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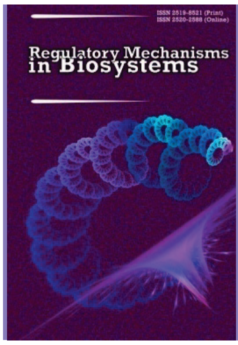

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Meat productivity and quality of meat and liver of broiler chickens after consuming diet with mineral supplements containing chelates of cuprum, iron, zinc, and manganese

O. P. Razanova, G. M. Ohorodnichuk, T. L. Holubenko, O. I. Skoromna, N. V. Novgorodska, A. M. Solomon, S. M. Ovsienko

Vinnytsia National Agrarian University, Vinnytsia, Ukraine

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Vinnytsia National Agrarian University, Sonyachna st., 3, Vinnytsia, 21008, Ukraine. Tel.: +38-096-256-00-84. E-mail: olenaop0205@ukr.net

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Poultry farming plays an important role as a producer of high-quality animal protein, which can solve issues of protein deficit among the population. Genetic growth potential of broiler chickens can be maximized through regular supply of microelements, especially chelate aminoacids. Those compounds improve metabolic processes in the body and increase increments in live mass and slaughter-yield of meat. The main objective of the study was identifying effects of mineral supplements with chelate microminerals on meat productivity of broiler chickens, quality of breast and thigh muscles, and content of mineral compounds in meat and liver. The studies were carried out on Kobb-500 broiler chickens, divided into three groups, each comprising 25 individuals. The experiment lasted from day 1 to day 42 of raising poultry. Broilers of the control group received the basic diet balanced in nutrients; the diet of birds of the second group was supplemented with Kronotsyd-L with chelates of copper, iron, zinc, and manganese in calculation of 0.25 mL/L of water, and chickens of the third consumed a diet with copper glycinate in calculation of 0.30 mL/L of water. Subject to mineral supplements with chelate microelements, the chickens had the highest mean-daily increments of live mass, slaughter yield, and yield of breast muscles. Use of mineral supplements in the diet of broiler chickens affected the quality of their meat, in particular its chemical composition. Those supplements led to changes in mineral composition of meat, influencing the concentrations of individual minerals in the tissues of the birds. Since minerals are important components of protein metabolism, the supplements augmented the content of dry matter and protein in meat. In the broiler chickens that had been receiving copper glycinate, the breast muscles had statistically significant increases in the mass shares of dry matter and protein. We found decrease in the content of fat in the breast and thigh muscles and the liver subject to copper glycinate and Kronotsyd-L with chelates of copper, iron, zinc, and manganese. This indicates improvement of the quality of meat and the liver. Use of mineral supplements with chelated microelements increased the ash content in dry matter because of higher concentrations of phosphorus, calcium, magnesium, iron, and manganese.

Keywords: broiler chickens; chelate microelements; chemical composition; mineral elements; muscles; liver.

Introduction

Modern animal farming aims at boosting productivity through genetic potential of animals and reducing production costs. Production of consumer-safe products also requires high-quality raw material. Analysis of the condition of meat poultry in Ukraine indicates the tendency towards increase in amounts of produced meat of broilers at industrial complexes. Heightened interest to broiler production is due to biological peculiarities of poultry and the will of producers to increase amounts of production of dietary meat (Wlaźlak et al., 2024).

Monitoring of scientific studies in the sphere of feeding animals and poultry suggests that the producers have been paying increasing attention to development and use of novel feed supplements with the purpose of maximum use of feeds and obtaining organic production in animal farming (Belloir et al., 2019, Skoromna et al., 2019). High level of balanced feeding using various feed supplements promotes improved consumption and enhances effectiveness of nutrition, ensuring maximum productivity (Poberezhets et al., 2023).

Minerals are vital for health and achieving necessary productivity of animals and poultry. They are components of all body cells, including blood, hormones, nerves, muscles, and bones (Klitsenko et al., 2001). Some minerals are essential components of enzymes that catalyze biochemical reactions necessary for proper organism functioning. Microelements are essential components of feeding and they are consumed in small quantities. Increased productivity requires more nutrients in food, including macro- and microelements that are essential for complex biochemical reaction of synthesizing nucleic acids, proteins, carbohydrates, and lipids. Recommendations regarding feeding of various agricultural animals often include general concentration of microelements in the diet, because concentration and bioavailability of those elements in vegetal feeds often significantly vary and can be too low to satisfy the animals' needs (Brugger et al., 2022; Kazakova & Marshinskaia, 2023). According to the studies by Burlaka et al. (2012), alunite and kaoline flour provided high productivity of swine and high slaughter-yield quality, technological and culinary parameters, and the muscle tissue of animals had less fatty tissue, which improved its calorie value.

The main purpose of efficient meat-poultry farming is providing the consumers with high-quality goods that satisfy their needs and tastes. Quality of products of broiler poultry farming depends mostly on the level of poultry nutrition (Goluch et al., 2023). Increasing biological completeness of mixed feeds, optimization of metabolism in the organism, and provision of normal functioning of the immune system of poultry are impossible without using various microelement supplements. In recent years, studies of new sources of mineral supplements, improvement of technologies of their application and elaboration of needs of poultry in microelements have gained momentum. Feed supplements that contain minerals, vitamins, proteins, and fats are significant for growth and development of animals. They reduce the feeding period and increase productivity and economic efficiency of nutrition (Ahmad et al., 2022). In-depth studies of using mineral food supplements can promote a stable development of the broiler sphere.

Research results indicate that the quality and safety of chicken meat, its taste characteristics and chemical composition depend on many factors, including genetic peculiarities of poultry, sex, and age, microclimate parameters in poultry enclosures, effects of stress factors on poultry, conducting veterinary events, balanced diet, and fodder quality (Hayat et al., 2021; Povarova, 2021; Bongiorno et al., 2022). Addition of the optimal dose of organic zinc (90 mg/kg of MHA-Zn) to low-protein diets led to heightened productivity of broilers and optimization of microbiota of the cecum, and also decrease in nitrogen emission into the environment (Dong et al., 2023). Adding humine compounds as growth stimulators positively influenced the morphological and biochemical parameters of blood (Stepchenko et al., 2021), causing increases in carcass yield and beneficial bacteria in the broilers (Domínguez-Negrete et al., 2019).

Quality and safety of meat from broilers is primarily determined by the chemical composition and quality of the mixed feeds they consume during cultivation (Avila-Ramos et al., 2013). Using cellulose enzyme, obtained from a *Aspergillus terreus* strain that was cultivated on agar with 0.5 mg/L of cuprum organic complex, led to increased deposition of protein in the meat of broiler chickens. This is significant from the standpoint of nutritional and dietary properties of poultry meat produced using biologically active compounds. Intensive growth of biomass of *Tetrachymena pyriformis* cells indicated that biological value of meat of broiler chickens fed with cellulose-enzyme-containing mixed feeds was 3.1% higher (Bomko, 2014). Studies by Osipenko et al. (2023) revealed that use of 3.0% and 4.5% biomass of vermiculture in mixed feeds for broiler chickens increased the nutritional value of meat by 10.9–12.7% as a result of accumulation of a large amount of essential aminoacids and other biologically active compounds in the breast and thigh muscles. Pitera & Otchenashko (2023) found that taste-aroma feed supplement in the form of dry powder of yeast extract (*Saccharomyces cerevisiae*) caused significant increase in live mass of broiler chickens. According to Kyryliv et al. (2017), the complex supplement Bilo-Aktyv, combined with a mineral supplement that contained zinc, copper, and manganese, increased live weight of the poultry and biological and nutritional values of their eggs and meat. This was achieved by increasing the content of valuable mineral compounds, thus improving the quality of products from them. Intake of biologically active supplements based on submerged bees, ash residual of which contains micro- and macroelements (calcium, magnesium, phosphorus, silica, iron, manganese, selenium, copper, and zinc), promoted a more efficient increase in meat yield from quail carcasses, the meat characterized by the best parameters (Razanova, 2018).

Microelements in animals' diets are usually added in small amounts, but problems such as low bioavailability, antagonism, and high rates of their removal from the body, limit their efficacy. By developing nanoparticles, one can increase the bioavailability of respective minerals by increasing their surface area (Hassan et al., 2020). According to Kirichenko (2016), the nanomicroelementary food supplement Mikrostymulin improved absorption of fodder and stimulated synthesis of aminoacids, increasing content of non-essential and essential aminoacids in the breast and thigh muscles of broiler chickens. Increasing biological availability of microelements for animals and poultry can be achieved by using chelate compounds in feeding. Various studies have indicated that the doses of chelate minerals in industrial mixed feeds for broilers could be reduced without any negative impact on the poultry productivity (Bao et al., 2007; Habibia et al., 2015; Majewska et al., 2016), system of antioxidant protection (Jiang et al., 2015), hematological and biochemical parameters, and also meat quality (Aksu et al., 2011). Moreover, it enhances the chickens' immunity (Nagalakshmi et al., 2015). By assessing the effects of various sources and levels of microelements on live mass, composition of carcass, and levels of production of minerals in Ross-308 broilers, Zhu et al. (2019) found that decrease in the amount of microelements caused no negative impact on the intensity of growth, yields of carcass and meat, though reduced removal of minerals with feces was observed. Broilers that had been given chelate microelements had increased increment of live mass, accumulation of mineral compounds in the tissues, and also heightened immunity and higher coefficient of fodder conversion compared with the chicken that consumed inorganic microelements in the same doses (Rao et al., 2016).

Chelated microelements can help avoiding using higher doses of inorganic microelements in fodders for poultry and can prevent environmental contamination, because they have lower levels of inclusion and expression (Bao et al., 2007, 2009). Studies conducted by Kong et al. (2022) confirmed that microelements based on organic acids have greater bioavailability. They researched usage of manganese, zinc, selenium, iron, and copper in the form of hydrate metal chelate of glycine. The researchers found that decreasing the supplementation of those microelements had no negative effect on the birds' growth. The chelated-minerals supplement based on organic acid not only did improve the productivity of the broilers, but also had an effect on the bone structure and blood parameters.

Chelated microelements in poultry diet improve the general condition of their health, thereby enhancing their overall well-being and performance (Byrne & Murphy, 2022). Chelated microelements can improve the bioavailability of metal ions and promote colonization of probiotic microbiota, which strengthens microbial barriers and supports gut health (Yin et al., 2022). According to the research by Ghasemi et al. (2020) and M'Sadeq et al. (2018), such an approach resulted in increased absorption of minerals, promoting active growth, solidifying the bone tissue, improving slaughter parameters, and organoleptic properties of meat. Introduction of chelate microelements into the diet of the poultry increased chicken production by 6.9% and improving meat quality, which is very important for the producers. Furthermore, Tymoshenko et al. (2018) confirmed significant decline in the parameters of fodder conversion. Youssef et al. (2022) recommended using chelated Cr-Meth in diets of broilers for improving the productivity and decreasing oxidative stress, reducing mortality, and increasing the coefficient of fodder conversion.

Supplementing diet of the broilers with methionine chelates or yeast proteinate forms of the microelements Cu, Fe, Mn, and Zn promoted increase in body mass and fodder-conversion coefficient, and also notably reduced the expression of those microelements. The studies by Singh et al. (2015) showed that the productivity of broilers can be improved and releases of critical microelements into the environment can be lowered by completely replacing inorganic microelements in their feeding regime with methionine or proteinate forms of yeasts.

The objective of our studies was to identify the effect of adding supplements with chelated microelements on the meat productivity of broiler chickens, quality of the breast and thigh muscles, and the content of mineral compounds in the meat and the liver.

Materials and methods

All the experimental procedures were conducted adhering to the General Ethical Principles of Experiments on Animals (Ukraine, 2001), which corresponded to the position On Protection of Animals from Abuse (No. 3447-IV as of 6/21/2006 with amendments as of 7/15/2021) (https://zakon.rada.gov.ua/laws/show/3447-15#n8) and the position of the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (ETS No. 123, Strasbourg, 1986) (https://rm.coe.int/168007a67b).

The studies were performed on broiler chickens of the Kobb-500 cross (Poland) in the vivarium at the Vinnytsia National Agrarian University (Ukraine) in 2023. A total of 75 one-day-old chickens were used, which were evenly divided into three groups according to the method of group analogues, 25 in each. The poultry were kept in three-tier cages INKI KB-45U for broiler chickens, equipped with nipple water drinkers and hanging feeders. During the experiment, the poultry were given fodder and drinking water based on the recommendation of the producers of Kobb-500 broiler chickens. The fodder diets for three growing periods (starter – 1–15 days of life; growing – 16–35 days; finisher – 36–42 days of life) were optimized according to NRC standards (1994). The mixed feeds corresponded to the current age needs in nutrients for cultivation of broilers, and contained no antibiotics or growth stimulators. Mixed feeds for chickens were used according to the raising phase (starter mixed feed Starter PK5-1, growth mixed feed Hrover, finishing mixed feed Finisher, Kalynka TM, Ukraine). Broiler chickens of the control group were fed the main diet without mineral supplements, the diet in the second group was supplemented with Kronotsyd-L in calculation of 0.25 mL/L of water, and the third group consumed chelate complex of copper with glycine in calculation of 0.3 mL/L of water. Chelated-copper complex contained 5% copper and 20% glycerine. The supplement Kronotsyd-L contains chelated copper, iron, zinc, manganese, and 19% acids. The supplements were given with water in free access.

The poultry were kept in the standard growing conditions, at which the air temperature was maintained on the optimal level, according to age and Directive of the European Council 2007/43/EC. Temperature in the vivarium at the beginning of the experiment was 32 °C, and during the experiment every week it was decreased by 2 until 24 °C. Throughout the studies, we also monitored the adherence to the light regime in vivarium. In the first week, the broilers were provided with light for 23 h. From days 8 to 39, the light period was gradually reduced to 20 hours, and from day 40 and until the end of the experiment it was increased again to 23 h a day.

The chickens were weighed on days 7, 14, 21, 28, 35, and 42 of the experiment. In addition, every day we checked the consumption of fodder and bird mortality. Based on the obtained data, we identified the increment of mass and fodder intake. By the end of the experiment, on the 42nd day, from each group we selected 5 individuals for slaughter, which were similar by live weight to the mean parameter in the group (according to DSTU 3136-2017 Agricultural Poultry for Slaughter). After slaughter, we measured weight of the breast muscles, thighs and drumsticks, internal organs, and also identified percentage of the yield. At the same time, we collected samples for further studies of chemical and mineral compositions of the muscles.

Representative samples of the breast and thigh muscles and the liver was gathered during anatomic dissection of the carcasses. Chemical composition of meat was identified according to the generally accepted methods of zootechnical analysis: general water content – by drying samples in a dryer at the temperature of 100–105 °C to permanent mass (DSTU ISO 1442:2005); protein – according to the Kjeldahl method (according to DSTU 13496.493); fat – by extracting with ethyl alcohol in a Soxhlet extractor (DSTU ISO 1443:2005); ash – by burning weighed amounts in a muffle furnace at the temperature of 525–550 °C (DSTU ISO 936:2008). Calorie value of meat was estimated according to the formula: $K = [C – (A + B)] \times 4.1 + (A \times 9.3)$, where K is calorie value of 100 g of natural water activity (kcal), C – content of dry matter in meat (%), A – fat content in meat (%), B – ash content in meat (%).

Statistical analysis of the results was conducted using the Statistica software, estimating mean arithmetic and standard deviation. Results are expressed in the form of x (mean value) ± SD (standard deviation). To identify statistically significant differences between values of respective groups of broilers, we used one-sided dispersion ANOVA analysis. To compare the data, we identified statistically significant differences between the mean values for respective groups of broiler chickens. Results at $P < 0.05$, $P < 0.01$, and $P < 0.001$ were considered statistically significant.

Results

Growing broiler chickens on a diet with mineral supplements influenced the intensity of growth and yield parameters. At the end of the experimental period (42nd day), live mass of the poultry that had consumed Kronotsyd-L was 6.7% ($P < 0.01$) higher and those that had consumed chelate complex of copper with glycine was higher by 13.9% ($P < 0.001$). Over the experiment, live weight of broiler chicken increased 38.0-fold in the second group, 40.9-fold in the third group, and 35.8-fold in the first group. Analysis of the data of daily live-mass gain revealed that it was higher by 6.8% in the second ($P < 0.05$) and by 14.2% in the third group ($P < 0.001$), compared with the first group (Table 1). At the same time, the best growth intensity was produced by copper glycinate, compared with the second group, where the birds had been receiving Kronotsyd-L. We saw positive changes that resulted from influence of mineral supplements on the biochemical processes in the bird organism, which improved the absorption of nutrients in the diet. More intensive growth of chickens in the experimental groups improved fodder conversion, leading to reduced expenditures of fodder per unit of increment in the third group – by 9.7% ($P < 0.01$).

Table 1
Meat productivity of broiler chickens consuming mineral supplements with chelated microelements (x ± SD, n = 25, the experiment lasted for 42 days)

Parameter	Main diet	Kronotsyd-L supplement containing chelated copper, iron, zinc, manganese (0.25 nL/L of water)	Chelate complex with copper glycine (0.30 mL/L of water)
Live mass at the beginning of the experiment, day 3, g	72.0 ± 1.0^a	72.3 ± 1.1^a	71.7 ± 0.8^a
Live mass at the end of experiment. Day 42, g	2580 ± 52^a	2752 ± 25^b	2937 ± 34^c
Live-mass gain	35.8 ± 1.7^a	38.0 ± 1.4^{ab}	40.9 ± 1.9^b
Mean daily gain of live mass, g	62.7 ± 1.3^a	67.0 ± 0.6^b	71.6 ± 0.9^c
Expenditures of fodder per increment of live mass, g	2197 ± 27^a	2136 ± 23^a	1983 ± 46^b
Pre-slaughter mass, g	2690 ± 38^a	2893 ± 18^b	2911 ± 34^b
Mass of processed carcass, g	2009 ± 34^a	2146 ± 19^b	2189 ± 28^b
Slaughter yield, %	74.6 ± 0.2^a	75.0 ± 0.4^{ab}	75.2 ± 0.2^b
Breast muscles to mass of processed carcass, %	30.4 ± 0.4^a	32.0 ± 0.3^b	32.3 ± 0.5^b
Thigh muscles to mass of processed carcass, %	11.8 ± 0.1^a	11.9 ± 0.1^a	11.9 ± 0.1^a
Drumstick muscles to mass of processed carcass, %	9.51 ± 0.12^a	9.42 ± 0.24^a	9.34 ± 0.15^a
Mass of the liver, g	57.3 ± 3.3^a	68.4 ± 3.0^b	68.2 ± 2.2^b
Yield of the liver to mass of processed carcass, %	2.89 ± 0.15^a	2.41 ± 0.11^b	2.33 ± 0.14^b

Note: different letters within each row indicate significant differences between groups according to the Tukey's HSD test results.

The conducted assessment of the slaughter parameters revealed higher slaughter yield from broiler chickens that had been additionally consuming the mineral supplements. Yield of the breast muscles was 5.3% ($P < 0.05$) higher in the second group and 6.3% ($P < 0.01$) higher in the third, compared with the first group. Inferring from the results, the yields of the thigh muscles of second- and third-group chickens were slightly higher, but the yields of the crus muscles were, by contrast, lower. However, the obtained data did not reach the statistical significance. Weight of the liver of second- and third-group chickens exceeded such of the first group ($P < 0.05$). However, ratio of this weight to the slaughter yield was 17.2% ($P < 0.05$) lower in the second group and 20.7% ($P < 0.05$) lower in the third group.

Enrichment of the main diet of the broiler chickens with mineral substances with chelated microelements affected the chemical composition of breast and thigh muscles. Mass share of dry matter in the breast muscles of broiler chickens in the third group was higher by 3.5% ($P < 0.01$), compared with the first (Table 2).

We found an upward tendency in the mass share of protein in the breast muscles of group-3 chickens by 6.7% ($P < 0.01$). Intake of chelated-microelements-containing mineral supplements in the diet caused 7.2% ($P < 0.01$) decrease in the content of fat in the breast muscles in the second group and 5.9% ($P < 0.001$) in the third. Ash content in the second and third groups was 4.1% ($P < 0.01$) higher than in the first. Kronotsyd-L-supplemented diet reduced the energy value of the breast muscles, while copper glycinate, by contrast, increased it.

The thigh muscles of the broiler chickens had a tendency towards increase in the water content and respectively decrease in the mass share of dry matter, unlike the breast muscles. However, introduction of mineral supplements with chelated microelements to the diet somewhat increased the mass share of dry matter. However, we saw no significant confirmation of such an increase. In the thigh muscles of the group-2 broiler chickens, we saw decrease in the mass share of fat (4.7%, $P < 0.05$), which caused insignificantly lower energy value of fat than in the first group. However, contents of protein and ash in the muscles of poultry of this group insignificantly increased. In the group of broiler chickens that had received copper glycinate (third group), mass share of protein increased, and the ash and fat content decreased. Energy value of the thigh muscles of group-1 birds was somewhat higher than in the first and second groups.

Content of the main mineral compounds (phosphorus, calcium, magnesium, iron, zinc, cuprum, manganese) in the breast and thigh muscles of the broiler chickens changed depending on the diet and the mineral supplement added (Table 3).

Table 2
Chemical composition and energy value of the breast and thigh muscles of broiler chickens consuming mineral supplements with chelated microelements (x ± SD, n = 5)

Muscles	Parameters	Main diet	Kronotsyd-L supplement containing chelates of copper, iron, zinc, manganese (0.25 nL/L of water)	Chelate complex of copper with glycerine (0.30 mL/L of water)
Breast	Moisture, %	74.04 ± 0.30[a]	73.97 ± 0.47[ab]	73.30 ± 0.14[b]
	Dry matter, %	25.957 ± 0.133[a]	26.030 ± 0.069[ab]	26.701 ± 0.089[b]
	Protein, %	20.50 ± 0.38[a]	21.23 ± 0.24[ab]	21.87 ± 0.14[b]
	Fat, %	2.353 ± 0.022[a]	2.177 ± 0.032[b]	2.213 ± 0.013[b]
	Ash, %	1.210 ± 0.011[a]	1.257 ± 0.024[ab]	1.256 ± 0.012[b]
	Energy value, kcal/100 g	113.70 ± 1.32[a]	112.89 ± 2.00[a]	115.83 ± 0.57[b]
Thigh	Moisture, %	74.75 ± 0.48[a]	74.68 ± 0.40[a]	74.54 ± 0.39[a]
	Dry matter, %	25.25 ± 0.24[a]	25.32 ± 0.15[a]	25.46 ± 0.17[a]
	Protein, %	17.77 ± 0.38[a]	18.63 ± 0.26[ab]	18.69 ± 0.33[b]
	Fat, %	5.727 ± 0.118[a]	5.456 ± 0.063[b]	5.560 ± 0.066[ab]
	Ash, %	1.093 ± 0.022[ab]	1.133 ± 0.024[a]	1.060 ± 0.017[b]
	Energy value, kcal/100 g	128.8 ± 2.5[a]	127.5 ± 1.8[a]	128.9 ± 1.9[a]

Note: see Table 1.

Table 3
Mineral composition of the breast and thigh muscles of broiler chickens consuming mineral supplements with chelated microelements (x ± SD, n = 5)

Name of element	Main diet	Kronotsyd-L supplement containing chelates of copper, iron, zinc, manganese (0.25 nL/L of water)	Chelate complex of copper with glycerine (0.3 mL/L of water)
Breast muscles			
Phosphorus, g/kg	7.847 ± 0.020[a]	7.883 ± 0.041[ab]	7.900 ± 0.026[b]
Calcium, g/kg	0.137 ± 0.013[a]	0.170 ± 0.011[b]	0.200 ± 0.011[c]
Magnesium, g/kg	0.933 ± 0.023[a]	0.980 ± 0.014[b]	0.951 ± 0.012[ab]
Iron, mg, kg	64.68 ± 0.21[a]	70.22 ± 0.13[b]	69.10 ± 0.15[c]
Zinc, mg/kg	40.40 ± 0.43[ab]	40.96 ± 0.40[a]	39.07 ± 0.41[b]
Cuprum, mg/kg	11.47 ± 0.18[a]	11.19 ± 0.20[a]	12.63 ± 0.26[b]
Manganese, mg/kg	3.517 ± 0.029[a]	5.490 ± 0.084[b]	5.613 ± 0.099[b]
Thigh muscles			
Phosphorus, g/kg	6.173 ± 0.037[a]	6.601 ± 0.052[b]	6.223 ± 0.064[a]
Calcium, g/kg	0.393 ± 0.032[a]	0.440 ± 0.029[ab]	0.487 ± 0.032[b]
Magnesium, g/kg	0.940 ± 0.029[a]	1.041 ± 0.026[b]	0.963 ± 0.015[ab]
Iron, mg, kg	48.55 ± 0.24[a]	56.26 ± 0.28[b]	68.19 ± 0.22[c]
Zinc, mg/kg	93.36 ± 0.28[a]	91.57 ± 0.21[b]	92.26 ± 0.21[c]
Cuprum, mg/kg	6.53 ± 0.20[a]	6.44 ± 0.19[a]	5.42 ± 0.18[b]
Manganese, mg/kg	5.20 ± 0.11[a]	5.58 ± 0.16[b]	7.07 ± 0.08[c]

Note: see Table 1.

Enrichment of diet of the broiler chickens with the Kronotsyd-L mineral supplements increased the content of calcium in the breast muscles – by 21.4% ($P < 0.05$), magnesium – by 5.4% ($P < 0.05$), iron – by 8.6% ($P < 0.001$), manganese – by 55.9% ($P < 0.001$). At the same time, the content of cuprum, by contrast, decreased, compared with the first group. In the third group, where chickens had consumed copper glycinate, we found: 42.8% increase in calcium ($P < 0.01$), 6.8% increase in iron ($P < 0.001$), 59.4% increase in manganese ($P < 0.001$), compared with the group that had been consuming mixed feeds of the main diet. Increases in magnesium, zinc, and phosphorus in the both groups had no significant confirmation. As compared with the first group, the thigh muscles of broiler chickens of the second and third experimental groups contained 12.8% and 25.6% (at $P < 0.05$) more calcium, 15.9% and 40.4% (at $P < 0.001$) more iron, and 7.3% and 35.9% (at $P < 0.001$) more manganese, respectively. Mass shares of magnesium and phosphorus in the thigh muscles of chickens of the second group was higher by 10.6 ($P < 0.05$) and 6.9% ($P < 0.001$). In the third group, increases in the mass shares of those elements were insignificant. We also observed decline in the mass share of zinc in the thigh muscles of the second and third groups.

Analysis of chemical and mineral composition of the liver of the broiler chickens revealed some effect of supplementing the diet with chelated microelements. In particular, in the liver of the chickens that received the Kronotsyd-L supplement and the chelate complex of copper, the mass share of organic compound increased ($P < 0.001$, Table 4).

Table 4
Chemical and mineral compositions of the liver of broiler chickens consuming mineral supplements with chelated microelements (x ± SD, n = 5)

Parameter	Group		
	Control (main diet)	experimental 2 (Kronotsyd-L)	experimental 3 (chelate complex of copper)
Organic matter, %	91.75 ± 0.63[a]	93.93 ± 0.75[b]	94.26 ± 0.44[b]
Protein, %	44.67 ± 0.57[a]	52.29 ± 0.53[b]	56.84 ± 0.40[c]
Fat, %	21.15 ± 0.14[a]	19.86 ± 0.18[b]	18.17 ± 0.19[c]
Ash, %	5.26 ± 0.14[a]	6.07 ± 0.14[b]	5.75 ± 0.11[c]
Phosphorus, g/kg	8.110 ± 0.052[a]	8.107 ± 0.032[a]	8.206 ± 0.021[b]
Calcium, g/kg	0.410 ± 0.038[a]	0.460 ± 0.031[ab]	0.51 ± 0.021[b]
Magnesium, g/kg	1.167 ± 0.032[a]	1.073 ± 0.038[b]	1.310 ± 0.052[c]
Iron, mg/kg	241.54 ± 1.04[a]	247.11 ± 0.55[b]	239.74 ± 0.67[c]
Zinc, mg/kg	152.11 ± 1.54[a]	158.16 ± 1.56[b]	156.52 ± 1.47[b]
Cuprum, mg/kg	10.390 ± 0.052[a]	8.973 ± 0.104[b]	10.933 ± 0.094[c]
Manganese, mg/kg	21.63 ± 0.60[a]	21.23 ± 0.40[a]	20.89 ± 0.75[a]

Note: see Table 1.

As with protein content in the liver, we should note the tendency towards increase ($P < 0.001$) in its mass share – by 17.0% the second group and 27.2% in the third group. We should note 6.1% ($P < 0.01$) decrease in fat content in the second group and 14.1% ($P < 0.001$) in the third group and 15.4% ($P < 0.01$) and 9.3% ($P < 0.05$) increases of ash in those groups, respectively.

Intake of various mineral supplements by the broiler chickens led to changes in the liver's mineralogical composition. In the second and third groups, the content of calcium was higher. Phosphorus in the liver of the first- and second-group chickens was at the same level, and its insignificant increase was seen in the third. Compared with the first group, mass share of magnesium in the second group was lower and 11.9% ($P < 0.01$) higher in the third group. We saw insignificant increase in iron in the second group and its decrease in the third. In the liver of chickens of the second group, content of zinc was 3.9% ($P < 0.05$) higher. Mass share of cuprum in the second group was lower and somewhat higher in the third. Content of manganese in the liver of the experimental groups was somewhat lower than in the control.

Discussion

The main objective of modern animal farming is achieving maximum productivity through realization of the genetic potential and survival of the populations, decrease in production costs, and production of high-quality meat. Studies by Yaremchuk et al. (2022) and Farionik et al. (2023) confirmed the importance of correcting the animals' diets with mineral premixes for more intensive growth and enhancement of meat quality. One of the key tendencies in the development of poultry farming has been not only continuous improvement of meatiness, but also improvement of the quality characteristics of the produced meat. Quality of meat products depends on morphological composition of carcasses, their physical-chemical properties and biological completeness.

Bird meat is known for its dietary value, as a source of complete proteins, mineral compounds, fatty acids, necessary for satisfaction of people's needs in the main nutrients and energy (Savinok et al., 2023). However, chemical composition of meat is determined by balance of fodders, their enrichment with mineral compounds, vitamins, and fodder supplements. As of now, there is an ongoing search for mineral premixes, oriented at growth stimulation and increase in slaughter yield of carcasses. Studies by Fotina et al. (2021) confirmed that some mineral supplements can reduce fodder expenditures for production in animal farming. The present study revealed decrease in fodder expenditures per unit increment of live mass after intake of the Kronotsyd-L supplement with chelated microelement and copper glycinate by the broiler chickens. Other studies also confirmed the importance of mineral supplements in animal husbandry. Some minerals, such as zinc, copper, selenium, and others, are essential to provide normal functioning of the animals' organisms. Addition of those minerals to the animals' diets can improve their health and increase productivity. Results of the scientific-economic experiment of Redka et al. (2019) suggest that the use of mixed feeds with mixed ligand complex of zinc, compared with sulfate, contributed to improvement in meat qualities and increase in yield of the edible carcass parts.

Minerals with organic complexes are growth stimulators that improve the general condition of health and enhance the poultry productivity. A study conducted by Sakara & Melnyk (2019) also confirmed the importance of using vitamin-aminoacid chelates of zinc and manganese in poultry nutrition. As is known, those minerals are crucial for the normal functioning of the birds' organisms. Vitamin-aminoacid chelates are a more available form of those minerals for birds, and thus are better absorbed. The results of using those chelates were increase in mass and improvement in blood clinical picture. The conducted studies of introduction of chelated-microelements-containing mineral supplements confirmed the results of other researchers. In particular, feeding broiler chickens with Kronotsyd-L increased the mean-daily increment in live mass by 6.8%, and copper glycinate increased it by 14.2% at much lower expenditures of fodder per unit increment.

In modern conditions, it is important not only to boost poultry productivity, but also pay attention to the quality of products. Considering the positive effect of chelates on biological availability of microelements and absence of negative impacts on quality of the products, their use can be beneficial for increasing productivity of poultry with no loss of meat quality (Timoshenko et al., 2019). A study conducted by Hrybanova & Soboliev (2014) revealed that inclusion of lithium in the amounts of 0.10 and 0.15 mg/kg in mixed feeds for goslings of the Danish breed Legart had a significant effect on meat quality. Also, the studies by Hunchak (2014) confirmed that addition of germanium in the amount of 0.2 mg/kg promoted improvement of the chemical composition of the muscular tissue of goslings, leading to improvement of energy and biological values of meat. This was achieved as a result of increased accumulation of dry matter, protein, and fat, which in turn increased the quality of the end product. Minerals with organic complexes were characterized by enhanced absorption and efficacy, which corresponds to the needs of poultry during introduction in even small doses. According to Youssef et al. (2022), use of chelated Cr-Meth in feeding broiler chickens increased carcass yield and decreased fat percentage in bird carcasses. Introduction of selenium organic compounds with higher bioavailability to the diet of broiler chickens positively influenced increase in live mass and improved the yield parameters as a result of greater increment in the breast and thigh muscles, which was a consequence of increased muscular mass and effective use of nutrients in the poultry diet (Poberezhets et al., 2023). In the conducted study, broiler chickens had a greater yield of the breast and thigh muscles after inclusion of mineral supplements with chelated microelements in the diet (Kronotsyd-L and glycinate of chelate copper) (Razanova et al., 2023).

Using glycine chelates of Zn, Cu, and Fe had a positive effect on the profile of fatty acids and dietary value of meat (Winiarska-Mieczan et al., 2021) and increased the antioxidant tolerance of the thigh meat (Winiarska-Mieczan et al., 2021). The study conducted by Holovko (2015) revealed that that addition of the nutraceutical nanomolibdenium citrate and the complex fodder supplement Probiks to the diet of broiler chickens increased the mass share of dry matter in white and red muscles as a result of reducing the mass share of water content, content of protein and ash, and also fat. Such changes were beneficial to the meat quality of the broiler chickens. The main advantage of the breast meat of broilers that had been receiving humic compounds was improvement of the quality of end products, which was expressed in increase in protein and decrease in fat (Semjon et al., 2020). Use of a mixture of phosphates for watering broiler chickens increased the nutritional value of their meat (Povarova, 2021). Analysis of chemical composition of meat revealed a difference between meat of the broiler chickens that had received chelate compounds of mineral elements and those that had received only the main diet. Enrichment of poultry diet with mineral supplements with chelated microelements heightened the content of dry matter, protein, and ash in the breast and thigh muscles. The breast muscles were different from the thigh muscles by chemical composition. There was found a downward tendency in the content of fat in the breast muscles of broiler chickens of the experimental and control groups, compared with the thigh muscles, which therefore resulted in lower energy value of white meat. In the thigh muscles, compared with the breast muscles, the shares of ash and protein were lower.

Aminoacid complexes of zinc can foster growth rates, increase zinc concentration in the tissues, and influence the formation of the breast muscles (Ma et al., 2024). The studies by Merzlov et al. (2012) found changes in the content of zinc, cobalt, and cuprum in meat of broiler chickens that had been consuming mixed feeds enriched with immobilized enzymes, iodine, and mixed ligand complex of cobalt. In the broiler chickens that had received the organic complex of copper, iron, manganese, and zinc, the concentrations of microelements in the tibia increased, while in the liver they, by contrast, decreased (Bao et al., 2007). Addition of chelate microelement supplements to the diet of poultry affected the mineral composition of breast and thigh muscles. The supplement Kronotsyd-L promoted the tendency towards increase in the content of phosphorus, calcium, magnesium, iron, and manganese in the breast and thigh muscles and the liver. The diet containing the chelate complex of copper with glycine increased the copper concentration in the breast muscles and the liver.

Conclusions

Adding mineral supplements with chelated microelements to the diet of the broiler chickens increased the increment in live mass, the slaughter-yield parameters, and chemical and mineral compositions of the breast and thigh muscles and the liver. Supplementing the diets of the broilers with Kronotsyd-L with chelated copper, iron, zinc, manganese, and copper glycinate increased the live mass and slaughter yield of the breast muscles. Subject to those supplements, dry matter and protein increased, whereas fat in the breast and thigh muscles decreased, thus resulting in less calorie-rich meat. In the liver of broilers of the second and third groups, there was higher content of organic matter and lower content of fat. There occurred changes in the chemical composition of the breast muscles because of substantial increase in calcium, iron, manganese in the second and third groups, in the thigh muscles in the second group, in calcium and manganese in the third, and in iron in the both groups.

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