 308 broiler chicks seems to be insufficient for femur development. This finding might suggest a necessity of supplementation with higher levels of Cu when are added irrespective of its form.

Keywords: ORGANIC COPPER, INORGANIC COPPER, BONE HISTOMORPHOMETRY, MECHANICAL TESTING, BROILER CHICKEN.

Copper (Cu) as an essential trace element is needed for many physiologic functions in animals and humans, including skeletal mineralization, erythropoiesis, leukopoiesis, connective tissue synthesis, myelin formation, melanin pigment synthesis, catecholamine metabolism, thermal regulation, cholesterol metabolism, immune function, cardiac function and glucose metabolic regulation [1, 2]. In bone metabolism, Cu as an essential co-factor is needed for the action of lysyl oxidase, which normalizes the deposition of calcium and phosphorus in bones [3–5]. For this reason, Cu deficiency leads to bone loss (osteopenia or osteoporosis) or demineralization [1, 2]. It could lead to decrease in bone mechanical strength and following fractures [4, 6].

Trace minerals are essential in the diets of poultry because they participate in the biochemical processes required for the maintenance of normal growth and development, including bone and eggshell formation [7–9]. The Cu requirement has been established to be 8 $mg \cdot kg^{-1}$ of diets for broiler chickens [10], but it is given to the commercial broiler diet in a larger amount due to its different bioavailability in various feed ingredients [10]. Therefore, several supplemental Cu sources such as inorganic sources (copper sulfate or carbonate), and organic sources (chelated form with higher Cu bioavailability) have been added to livestock diet, including broilers [6, 11–13]. Excessive mineral supplementation leads to environmental pollution [11]. Therefore, it seems that the use of a mineral chelate allows maintaining performance with decreased its amount in the commercial poultry diet [13, 14].

The objective of this study was to compare the effect of administration of the amino acid Cu complex or sulphate in growing male Ross 308 chickens fed with Cu-poor diet (25 % of recommended dose), on the basis of mechanical, geometric, and histomorphometric parameters of femur.

Materials and methods. The experimental procedures used throughout this study were approved by the Local Ethics Committee on Animal Experimentation of University of Life Sciences of Lublin, Poland. The birds were maintained in an animal house according to the guidelines of this committee. All efforts were made to minimize the number of animals used as well as their suffering.

Animals and experimental design

A total of 120 1-day-old Ross 308 broiler chickens were obtained from a commercial hatchery. Birds were weighed after hatching and randomly selected to one of 3 dietary treatments, each in one group of 40 chicks. The chickens were assigned to a control group (the Cont group; 40 birds divided into 10 pens with 4 birds per each pen); a group fed with lowered level of organic Cu in the form of glycinate chelate (Cu-Gly) as an experimental group I (the Cu-Gly group; 40 birds divided into 10 pens with 4 birds in each pen); and a group fed with lowered level of inorganic Cu in the form of sulphate as an experimental group II (the Cu-S group; 40 birds divided into 10 pens with 4 birds in each pen). All birds were raised in battery cages (76×97×45 cm, width×length×height) placed in an environmentally controlled room and kept under standard rearing conditions and air temperature set at the optimal level depending on age. During the first week, the chickens were kept at 33 °C, which was reduced by 2 °C weekly, until the final temperature of 24 °C. The chickens had constant access to fresh water and appropriate feed supplied *ad libitum* in accordance with this stage of the production cycle (table 1). The birds were fed with a diet corresponding to periods of rearing: starter (1-21 days), grower (22-35 days), and finisher (36-42 days). The chickens received a starter diet in the form of crumble, and grower and finisher diets in the pellet form. At the end of the experiment, 10 birds randomly selected from each group (1 bird from each pen) were weighed and slaughtered by cutting the carotid arteries. Ten hours before the slaughter, the selected birds were not given feed, but only provided with unlimited access to water.

Immediately after slaughter the femora were dissected, cleaned from the remnants of adherent tissues and their weight and length were measured. Directly after the measurements, each bone was wrapped in gauze soaked in isotonic saline and frozen at –25 ºC for further analyses.

Table 1

Composition and nutritive value of the experimental diet

Ingredients (%)	Starter (1-21 day)	Grower (22-35 day)	Finisher (36-42 day)
Corn	24.5	40.0	40,0
Wheat	42.9	27.9	28.8
Soybean meal*	25.0	24.9	22.9
Soybean oil	2.50	3.69	3.98
Monocalcium phosphate	0.90	0.90	0.81
Limestone	1.40	1.13	1.09
Sodium bicarbonate	0.08	0.08	0.08
NaCl	0.29	0.25	0.26
Vitamin–mineral premix (without Cu)	0.50[a]	0.50[b]	0.50[c]
Protein-fat concentrate **	1.00	-	1.00
DL-methionine 99 %	0.30	0.23	0.23
L-lysine HCl	0.42	0.28	0.27
L-threonine 99 %	0.18	0.13	0.07
The nutritional value of diet:			
[e] ME***, MJ·kg^{-1}	12.7	13.1	13.2
[d] Total protein, %	21.2	20.4	19.9
[d] Crude fibre, %	1.64	1.59	1.73
[d] Crude fat, %	4.57	5.42	5.53
[d] Lysine, total, %	1.28	1.14	1.08
[d]Met + Cys, %	0.92	0.81	0.82
[d] Total Ca, %	0.87	0.79	0.76
[d] Total P, %	0.65	0.66	0.64
[e] Bioavailable P, %	0.42	0.41	0.39
[e] Total Ca / P bioavailable	2.07	1.93	1.95
[d] Cu from plants in basal diet, mg·kg^{-1}	6.04	6.07	5.91
[d]Cu, mg·kg^{-1}			
4 mg Cu-Gly	10.28	10.34	10.21

[a] content of vitamins and minerals per 1 kg of starter: Mn 100 mg, I 1 mg, Fe 40 mg, Se 0.15 mg, vitamin A 15 000 UI, vitamin D_3 5 000 UI, vitamin E 75 mg, vitamin K_3 4 mg, vitamin B_1 3 mg, vitamin B_2 8 mg, vitamin B_6 5 mg, vitamin B_{12} 0,016 mg, biotin 0.2 mg, folic acid 2 mg, nicotinic acid 60 mg, pantothenic acid 18 mg, choline 1 800 mg

[b] content of vitamins and minerals per 1 kg of grower: Mn 100 mg, I 1 mg, Fe 40 mg, Se 0,15 mg, vitamin A 12 000 UI, vitamin D_3 5 000 UI, vitamin E 50 mg, vitamin K_3 3 mg, vitamin B_1 2 mg, vitamin B_2 6 mg, vitamin B_6 4 mg, vitamin B_{12} 0.016 µg, biotin 0.2 mg, folic acid 1.75 mg, nicotinic acid 60 mg, pantothenic acid 18 mg, choline 1 600 mg

[c] content of vitamins and minerals per 1 kg of finisher: Mn 100 mg, I 1 mg, Fe 40 mg, Se 0.15 mg, vitamin A 12 000 UI, vitamin D_3 5 000 UI, vitamin E 50 mg, vitamin K_3 2 mg, vitamin B_1 2 mg, vitamin B_2 5 mg, vitamin B_6 3 mg, vitamin B_{12} 0.011 µg, biotin 0,05 mg, folic acid 1.5 mg, nicotinic acid 35 mg, pantothenic acid 18 mg, choline 1 600 mg

[d] analyzed values;

[e] calculated values

* 46 % total protein in dry matter; ** 1 kg concentrate protein-faty contains: 2 % crude fat, 39 % crude protein, 10,8 MJ ME; *** ME - Metabolizable energy

Supplementation of Cu amino acid chelate and phytase

The control group was fed with basal diet supplemented with the premix which provided Cu as a sulphate in 100 % of daily demand (16 mg·kg^{-1}). The experimental diets

were formulated by supplementing a corn-wheat-soyabean meal mixture (table 1) with lowered levels (25 % of the total daily recommended amount for Ross 308 broiler, 4 $mg \cdot kg^{-1}$) of Cu from Gly-Cu or Cu-S. The experiment involved the use of Glystar Forte chelate (Arkop Sp. Z o.o., Bukowno, Poland) containing 16 % of Cu. An application of glycine chelate was in accordance with the EU Directive 1334/2003 [15].

The amount of Cu in the premix was based on nutritional recommendations for Ross 308 broilers [10, 19], i.e. 16 $mg \cdot kg^{-1}$ of Cu, irrespective of its content in the components of the basal diet. According to these recommendations, the Cu content should be the same in all periods of rearing, which was taken into account in the study [10, 16].

Mechanical properties

The mechanical properties of the bone were determined for all the groups after 3-hour thawing at room temperature using the three-point bending test of bone mid-diaphysis. The mechanical properties were examined on a Zwick Z010 universal testing machine (Zwick GmbH & Company KG, Ulm, Germany), equipped with a measuring head of operation range up to 10 kN, linked to a computer with TestXpert II 3.1 software (Zwick GmbH & Company KG, Ulm, Germany), registering the relationship between force perpendicular to the longitudinal axis of the bone and the resulting displacement. The distance between the supports was set at 40 % of the total bone length. The measuring head loaded bone samples with a constant speed of 10 $mm \cdot min^{-1}$ until fracture [17]. The ultimate load was determined as the force causing bone fracture and the yield load as maximal force under elastic (reversible) deformation of bone [18].

Geometric parameters

Geometric properties such as the cross-section area (A), mean relative wall thickness (MRWT), and cortical index (CI; defined as the ratio of the thickness of cortical part to the thickness of the midshaft measured in the middle part of the bone) were estimated on the basis of horizontal and vertical diameter measurements of the mid-diaphyseal cross-section of bone [19].

Histomorphometric analysis

The samples of proximal end of each bone were subjected to histology [2]. The Goldner's trichrome staining was used to assess histomorphometrical parameters of trabeculae. The bone volume (BV), tissue volume (TV), the relative bone volume (BV/TV), trabecular thickness (Tb.Th), trabecular separation (Tb.Sp), and trabecular number (Tb.N) were measured [20].

Statistical analysis

All results are expressed as means ± SD (standard deviation). Differences between the means were tested with the One Way ANOVA and *post hoc* Tukey's HSD test as the correction for multiple comparisons. Normal distribution of data was examined using the Shapiro-Wilk W-test and equality of variance was tested by the Brown-Forsythe test. A P-value of less than 0.05 was considered statistically significant. All statistical analyses were carried out by means of Statistica 12 software (StatSoft, Inc., Tulsa, OK, USA; http://www.statsoft.com).

Results and discussion.

Body weight

The initial and final body weights of the control and birds treated with Cu-Gly or Cu-S were similar (data not shown).

Bone morphology, geometry, and mechanical properties

The intake of Cu in the Cu-Gly or Cu-S form at the concentration of 25 % of daily demand decreased the bone weight and did not influence of the length (Table 2). As the result, the chickens fed Cu-poor diet irrespective of the form had decreased cross section area compared to the control chickens. However, mean relative wall thickness decreased in the Cu-

Gly group as well as coetical index. While, mean relative wall thickness increased in the Cu-S group and cortical index decreased compared to the control group (table 2).

The addition of Cu-S in Cu-poor diet resulted in an decrease in the yield strength. However, the values of ultimate strength was not changes (table 2).

Table 2

Physical, mechanical and geometric properties of femur obtained from 42-day-old broilers

Item	Group		
	Cont (n=10)	Cu-S (n=10)	Cu-Gly (n=10)
Bone weight, g	15.1±2.1[a]	13.8±1.6[b]	13.7±1.7[b]
Bone length, mm	80.1±2.5	79.9±2.5	81.5±0.9
Cross section area A, mm^2	53.1±5.2[a]	39.4±14.8[b]	39.6±9.1[b]
Mean relative wall thickness MRWT	0.78±0.12[a]	0.91±0.19[b]	0.49±0.11[c]
Cortical index CI, %	42.5±6.9[a]	47.1±5.4[a]	32.8±5.1[b]
Yield strength, N	170±10[a]	125±8[b]	172±4[a]
Ultimate strength, N	234±10	254±25	242±4

[a, b, c] – mean values in rows with different letters differ significantly at P<0.05; SEM – standard error of the mean

Cont – the control group received 100 % of Cu-S in premix

Cu-S – the group received Cu in 25 % of daily demand from sulphate

Cu-Gly– the group received Cu in 25 % of daily demand from Cu-Gly

Bone histomorphometry

Microscopic assessment of cancellous bone in both experimental groups supplemented with Cu at the concentration of 25 % of daily demand showed a significant decrease in the real bone volume (BV/TV), mean (Tb.Th mean) and maximal (Tb.Th max) trabecular thickness (table 3). However, an increase in mean (Tb.Sp mean) and maximal (Tb.Sp max) trabecular space in the Cu-Gly group compared to the control group and the Cu-S was (table 3). Moreover, in the Cu-Gly group the decrease in the trabecula number (Tb.N) was observed when compared to other groups.

Table 3

Histomorphometrical parameters of trabecula of cancellous bone in femur obtained from 42-dy-old broilers

Item	Group		
	Cont (n=10)	Cu-S (n=10)	Cu-Gly (n=10)
BV/TV, %	28.2±4.8[a]	19.4±1.3[b]	17.6±1.2[b]
Tb.Th mean, µm	63.4±11.3[a]	38.3±11.1[b]	42.1±10.1[b]
Tb.Th max, µm	180±31[a]	140±35[b]	139±22[b]
Tb.Sp mean, µm	178±29[a]	165±55[b]	293±41[b]
Tb.Sp max, µm	470±28[a]	423±58[a]	750±53[b]
Tb.N, mm^{-1}	4.69±0.26[a]	4.68±0.25[a]	4.43±0.18[b]

[a, b, c] –mean values in rows with different letters differ significantly at P<0.05; SEM – standard error of the mean.

Cont – the control group received 100% of Cu-S in premix.

Cu-S – the group received Cu in 25% of daily demand from sulphate.

Cu-Gly– the group received Cu in 25% of daily demand from Cu-Gly.

BV/TV – relative bone volume; Tb.Th – trabecular thickness, Tb.Sp – trabecular separation, Fd – fractal dimension of trabecular bone; Tb.N – trabecular number.

Adequate Cu intake in poultry production is necessary to reach not only genetically optimal growth but to maintain proper function of the skeletal system, which is an important mineral source and provides structural support for well-muscled and fast-growing breeds [14,

21]. Weak bones result in dyschondroplasia, osteochondrosis or bone loss. Thus, chelates supplementation of trace elements below recommended dosages is an attractive tactic, because inorganic mineral salts in poultry breeding are often used at doses higher than the recommended ones in order to avoid trace mineral deficit [20]. Nevertheless, studies concerning how the skeletal system will adapt to Cu-poor diet are still limited and therefore required.

The results of this study are new and, to our knowledge, the organic and inorganic (sulphate) sources of Cu (glycine chelate) administered below the recommended level has not been investigated so far in any other animals in relation to bone tissue histomorphometry, geometry, and mechanics. Our study showed that Cu addition in reduced amount to broilers irrespective of its chemical form did not influence final body weight. However, our broiler chickens from both experimental groups had shorter femur. Similar results were obtained in the other study with Cu-deficient chicken, showing no difference not only in body weight but also in the basal morphology of tibia between the Cu-poor and chickens from un-supplemented control group [22]. There is also other study conducted with Cu-Gly given to growing chicken throughout 6-week period which shows that the reduction of dietary copper to 25 % of recommended level results in an increase in bone weight but without changes in its length [23].

The results of our study showed also that Cu lowered to 25 % of recommended amount in Cu-glycine chelate or sulphate form did not affect weight of leg bone. In our study, a significant alteration was noted in bone geometry, which was dependent on chemical form of Cu. Our broilers from Cu-Gly group had more mature bone although its cross-sectional area did not differ from chickens from the Cu-S group, but it resulted in unchanged yield strength compared to the control group. Unchanged value yield strength revealed an enlargement of region of elastic deformation after Cu-Gly supplementation.

Further, our observation showed that the low concentration of Cu in poultry diet had adverse effects. Histomorphometric analysis showed rapid loss in real bone volume in the trabecular bone of the leg in birds fed with the both sources of Cu in 25 % of the recommended amount. This treatment also resulted in a decrease in the thickness of trabeculae and an increase in the trabecular space. This result might suggest that there was insufficient bone formation or bone loss, and the trabeculae looked like osteoporotic. Investigation of bone development in relation to trace minerals from organic sources in poultry is very important because bone weakness and lesions lead to decreased meat production. Weak legs are associated with reduced feed intake and finally affect weight gain. The bone leg quality is commonly used as an indicator of mineral adequacy in poultry diet.

In conclusion, it can be assumed that the supplementation of Cu-Gly even in a lowered amount positively influences bone metabolism resulting in more mature bone and better mechanical strength in growing broilers. It seems that the amount of Cu needed to maintain the mechanical integrity of bone is substantially less than that required for growth. On the other hand, the use of chelate or sulphate in the reduced amount resulted in worse morphologic and geometric parameters of chicken femur compared to the recommended dose. However, histomorphometry revealed a disproportionately large osteoporotic surface. The changes in femoral trabecular bone suggest that the diet supplemented with Cu only in 25 % of the total requirement of the component recommended for Ross 308 broiler chicks seems to be insufficient for femur development. This finding might suggest a necessity of supplementation with higher levels of Cu when are added irrespective of its form.

Acknowledgements. The authors wish to thank ARKOP Sp. z o.o. (Bukowno, Poland) for providing the necessary organically complexed copper (GLYSTAR FORTE Cu) used for the purposes of this experiment. This work was financially supported by the project NN 311543540 from the Ministry of Science and Higher Education, Poland.

ПОРІВНЯННЯ ВПЛИВУ ОРГАНІЧНИХ ТА НЕОРГАНІЧНИХ СОЛЕЙ МІДІ В CU-ДЕФІЦИТНІЙ ДІЄТІ НА ГЕОМЕТРИЧНІ ТА СТРУКТУРНІ ПАРАМЕТРИ КІСТОК, А ТАКОЖ ХАРАКТЕРИСТИКИ МАТЕРІАЛУ В КУРЧАТ-БРОЙЛЕРІВ

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А Н О Т А Ц І Я

Досліджені механічні та гістоморфометричні ознаки стегнової кістки вирощених курчат-бройлерів Ross 308, яких годували раціоном з міді (Cu) з органічних або неорганічних джерел при зниженій на 25 % добовій потребі. Контрольну групу годували основною дієтою, доповненою премісом, який був джерелом Cu як сульфат у 100 % добовій потребі (8 мг/кг$^{-1}$). Раціони експерементальних груп формувались шляхом додавання суміші з борошном кукурудзи з пшеницею та соєю з низьким рівнем (25 % загальної добової рекомендованої кількості для бройлеру Ross 308,4 мг/кг$^{-1}$) вмісту Cu від Gly-Cu або Cu-S. Оцінено механічні та геометричні властивості, такі як площа поперечного перерізу (A), середня відносна товщина стінки (MRWT) та кортикальний індекс (CI). Також вимірювали відносний об'єм кістки (BV / TV), трабекулярну товщину (Tb.Th), трабекулярне розділення (Tb.Sp) та трабекулярне число (Tb.N). Споживання Cu у формі Cu-Gly або Cu-S при концентрації 25 % добової потреби знизило вагу кістки і не вплинуло на довжину. Як наслідок, у курей, що отримували раціон з низьким вмістом міді, незалежно від форми, була зменшена площа поперечного перерізу в порівнянні з курчатами контрольної групи. Однак, середня відносна товщина стінки зменшилася в групі Cu-Gly, так само як і кортикальний індекс. Тоді як середня відносна товщина стінки збільшується в групі Cu-S, кортикальний індекс зменшується порівняно з контрольною групою. Мікроскопічна оцінка трубчастої кістки показала значне зменшення реального об'єму кістки (BV / TV), середньої (Tb.Th середньої) та максимальної (Tb.Th max) трабекулярної товщини в обох експериментальних групах. Спостерігається збільшення середнього (Tb.Sp середнє) та максимального (Tb.Sp max) трабекулярного простору в групі Cu-Gly порівняно з контрольною групою та Cu-S. Крім того, у групі Cu-Gly спостерігалося зменшення числа трабекул (Tb.N) у порівнянні з іншими групами. Зміни в стегновій трабекулярній кістці показують, що раціон з додаванням Cu, у дозі лише 25 % від добової потреби, рекомендованих для курчат-бройлерів Ross 308, є недостатнім для розвитку стегнової кістки. Цей висновок може припускати необхідність додавання більшої кількості Cu, незалежно від того, у якій формі він надходить.

Ключові слова: ОРГАНІЧНА МІДЬ, НЕОРГАНІЧНА МІДЬ, КІСТКОВА ГІСТОМОРФОМЕТРІЯ, МЕХАНІЧНЕ ВИПРОБУВАННЯ, КУРЧАТА-БРОЙЛЕРИ.

СРАВНЕНИЕ ВЛИЯНИЯ ОРГАНИЧЕСКИХ И НЕОРГАНИЧЕСКИХ СОЛЕЙ МЕДИ В CU-ДЕФИЦИТНОЙ ДИЕТЕ НА ГЕОМЕТРИЧЕСКИЕ И СТРУКТУРНЫЕ ПАРАМЕТРЫ КОСТЕЙ, А ТАКЖЕ ХАРАКТЕРИСТИКИ МАТЕРИАЛА У ЦЫПЛЯТ- БРОЙЛЕРОВ

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А Н О Т А Ц И Я

Исследованы механические и гистоморфометрические признаки бедренной кости выращенных цыплят-бройлеров Ross 308, которых кормили рационом из меди (Cu) из органических или неорганических источников при сниженной на 25 % суточной потребности. Контрольную группу кормили основной диетой, дополненной премиксом, который был источником Cu как сульфат в 100 % суточной потребности (8 мг/кг- 1). Рационы експерементальних групп формировали путем добавления смеси с мукой кукурузы с пшеницей и соей с низким уровнем (25 % общего суточного рекомендованного количества для бройлеру Ross 308,4 мг/кг- 1) содержимого Cu от Gly - Cu или Cu - S. Оценены механические и геометрические свойства, такие как площадь поперечного перереза (A), средняя относительная толщина стенки (MRWT) и кортикальний индекс (CI). Также измеряли относительный объем кости (BV / TV), трабекулярную толщину (Tb.Th), трабекулярное разделение (Tb.Sp) и трабекулярное число (Tb.N). Потребление Cu в форме Cu - Gly или Cu - S при концентрации 25 % суточной потребности снизило вес кости и не повлияло на длину. Как следствие, у кур, которые получали рацион с низким содержимым меди, независимо от формы, была уменьшенная площадь поперечного перереза по сравнению с цыплятами контрольной группы. Однако, средняя относительная толщина стенки уменьшилась в группе Cu - Gly, равно как и кортикальний индекс. Тогда как средняя относительная толщина стенки увеличивается в группе Cu - S, кортикальний индекс уменьшается сравнительно с контрольной группой. Микроскопическая оценка трубчатой кости показала значительное уменьшение реального объема кости (BV / TV), средней (Tb.Th средней) и максимальной (Tb.Th max) трабекулярной толщины в обеих экспериментальных группах. Наблюдается увеличение среднего (Tb.Sp среднее) и максимального (Tb.Sp max) трабекулярного пространства в группе Cu - Gly сравнительно с контрольной группой и Cu - S. Кроме того, в группе Cu - Gly наблюдалось уменьшение числа трабекул (Tb.N) в сравнении с другими группами. Изменения в бедренной трабекулярной кости показывают, что рацион с добавлением Cu, в дозе лишь 25 % от суточной потребности, рекомендованных для цыплят-бройлеров Ross 308, является недостаточным для развития бедренной кости. Этот вывод может допускать

необходимость добавления большего количества Cu, независимо от того, в какой форме он поступает.

Ключевые слова: ОРГАНИЧЕСКАЯ МЕДЬ, НЕОРГАНИЧЕСКАЯ МЕДЬ, КОСТНАЯ ГИСТОМОРФОМЕТРИЯ, МЕХАНИЧЕСКОЕ ИСПЫТАНИЕ, ЦЫПЛЯТА-БРОЙЛЕРЫ.

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