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Quality of Broiler Chicken Meat with the Addition of Chelated Compounds of Microelements to the Diet

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Abstract. At present, the current direction in poultry farming is the development of methods for raising poultry without the use of antibiotics to overcome antibiotic resistance. For this purpose, it is recommended to use mineral supplements of chelated forms of microelements of zinc, copper, and manganese in poultry diets. Chelated minerals are characterised by better digestibility during intensive broiler farming, which limits the use of minerals and reduces environmental pollution. The purpose of the study was to examine the quality of meat of broiler chickens of the Cobb-500 cross, provided that chelated forms of zinc, copper, and manganese are included in the diet. Experimental studies were conducted in 2021 on broiler chickens of the Cobb-500 cross. Two groups of 20 heads of poultry were formed to examine the chemical composition of meat. Poultry of the control group received a basic diet with zinc, copper, and manganese sulfates, and poultry of the experimental group – enriched with chelated compounds of these microelements. The addition of chelated compounds of zinc, copper, and manganese to the diet of broiler chickens leads to an increase in the amount of fat, calcium and zinc in white muscles by 69.6, 24.6% and 1.4 times, and in red muscles-by 41.1, 30.9% and 3.4 times, respectively. The content of copper and manganese increases by 48.0 and 95.5% in red muscles and by 28.1 and 15.2% in white muscles compared to the control group. Therewith, there is a decrease in the relative content of essential amino acids by 1.1-1.3% and an increase in non-essential amino acids by 2.6-2.7%. According to the overall assessment of organoleptic parameters of broiler chickens fed zinc, copper, and manganese chelates, the sum of points was 2.0 points higher in the femoral muscles and 1.5 points higher in the pectoral muscles. In addition, according to the tasting assessment of meat from the thigh muscles of broiler chickens, more points were obtained in terms of tenderness by 10.0%, taste by 12.2%, and aroma by 13.2%. According to the tasting assessment of meat from the pectoral muscles of broiler chickens, more points were obtained in terms of tenderness by 18.9% and aroma by 10.3%. According to the reaction with copper sulfate, the content of ammonium and ammonia salts, broiler chicken meat was fresh and obtained from healthy poultry. As a result of organoleptic, physico-chemical, and biochemical studies of broiler chicken meat under the conditions of adding microelement chelates to the diet, it was established that it belongs to fresh and high-quality for consumption. These studies argue for the use of chelated compounds of microelements in poultry farming and contribute to their further introduction into production

Keywords: poultry, white and red muscles, zinc, copper, manganese, chemical composition

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Introduction

Zinc, copper, and magnesium are important microelements that are necessary for poultry in small but sufficient quantities for normal biological functioning. Since drinking water is generally not considered the main source of minerals, feed and supplements are the main source of minerals for poultry. However, due to the potentially dangerous content of microelements and the difference in bioavailability among typical feed ingredients, micromineral additives, usually in the form of inexpensive oxides and sulfates, have become common practice, always providing a high supply of minerals in the body [1]. In addition, some microelements (such as copper and zinc) can be used at the pharmacological level to improve the health and productivity of poultry. Given the fact that the absorption of many minerals from the gastrointestinal tract is carefully regulated, and the effectiveness decreases with increasing mineral intake [2], most of the excess amount of microelements is simply released into the environment, which can be toxic to plants and microorganisms or contribute to the spread of microbial genes that give them resistance to antimicrobial substances [3; 4].

Microelements are essential components in the poultry diet. They are essential for the growth and development of bones and the formation of natural plumage. Microelements are part of enzymes, and also perform the function of appetite stimulants. Mineral microelements act as catalysts for many biological reactions in the body [1; 2; 4]. There are two sources of microelements: inorganic and organic. Common sulfates, oxides, chlorides, and carbonates are inorganic sources, but they do not have sufficient bioavailability. Due to the combination of amino acids and hydrolysed protein, organic microelements are formed by chelating a soluble salt. Through a coordinated bond, chelated minerals bind to the organic ligand. The relative bioavailability and efficacy of organic microelements may vary depending on the ligand attached to the mineral, the bond strength, and the ligand-to-mineral ratio [3].

It is well known [4] that organic chelates play a crucial role in the absorption of nutrients in the intestine and increase bioavailability. Iron, copper, zinc, manganese, chromium, and selenium are common organic microelements. The main function of zinc and copper is to improve the health and productivity of poultry. Organic manganese is important for enhancing bone growth, development, and reproductive function in animals and poultry [1]. Iron promotes the transport of oxygen and carbon dioxide in the body. In commercial practice, to meet the need for microelements, to avoid micronutrient deficiencies, and to help poultry reach its genetic growth potential, inorganic microelements are used in amounts that are 2-10 times higher than recommended by the National Research Council for Poultry Diet [5]. The use of inorganic microelements in the diet of poultry has two main disadvantages. Copper sulfate and zinc oxide are common inorganic sources of copper and zinc used in poultry diets, but these two sources are derived from the metallurgical industry and contain substantial amounts of pollutants such as fluorine and cadmium entering poultry feed [6]. Secondly, the antagonistic effect between inorganic microelements can reduce their metabolism and absorption rate. Chelated complexes of metals with amino acids exhibit inert properties since covalent and Ionic bonding occurs between the mineral and the ligand. Based on this, these forms remain under the influence of factors that lead to precipitation, similar to what happens with inorganic minerals after salt dissolution [5]. In addition, the sise and stability of chelated compounds of microelements can protect the latter during movement in the gastrointestinal tract and ensure their absorption unchanged, without any destruction of amino acids. Organic microelements have better bioavailability than their inorganic forms [2; 3; 7]. In the diet of poultry, a lower concentration of organic forms of minerals is required, which prevents negative effects on poultry productivity and the environment [7].

The purpose of the study is to determine organoleptic and biochemical parameters, examine the chemical and amino acid composition of meat of broiler chickens of the Cobb-500 cross, provided that chelated forms of zinc, copper, and manganese are included in the diet.

Literature Review

Different forms of organic minerals may differ in the degree of availability of chelated compounds, and therefore their effects on productivity, meat yield, and other indicators may also vary. Therefore, their effectiveness in the comparative aspect in relation to changes in the chemical composition of meat requires further study [2]. Common inorganic forms (sulfates) tend to easily separate from inorganic salts when exposed to acidic pH values in the gastrointestinal tract, which can increase the frequency of antagonism with other components of the poultry diet [3]. This may reduce their absorption and excretion in the faeces [4]. In scientific literature sources, it is noted [2; 5] that the use of chelated compounds in the form of premixes in the diet of industrial poultry contributes to the improvement of productivity, poultry health, and meat quality. Therefore, the researchers [7] comprehensively analysed chelates of minerals and amino acids, including copper. The productivity of laying hens and eggshell quality improved after the addition of copper methionine, compared to the performance of poultry that received additional copper sulfate.

Among chickens treated with chelated microelements, there was a substantial increase in body weight gain, mineral deposition in tissues, improved immunity, and an increase in feed conversion rate compared to chickens treated with inorganic microelements at the same dose [8]. Broiler chickens whose diet was supplemented with organic chromium (0.5 mg/kg) had an increased body weight compared to poultry whose diet was supplemented with chromium from inorganic sources [9]. The feed conversion rate increased in chickens fed organic minerals compared to chickens fed inorganic minerals (1.6 vs. 1.7). In addition, the introduction of mineral proteins to the broiler diet helped reduce ascites cases from 5% to 2% [9].

Zinc or copper methionine enhances humoral and cell-mediated immune functions [10]. Therefore, the researchers comprehensively analysed chelates of minerals and amino acids, including copper [9; 10]. Copper is considered a growth stimulator in poultry farming [8], especially given the fact that the use of antibiotics as growth stimulants is prohibited in the European Union [11]. In this regard, researchers [12-14] are searching for new alternative methods of treatment and prevention of animal diseases.

Copper is an extremely active catalyst for lipid peroxidation reactions [7]. Given the dominant degree of oxidation, zinc [10] is an integral part of several biochemical pathways as a catalytic or regulatory cofactor. It also plays a structural role in many other functional proteins [3]. Manganese is involved in various biological processes as a cofactor of superoxide dismutase, transferase, hydrolase, and lyase [5]. Manganese deficiency, especially in growing chickens, is closely associated with many side effects, manifested by growth retardation and skeletal abnormalities. Given that such chelates may soon be largely introduced into broiler feed, their impact on the nutritional value of meat should be considered.

In the course of the study, researchers identified [8] that the use of feed additives with chelated compounds of zinc, copper, and manganese stimulates an increase in the overall natural resistance of broilers, accompanied by an increase in bactericidal activity by 7.4%, phagocytic activity by 8.3%, and lysozyme activity by 6.6%. In this regard, it is advisable to involve chelated elements in industrial poultry farming, since they can be used as a powerful immunostimulator that ensures high quality of meat products without the use of antibiotics.

The use of zinc chelated supplements improves the antiviral response and systemic immunity, and also promotes specific suppression of viral replication or infection-related symptoms [15].

The use of chelated compounds of zinc, copper, and manganese increases the hatchability of chickens by 1.9%, egg production of chickens – by 5.8%, reduces feed conversion by almost 6.0%. Therewith, an increase in the ash level by 4.3% in the dry matter of the bones of day-old chickens indicates an improvement in the skeletal structure [8].

The dose of chelated compounds added to feed for broiler chickens can be reduced or increased, which does not create a negative impact on their productivity, the body's antioxidant defence system, hematological parameters, and meat quality [3; 6; 10].

Studies by F. Hussan, D. Krishna, V.C. Preetam, P.B. Reddy, S. Gurram [4] proved that the introduction of chelated minerals in the amount of 25% in the diet of poultry does not negatively affect productivity indicators, such as weight gain and feed intake. Therewith, the addition of up to 20% inorganic microelements also has no negative effect on weight gain and feed conversion rate, with the advantage of reducing environmental pollution due to lower mineral excretion.

Materials and Methods

Experimental studies were conducted in 2021 at the Department of Virology, Pathanatomy, and Poultry Diseases, and at the Department of Veterinary Expertise, Microbiology, Zoohygiene, and Safety and Quality of Livestock Products of Sumy National Agrarian University. Two groups of broiler chickens of the Cobb-500 Cross were formed according to the principle of analogues (control and experimental), 20 heads each to examine the chemical composition of poultry meat based on the vivarium of the Faculty of Veterinary Medicine of Sumy National Agrarian University. The bird was kept by the floor method in accordance with DSTU (National Standard of Ukraine) 8219:2015 [16]. Drinking of the bird was organised from drip drinkers and was not limited.

Poultry of the control group received a basic diet with zinc sulfates (100 mg/kg), copper (20 mg/kg), and manganese (100 mg/kg), and the experimental group – enriched with chelated compounds of zinc (56 mg/kg), copper (14 mg/kg), and manganese (56 mg/kg). For feeding broiler chickens, mixed feed with the addition of MINTREX® premix produced by Novus International was used. This premix contains mineral compounds, in particular chelated minerals zinc, copper, and manganese, which are distinguished by the presence of methionine hydroxyanalog as a ligand. In this case, two ligands covalently bind one metal atom. Experimental studies lasted 42 days.

All animal studies were conducted in accordance with Directive 2010/63/EU, as amended by Regulation (EU) 2019/1010 [17].

On the 42nd day of the experiment, poultry was slaughtered. Ten heads of broiler chickens from each group were selected for experimental studies. After 24 hours of cooling at 4°C, the meat from the carcasses was separated from the bones. White (pectoral muscles) and red muscles (thigh muscles) were used for the study. The samples were frozen at -20°C for further chemical analysis.

The content of dry matter, ash, protein, and fat in meat samples was determined by the standard AOAC method [18]. Total tissue lipids were extracted by Folch *et al.* method [19]. The content of calcium, zinc, copper, and manganese in meat samples was determined by the AAS flame method [20] on the Unicam 939 device (AA spectrometer Unicam, Great Britain) after ashing at a temperature of 550°C according to The AOAC method.

Standard ion solutions were purchased from Merck (Germany) for the production of calibration lines. Standard solutions of 20 mEq/L, 40, 60, 80, and 100 mEq/L were used for zinc, copper, manganese, and calcium.

The cholesterol content was determined by the colourimetric method [21]. The amino acid profile of meat samples was analysed by liquid hydrolysis in 6 M hydrochloric acid to obtain amino acids from protein using liquid chromatography on an LC-10ad chromatograph (Shimadzu Liquid Chromatograph, Japan), which was connected to an automatic sampler and a fluorimeter (JASCO-Intelligent Spectrofluorimeter 821fp, UK) [22].

The tasting assessment of boiled meat of broiler chickens of the experimental groups was conducted on a 5-point scale, where 1 point is the worst indicator, and 5 is the best indicator. In boiled meat, poultry was evaluated for taste, aroma, juiciness, tenderness; in meat broth – aroma, colour, taste, transparency, and richness. The research was conducted according to the methods set out in DSTU ISO 6658:2005 [23].

Veterinary and sanitary assessment of broiler meat was conducted using generally accepted methods [24]. The study of meat was conducted after its aging at a temperature of 0 to + 4°C. For the study, meat samples were taken from the pectoral and thigh muscles. Organoleptic and biochemical parameters were determined.

During the veterinary and sanitary assessment, the following organoleptic indicators were determined: the appearance of muscles, their smell, colour, the condition of muscles on the incision, the condition and elasticity of fat and muscle tissue, and the indicators of the cooking sample. For biochemical studies, an extract of meat was prepared with water in a ratio of 1 to 3. Production of the extract for research was conducted separately from the red and white muscles of broiler chickens.

According to the reaction of measuring the activity of the peroxidase enzyme in meat, which is based on the oxidation of hydrogen peroxide by benzidine in the presence of the peroxidase enzyme to form paraquinondiamide, its quality was evaluated. With a positive reaction, a blue-green colour was formed, which after a while changed to brown.

A reaction with Nessler's reagent was used to determine the presence of ammonia and ammonium salts in meat. As a result of this reaction, a compound of dimercuramonium iodide is formed, namely its complex salt, which provides the appearance of a yellow-orange colour.

A reaction with copper sulfate was used to determine such an indicator as the freshness of meat. During this reaction, meat proteins are deposited during heating and copper sulfate complexes are formed with the products of primary protein breakdown.

Isolation of volatile fatty acids from broiler chicken meat was conducted by distillation with water vapour and titration with 0.1 N potassium hydroxide solution. The analysis was conducted using water vapour distillation equipment, which consists of a round-bottomed flask, a flask heater, a flat-bottomed flask, a safety tube, a steam-removing tube, a drop trap, a refrigerator and a conical flask. For a control study, distilled water with reagents was used, without the use of meat extracts.

The obtained digital results were processed using variational and statistical methods. The arithmetic mean (M) and statistical error of the arithmetic mean (m) were determined. The probability of difference was determined by the reliability criterion (td) and by the Student's method [25]. The difference between the two values was considered probable for *$P < 0.05$.

Results and Discussion

The study began with an assessment of the condition of broiler chicken carcasses in the experimental and control groups. It was established that broiler chickens had a shiny beak, the oral mucosa was shiny, pale pink in colour and characterised by little moisture, and the eyeballs are convex in shape and have a shiny cornea.

In broiler chicken carcasses, the skin surface had a dry consistency, white-yellow colour, with a reddish tinge. The muscles of broiler chickens on the cut are moistened, pale pink in colour, elastic in consistency, with a specific characteristic smell of fresh meat. No changes in internal organs or adipose tissue were observed. Therewith, the tendons in the carcasses of broiler chickens are dense, elastic, and the surface of the joints is smooth and glossy. According to the sample of cooking meat, a clear and aromatic broth was obtained, with a characteristic specific smell and taste.

According to some indicators of the chemical composition of red and white muscles of broiler chickens of the experimental and control groups, namely: in terms of humidity, dry matter, relative protein, and ash content, no statistically substantial difference was established (Table 1).

Table 1. Chemical composition of broiler chicken meat, M ± m, n = 10

Indicator	Research group		Control group	
	Red muscles	**White muscles**	**Red muscles**	**White muscles**
Humidity, %	72.37 ± 0.12	70.78 ± 0.13	74.14 ± 0.14	73.05 ± 0.21
Dry matter, %	27.63 ± 0.12	29.22 ± 0.13	25.86 ± 0.14	26.95 ± 0.21
Protein, %	22.91 ± 0.12	23.02 ± 0.21	20.91 ± 0.22	19.94 ± 0.31
Fat, %	6.84 ± 0.14*	10.23 ± 0.31*	2.08 ± 0.21	6.03 ± 0.22
Cholesterol, mg/100 g	41.32 ± 0.26*	46.10 ± 0.32*	54.31 ± 0.43	56.12 ± 0.24
Mineral substances, %	1.13 ± 0.32	1.14 ± 0.18	0.98 ± 0.11	1.02 ± 0.1
Calcium, mg/100 g	8.02 ± 0.53*	4.52 ± 0,36*	5.54 ± 0.61	3.41 ± 0.32
Zinc, mg/100 g	6.32 ± 0.24*	1.94 ± 0.12*	1.84 ± 0.12	1.37 ± 0.10
Copper, mg/100 g	0.037 ± 0.005*	0.041 ± 0.001*	0.025 ± 0.001	0.032 ± 0.001
Manganese, mg/100 g	0.043 ± 0.002*	0.038 ± 0.002*	0.022 ± 0.002	0.033 ± 0.001

Note: * $P < 0.05$, compared to the control group

However, the relative amount of fat in the white muscles of broiler chickens in the experimental group was higher by 69.6% ($P < 0.05$), and in red – by 41.1% ($p < 0.05$) compared to the control group (Table 1). Fat has a positive effect on the texture and taste of poultry meat [19]. In turn, the cholesterol content in the white muscles of broiler chickens in the experimental group was lower by 23.9%, and in red – by 17.9% compared to the control group.

The addition of chelated compounds to the feed of chickens in the experimental group contributed to a 30.9% increase in calcium content in red muscle and 24.6% in white muscle compared to the control group. In the study group, an increase in zinc content was also noted, 3.4 times higher for red muscles and 1.4 times higher for white muscles. The content of copper and manganese increased by 48.0 and 95.5% ($P < 0.05$) in red muscles, respectively, and by 28.1 and 15.2% ($p < 0.05$) in white muscles compared to the control group.

The enriched mineral composition of meat provides an increase in the nutritional value of the product, which also indicates a decrease in the release of microelements by poultry in faeces [3].

In addition, the amino acid composition of broiler chicken meat was investigated (Table 2).

Table 2. Comparative assessment of muscle tissue protein usefulness in broiler chickens, %, n = 10

Amino acid	Control group		Research group	
	Red muscles	White muscles	Red muscles	White muscles
Essential amino acids				
Valine	4.36 ± 0.02	4.30 ± 0.08	4.11 ± 0.06*	4.54 ± 0.07*
Isoleucine	3.92 ± 0.03	3.74 ± 0.05	3.68 ± 0.07*	3.96 ± 0.10
Leucine	7.32 ± 0.24	7.48 ± 0.32	6.82 ± 0.08	7.31 ± 0.09
Lysine	9.02 ± 0.09	8.71 ± 0.12	9.18 ± 0.18	7.41 ± 0.12
Methionine	1.69 ± 0.03	1.79 ± 0.02	2.41 ± 0.06*	1.87 ± 0.09
Threonine	3.52 ± 0.05	3.55 ± 0.03	3.24 ± 0.08	3.12 ± 0.10
Tryptophan	1.42 ± 0.02	1.32 ± 0.03	1.45 ± 0.02	1.63 ± 0.02*
Phenylalanine	3.96 ± 0.12	3.58 ± 0.09	3.24 ± 0.07	3.36 ± 0.08
Total	35.21 ± 0.60	34.47 ± 0.74	34.13 ± 0.62	33.20 ± 0.67
Non-essential amino acids				
Alanine	5.18 ± 0.21	5.34 ± 0.12	6.56 ± 0.18*	5.94 ± 0.26
Arginine	6.40 ± 0.16	6.17 ± 0.18	7.03 ± 0.20*	6.72 ± 0.31
Aspartic acid	7.98 ± 0.18	7.09 ± 0.17	8.69 ± 0.17*	5.53 ± 0.19*
Histidine	2.26 ± 0.09	2.01 ± 0.10	2.53 ± 0.21	2.37 ± 0.22
Glycine	4.98 ± 0.17	4.78 ± 0.23	5.02 ± 0.09	4.68 ± 0.18
Glutaric acid	14.7 ± 1.21	13.7 ± 1.13	14.14 ± 1.11	14.59 ± 1.24
Oxyproline	0.19 ± 0.02	0.16 ± 0.03	0.26 ± 0.08	0.34 ± 0.06*
Proline	3.88 ± 0.21	3.59 ± 0.19	3.83 ± 0.15	3.96 ± 0.21
Serine	3.57 ± 0.15	3.99 ± 0.24	4.28 ± 0.20*	3.94 ± 0.23
Tyrosine	2.43 ± 0.21	2.15 ± 0.17	2.03 ± 0.08	2.48 ± 0.14
Cysteine	1.57 ± 0.14	1.27 ± 0.18	1.35 ± 0.12	1.36 ± 0.17
Total	53.14 ± 2.75	50.25 ± 2.74	55.72 ± 2.59	52.91 ± 3.21

Note: * $P < 0.05$, compared to the control group

Based on the results presented in Table 2 it follows that from the investigated essential amino acids in red muscles, the relative content of valine and isoleucine decreases by 1.1 times, respectively ($P < 0.05$). However, in white muscles, on the contrary, the relative valine content increases – by 1.1 times ($P < 0.05$) compared to the control group. Therewith, such methionine increases 1.4 times ($P < 0.05$) in red muscles and tryptophan increases 1.2 times ($P < 0.05$) in white muscles.

Among the investigated non-essential amino acids, an increase in the relative content of alanine by 1.3 times was noted ($P < 0.05$), arginine by 1.1 times ($P < 0.05$), aspartic acid, and serine, respectively, by 1.1 and 1.2 times ($P < 0.05$) in red muscles compared to the control group. In white muscles, the oxyproline content increased by 2.1 times ($P < 0.05$), and the aspartic acid content decreased by 1.3 times ($P < 0.05$) compared to the control group. The results of the tasting evaluation of boiled broiler chicken meat are shown in Table 3.

Table 3. Tasting assessment of boiled broiler chicken meat, M ± m, n = 10

Indicator	Juiciness	Tenderness	Taste	Aroma	Total points
Femoral muscles					
Control group	4.2 ± 0.3	4.0 ± 0.1	4.1 ± 0.2	3.8 ± 0.1	19.8
Research group	4.5 ± 0.2	4.4 ± 0.1*	4.6 ± 0.1*	4.3 ± 0.2*	17.8
Pectoral muscles					
Control group	3.7 ± 0.6	3.7 ± 0.2	4.1 ± 0.2	3.9 ± 0.1	15.4
Research group	3.9 ± 0.5	4.4 ± 0.2*	4.3 ± 0.3	4.3 ± 0.1*	16.9

Note: * $P < 0.05$, compared to the control group

According to the tasting assessment (see Table 3), boiled meat (thigh muscles) of broiler chickens of the experimental group had an increase in the indicators of tenderness by 10.0% ($P < 0.05$), taste by 12.2% ($P < 0.05$), and aroma by 13.2% ($P < 0.05$) compared to the indicators of the control group. According to the tasting assessment (Table 3), boiled meat (pectoral muscles) of broiler chickens of the experimental group demonstrated an increase in tenderness indicators by 18.9% ($P < 0.05$) and aroma by 10.3% ($P < 0.05$) compared to the control group. For other investigated indicators, no statistically substantial difference was identified (Table 3). Therewith, there are no foreign odours or taste in the meat of the experimental and control groups.

In addition, the total amount of points for the tasting assessment of broiler chicken meat was analysed and it was identified that the indicators in the femoral muscles exceed by 2.0 points those in the control group. Instead, the scores assigned to the tasting assessment of the pectoral muscles of broiler chickens were 1.5 times higher than in the control group.

During the tasting of broiler chicken broth, the experimental group received 0.2-0.3 points more than the control group.

Thus, boiled meat and broth from it of broiler chickens fed microelements in chelated form had better results on tasting assessment than boiled meat and broth obtained from broiler chickens of the control group.

According to the biochemical parameters of broiler chicken meat as the acid number of fat, the amount of volatile fatty acids, the peroxide number of fat and PH, no statistically substantial difference was identified (Table 4).

Table 4. Biochemical parameters of broiler chicken meat, M ± m, n = 10

Indicator	Control group	Research group
The acid number of fat, mg AV	0.53 ± 0.11	0.48 ± 0.21
Amount of volatile fatty acids, mg AV/g	2.7 ± 0.1	2.8 ± 0.1
Peroxide number of fat, g of iodine	$9.02\ 10^{-3} \pm 0.02 \cdot 10^{-3}$	$9.06 \cdot 10^{-3} \pm 0.02 \cdot 10^{-3}$
PH value of white meat	5.6 ± 0.1	5.5 ± 0.2
PH value of red meat	5.9 ± 0.2	6.0 ± 0.1
Reaction with copper sulfate	Negative	Negative
Qualitative reaction to ammonia and ammonium salts	Negative	Negative
Qualitative response to peroxidase activity in white meat	Negative	Negative
Qualitative response to peroxidase activity in red meat	Positive	Positive

As can be seen from the results in Table 4, the reaction with copper sulfate is negative, which indicates the absence of protein breakdown products in the broiler chicken broth of the experimental group.

Therewith, the absence of ammonia and ammonium salts in the meat of broiler chickens of the experimental group indicates the freshness of the meat and the fact that it is obtained from healthy poultry. According to the qualitative reaction to determine the activity of the peroxidase enzyme, its presence was established in the red meat of broiler chickens of the experimental and control groups. In turn, in the white muscles of broiler chickens of the experimental and control groups, this enzyme is absent.

The addition of zinc nanoxide to the diet of broilers in experiments conducted by the authors [4] did not substantially affect the amount of fat in poultry carcasses, pH values, and cholesterol, but according to their own studies, a substantial increase in the amount of fat was by 69.6% ($P < 0.05$) in the white muscles of broiler chickens, and in red – by 41.1%. Studies have shown that the cholesterol content in the white muscles of poultry, to the diet of which chelated elements were added, was lower by 23.9%, and in red – by 17.9% compared to the control group.

According to the conducted experimental studies, an increase in the zinc content in the red muscles of broiler chickens was by 3.4 times, and in white ones – by 1.4 times. Therewith, the red muscles of broiler chickens increased the content of copper and manganese, respectively, by 48.0 and 95.5%, and in white – by 28.1 and 15.2% ($P < 0.05$) compared to the control group. The results obtained are consistent with the results of other researchers [6].

Therefore, adding chelated minerals in to the diet of broiler chickens is advisable for obtaining high-quality meat. H.A. Ghasemi [26] and other authors also note a positive effect of chelated compounds on growth, mineral absorption, skeletal bone condition, and antioxidant status in broiler chickens. C. Feng *et al.* [7] discovered that chelated minerals are characterised by better digestibility. Therefore, they can be used 75% less than the recommended level, without substantially reducing the production efficiency and slaughter yield of poultry, which reduces the ingress of minerals into the environment [8]. Today, the use of minerals is limited in the intensive cultivation of broiler chickens, which accordingly reduces environmental pollution.

Conclusions

The use of chelated compounds of zinc, copper, and manganese in the diet of broiler chickens does not affect the humidity level and relative content of dry matter, protein, and ash in meat. The amount of fat in the white muscles of broiler chickens increases by 69.6%, and in red – by 41.1% compared to the control. The calcium content of broiler chicken meat increases by 30.9% in red muscles and 24.6% in white muscles, and the zinc content in red and white muscles increases by 3.4 and 1.4 times, respectively. There is an increase in the content of copper and manganese by 48.0 and 95.5% in red muscles and by 28.1 and 15.2% in white muscles, respectively, compared to the control group.

In the red muscles of broiler chickens, when microelement chelates are added, the relative content of essential amino acids, namely valine and isoleucine, decreases by 1.1 times, respectively, and methionine increases by 1.4 times. Therewith, the relative content of valine and tryptophan in white muscles increases by 1.1 times.

In addition, red muscles show an increase in the relative content of non-essential amino acids: alanine by 1.3 times, arginine by 1.1 times, aspartic acid and serine, respectively, by 1.1 and 1.2 times. In white muscles, the relative content of oxyproline increases by 2.1 times and aspartic acid decreases by 1.3 times.

In addition, the indicators of organoleptic assessment of the femoral muscles of broiler chickens, which were added premix with chelated compounds of zinc, copper, and manganese to the main diet, predominate by 2.0 points, and the pectoral muscles – by 1.5 points.

The addition of premix with chelated compounds of microelements to the diet of broiler chickens does not affect the quality indicators of broiler chicken meat: acid and peroxide fat number, volatile fatty acid content, and pH value. Therewith, the content of ammonium and ammonia salts and the reaction with copper sulfate confirmed the freshness of meat and its receipt from healthy poultry. Thus, the results obtained indicate the prospects of using chelated compounds of microelements in poultry farming.

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Якість м’яса курчат-бройлерів за додавання до раціону хелатних сполук мікроелементів

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Анотація. Нині актуальним направленням у птахівництві є розробка методів вирощування птиці без застосування антибіотиків задля подолання антибіотикорезистентності. Для цього рекомендовано використання в раціонах птиці мінеральних добавок хелатних форм мікроелементів цинку, міді та марганцю. Хелатні мінерали характеризуються кращою засвоюваністю під час інтенсивного вирощування бройлерів, що обмежує використання мінералів і зменшує забруднення навколишнього середовища. Метою роботи було дослідження якості м’яса курчат-бройлерів кросу Кобб-500 за умови включення до раціону хелатних форм цинку, міді та марганцю. Експериментальні дослідження проводилися протягом 2021 року на курчатах-бройлерах кросу Кобб-500. Для дослідження хімічного складу м’яса було сформовано дві групи по 20 голів птиці. Птиця контрольної групи отримувала основний раціон із сульфатами цинку, міді та марганцю, а птиця дослідної групи – збагачений хелатними сполуками цих мікроелементів. Додавання до раціону курчат-бройлерів хелатних сполук цинку, міді та марганцю призводить до збільшення кількості жиру, кальцію та цинку в білих м’язах на 69,6, 24,6 % і в 1,4 раза, а в червоних – на 41,1, 30,9 % і в 3,4 раза, відповідно. При цьому, підвищується вміст міді та марганцю на 48,0 і 95,5 % у червоних м’язах і на 28,1 і 15,2 % – у білих порівняно з контрольною групою. Водночас спостерігається зниження відносного вмісту незамінних амінокислот на 1,1-1,3 % і збільшення – замінних амінокислот на 2,6-2,7 %. За загальною оцінкою органолептичних показників м’яса курчат-бройлерів, яким згодовували хелати цинку, міді та марганцю, сума балів була більшою на 2,0 бали в стегнових м’язах і на 1,5 – в грудних. При цьому, за дегустаційною оцінкою м’яса з стегнових м’язів курчат-бройлерів отримано більше балів за показниками: ніжності на 10,0 %, смаку на 12,2 % і аромату на 13,2 %. Водночас за дегустаційною оцінкою м’яса з грудних м’язів курчат-бройлерів отримано більше балів за показниками: ніжності на 18,9 % і аромату на 10,3 %. За реакцією з міді сульфатом, вмістом солей амонію та аміаку м’ясо курчат-бройлерів належало до свіжого та отриманого від здорової птиці. В результаті проведених органолептичних, фізико-хімічних і біохімічних досліджень м’яса курчат-бройлерів за умов додавання до раціону хелатів мікроелементів встановлена приналежність його до свіжого та якісного для споживання. Ці дослідження аргументують використання хелатних сполук мікроелементів в птахівництві і сприяють їх подальшому впровадженню у виробництво

Ключові слова: птиця, білі та червоні м’язи, цинк, мідь, марганець, хімічний склад