
EFFECT OF SUPPLEMENTATION WITH COPPER IN DIFFERENT CHEMICAL FORMS ON SELECTED PHYSIOLOGICAL BLOOD MARKERS AND CONTENT OF MINERALS IN SELECTED TISSUES OF TURKEYS

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Abstract

Scientific research has demonstrated that different compounds containing copper are capable of stimulating body weight gains, improving the health of animals and attaining high production performance without causing excessive accumulation of various chemical compounds in animal tissues. Besides, copper has been reported to exert a positive effect on the immune system, haematological blood markers and the microbiological balance in the gastrointestinal tract of turkeys.

The experiment was conducted on 60 BUT-9 line turkeys. The birds were divided into 5 experimental groups. Each group included 12 turkeys kept in cages. The birds were reared for 19 weeks. The first group served as control. Group II received CuSO_4 added to water in a dose of $10 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$. Group III was composed of birds administered a Cu chelate with lysine in a dose of $10 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$. Group IV received CuSO_4 in a dose of $20 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$, whereas group V were given a Cu-lysine supplement in a dose of $20 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$. The birds were fed commercial complete feed mixes. The copper preparations were added to drinking water since the 3rd week of rearing. The objective of this study has been to determine the effect of Cu supplementation in the organic and inorganic form and in two doses on the health of birds and on accumulation of minerals in their breast muscle and liver. Further analyses involved the determination of haematological and biochemical markers in blood as well as assays of selected minerals in the birds' blood, breast muscle and liver. The analysis of the results indicated that the doses of copper improved the health of the turkeys, as verified by better haematological markers. Statistically significant difference appeared in the group receiving 20 mg Cu dm^{-3}

H₂O irrespective of the chemical form in which copper was administered. The study also shows that Cu supplementation has a significant effect on the metabolism of lipids and a non-significant impact on the content of mineral elements in the analyzed tissues. It was not until the 20 mg dose of Cu as a chelate had been applied that the accumulation of copper in the turkey's liver was enhanced.

Key words: turkeys, copper, blood haematology and biochemistry, mineral elements in tissues, body weight gains.

WPLYW SUPLEMENTACJI MIEDZIĄ PODAWANĄ W RÓŻNYCH FORMACH CHEMICZNYCH NA WYBRANE WSKAŹNIKI FIZJOLOGICZNE KRWI ORAZ ZAWARTOŚĆ PIERWIĄTKÓW MINERALNYCH W WYBRANYCH TKANKACH INDYKÓW

Abstrakt

Z badań naukowych wynika, że różne związki miedzi można zaliczyć do substancji stymulujących przyrosty masy ciała oraz poprawiających zdrowotność zwierząt, co sprzyja uzyskiwaniu lepszych efektów produkcyjnych, nie powodując nadmiernego akumulowania związków chemicznych w tkankach zwierząt. Ponadto miedź korzystnie wpływa na funkcjonowanie układu immunologicznego, poprawia wskaźniki hematologiczne krwi oraz umożliwia utrzymanie równowagi mikrobiologicznej przewodu pokarmowego indyków.

Badania przeprowadzono na 60 indykach linii BUT-9 podzielonych na 5 grup doświadczalnych. Każda grupa liczyła po 12 indyków, które były utrzymane w klatkach. Odchów zwierząt trwał 19 tygodni. Pierwsza grupa stanowiła kontrolę. Grupa II otrzymywała dodatek CuSO₄ do wody w ilości 10 mg Cu dm⁻³ H₂O, grupa III – dodatek chelatu Cu z lizyną w dawce 10 mg Cu dm⁻³ H₂O, grupa IV – dodatek CuSO₄ w dawce 20 mg, grupa V – suplement Cu – lizynę w dawce 20 mg Cu dm⁻³ H₂O. Paszę stanowiła typowa mieszanka pełnoporcjowa dostępna na rynku. Preparaty miedzi dodawano do wody pitnej od 3. tygodnia odchowu. Celem badań było określenie wpływu suplementacji Cu stosowanej w formie nieorganicznej i organicznej oraz w dwóch różnych dawkach na zdrowotność indyków oraz stopień akumulacji elementów mineralnych w mięśni piersiowym i wątrobie. W badaniach oznaczono wskaźniki hematologiczne i biochemiczne krwi indyków oraz zawartość wybranych elementów mineralnych we krwi, mięśni piersiowym i wątrobie ptaków. Wykazano, że zastosowane dawki miedzi spowodowały poprawę stanu zdrowia indyków, co wyrażało się korzystnymi zmianami wskaźników hematologicznych. Statystycznie istotne wartości odnotowano w grupie ptaków, które otrzymywały 20 mg Cu dm⁻³ H₂O niezależnie od formy chemicznej. Z badań wynika, że suplementacja Cu ma znaczący wpływ na gospodarkę lipidową. Miedź miała nieznaczny wpływ na zawartość elementów mineralnych w tkankach. Jedynie dawka 20 mg Cu w formie chelatu spowodowała zwiększoną kumulację tego pierwiastka w wątrobach ptaków.

Słowa kluczowe: indyki, miedź, hematologia i biochemia krwi, elementy mineralne w tkankach, przyrosty.

INTRODUCTION

In poultry breeding practice, much attention is paid to the proper feeding of birds and rational use of feed supplements supposed to increase productivity, which is necessitated by legal regulations, economic considerations

and protection of consumers' health (JAMROZ, POTKAŃSKI 2004). Changes in the law governing the use of drugs in animal breeding for human consumption have forced the breeders to apply supplementation which is consistent with the currently binding regulations and which helps to improve the health of animals and to attain high production performance without causing excessive accumulation of various chemical compounds in animal tissues (OLEJNIK et al. 2009). This fact has contributed to an increased interest in non-antibiotic growth stimulators, which are not a health hazard to consumers (NOYCE et al. 2006). Scientific research has demonstrated that different compounds containing copper are capable of stimulating body weight gains and improving feed utilization (HARMS, BURESH 1986, PESTI, BAKALII 1996, SMULIKOWSKA 1996). The stimulating effects of copper are claimed to be produced owing to improved hematological blood markers (JAMROZ 1990, MAKARSKI et al. 2002). Other authors additionally point to the contribution of copper to the synthesis and activation of many enzymes (BOGUSZEWSKA et al. 2003). This element has been reported to exert a positive effect on the immune system by stimulating the biosynthesis of antibodies (FAILLA et al. 1998) as well as by inhibiting the growth of pathogenic microorganisms (BRUNCH et al. 1965, JAMROZ, POTKAŃSKI 2004, NOYCE et al. 2006, KUŹLIK-WYROSTEK, MAKARSKI 2009). In turn, a study conducted by MAKARSKI (2002) demonstrated that the application of copper modified the composition of bacterial flora in the gastrointestinal tract of turkeys. Consequently, copper supplementation enabled the birds to maintain the microbiological balance, which has an indirect, positive effect on body functions, also improving body weight gains.

The objective of this study has been to determine the effect of copper supplementation in two chemical forms and in various doses on levels of selected hematological and biochemical blood markers of turkeys. In order to assess accumulation of minerals in tissues, levels of minerals were assayed in blood, breast muscle and liver of the birds.

MATERIAL AND METHODS

The experimental material were 60 BUT-9 line turkeys reared for 19 weeks. The birds were divided into 5 experimental groups. The first group served as control. Group II received CuSO_4 added to drinking water in a dose of $10 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$. Group III consisted of birds administered supplementary Cu chelate with lysine in a dose of $10 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$. Group IV received CuSO_4 in a dose of $20 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$, whereas the group V birds were given Cu-lysine supplement in a dose of $20 \text{ mg Cu dm}^{-3} \text{ H}_2\text{O}$. The experimental preparations were administered with drinking water to eliminate the antagonistic effect of feed mix ingredients on the availability of this element (NOY et al. 1994).

Each group included 12 turkeys kept in cages. All birds were provided identical zoohygienic conditions, pursuant to the requirements for slaughter turkey rearing. The birds had an *ad libitum* access to feed and water. They were kept on straw litter and fed typical complete feed mixes available on the Polish market. The quality of water used in the experiment met sanitary requirements stipulated in the Regulation of the Ministry of Health and Environmental Protection (MZiOS) of 4th May 1990 (Journal of Law no 3, item 250/1990) and the requirements set up for water for drinking and household purposes.

Before slaughter, in the 19th week of life, blood was sampled from the brachial vein for haematological and biochemical analyses. Haematological markers, including red blood cells (RBC) count, haemoglobin (Hb) and haematocrit (Ht), were determined in the blood samples according to the clinical methods. In addition, an automatic blood analyzer Hitachi 704 was used to assay the following biochemical parameters in serum: aspartate aminotransferase (AST), alanine aminotransferase (ALT), total cholesterol (CHOL), uric acid (UA), triacylglycerols (TG), glucose (GLU) as well as the content of mineral elements in blood (Ca, Mg and P). All analyses were carried out with reagents produced by the company called Katal. The concentrations of Fe, Cu and Zn were determined directly from serum after dilution (1:4) by means of the ASA method.

The slaughter was followed by detailed dissection, during which samples of liver and breast muscle were collected for analyses. All samples were individually marked, packed in plastic bags, tagged and frozen at -18°C. According to the design of the experiment, samples of liver and breast muscle were determined for concentrations of Zn, Cu, Mn, Fe, P, K, Ca, and Mg. These determinations were carried out on standardized and thoroughly comminuted turkey tissues, from which 1-g samples were collected for analyses. Next, weighed portions of the analytical material were transferred into glass thimbles, to which 5 ml of 70% HClO₄ and 65% HNO₃ in a 1:5 ratio were added. Afterwards, the thimbles were placed in a mineralizer, and the samples were mineralized first at 80°C for 60 min, and then at 200°C for ca 90 min. The resultant solution was transferred to a measuring flask, which was filled up to 50 ml with redistilled H₂O. The solution thus prepared was assayed for the concentration of Cu using an atomic absorption spectrophotometer (AAS) on a UNICAM 939 apparatus. Concentrations of the other elements, i.e. Ca, Fe, Zn, and Mg, were assayed with the use of an SP9 AS atomic absorption spectrophotometer by Unicam. The complete feed mixes applied in the experiment were also analyzed for the content of major minerals, i.e. Cu, Zn, Mn, Fe, Ca, and Mg, following the above procedures.

The experimental data underwent statistical analysis with Statistica 5.0 PL 97 software, using a one-way analysis of variance at significance levels of 0.05 and 0.01.

RESULTS AND DISCUSSION

The biological experiment discussed in this paper has involved the application of five types of complete feed mixes, whose nutritive value was balanced depending on the age and physiological needs of turkeys. The composition of the feed mixes declared by the producer is presented in Table 1.

Table 1

Nutritive value of the complete mixes for turkeys

Feeding period	0-3 week	4-6 week	7-10 week	11-14 week	15-19 week
Metabolizable energy (kcal kg ⁻¹)	2800	2900	3000	3075	3150
Total protein (%)	27.00	25.50	23.00	21.00	18.00
Raw fibre (%)	4.00	3.50	3.50	4.00	4.00
Lysine (%)	1.70	1.60	1.45	1.30	1.10
Methionine (%)	0.62	0.62	0.57	0.54	0.50
Methionine + cystine (%)	1.10	1.02	0.96	0.91	0.82
Tryptophan (%)	0.32	0.26	0.25	0.22	0.19
Calcium (%)	1.30	1.30	1.15	1.10	1.00
Available phosphorus (%)	0.70	0.65	0.63	0.60	0.58
Sodium (%)	0.15	0.16	0.15	0.15	0.15

The feed mixes were tested for their content of selected mineral elements, i.e.: Cu, Zn, Mn, Fe, K, and Mg, and the results are given in Table 2. The analysis of these results demonstrated that the content of minerals in the feed mixes was above the recommended levels (KRATZER et al. 1994), but not toxic (NOY et al. 1994). According to SMULIKOWSKA (1996), the recommended dose of copper is 10 to 20 mg kg⁻¹ whereas POLONIS et al. (1999) indicate that for growing turkeys this dose may be as high as 20-30 mg kg⁻¹.

Table 3 presents the final body weights of turkey hens after 19 weeks of rearing. The experimental factors applied in the particular groups did not cause increased body weight gains of turkey hens as compared to the control group. The results just imply a growing tendency along with an increasing dose of copper in particular groups. However, the recorded differences were statistically insignificant. Other investigations (MAKARSKI, ZADURA, 2006) demonstrated that copper addition in the organic form and in a dose of 10 mg dm⁻³ H₂O resulted in a significant increase in body weight of turkeys as compared to the control birds.

Haematological blood analyses are the basic source of information on the health of an animal. Table 4 presents levels of haematological blood

Table 2

Mineral elements in the feed mixes for turkeys

Feed mixes (feeding period)	Minerals					
	Cu (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Fe (mg kg ⁻¹)	K (mg kg ⁻¹)	Mg (mg kg ⁻¹)
0-3 week	12.8	73.1	114.6	77.0	9.7	1.7
4-6 week	13.8	73.0	118.0	79.0	11.3	2.0
7-10 week	18.7	73.0	110.0	64.0	10.2	1.9
11-14 week	23.9	77.0	120.0	62.0	9.4	1.8
15-19 week	22.1	69.0	104.0	55.0	10.4	1.9

Table 3

Final body weights of turkey hens after 19 weeks of rearing

Indicator	Group I	Group II	Group III	Group IV	Group V
	control	CuSO ₄	chelate Cu - Lys	CuSO ₄	chelate Cu - Lys
	-	10 mg Cu dm ⁻³ H ₂ O		20 mg Cu dm ⁻³ H ₂ O	
Body weight (g)	13 235.00 ±770.00	12 180.00 ±706.80	12 340.00 ±1056.80	12 590.00 ±1103.50	13 220.00 ±1188.10

Table 4

The level of haematological indices in blood of 16-week-old turkeys

Index	Group I	Group II	Group III	Group IV	Group V
	control	CuSO ₄	chelate Cu - Lys	CuSO ₄	chelate Cu - Lys
	-	10 mg Cu dm ⁻³ H ₂ O		20 mg Cu dm ⁻³ H ₂ O	
RBC (10 ¹² dm ⁻³)	2.02 ^b ± 0.69	2.28 ^{ab} ± 0.73	2.35 ^{ab} ± 0.69	2.58 ^a ± 0.14	2.55 ^a ± 0.14
Hb (g dl ⁻¹)	13.00 ^b ± 4.30	13.80 ^b ± 4.55	14.77 ^b ± 4.31	16.00 ^a ± 0.58	15.55 ^a ± 0.21
Ht (%)	34.13 ^b ± 11.62	38.60 ^{ab} ± 12.23	39.45 ^{ab} ± 11.66	42.84 ^a ± 1.79	42.05 ^a ± 0.92

a, b – statistically significant difference at $p \leq 0.05$

markers of the turkeys in the 19th week of life. The results suggest that the Cu supplementation in doses of 10 mg as well as 20 mg Cu dm⁻³ H₂O had a beneficial influence on all analyzed markers. Statistically significant differences were noted in the group of birds receiving 20 mg Cu dm⁻³ H₂O irrespective of the chemical form in which Cu was administered. The above

results confirm the usability of copper for the biosynthesis of haeme, which improves iron utilization from feed ingested by turkeys. Similar observations were made by other authors (JAMROZ 1990, MAKARSKI et al. 2002).

Table 5 contains levels of selected biochemical serum markers of turkeys in the 19th week of life. In order to assess toxicity of the applied copper doses, determinations were carried out on activities of blood serum enzymes. The analyses showed enhanced activity of AST in groups III and IV. With respect to the increased ALT activity, a statistically significant value was reported in the group receiving 20 mg Cu dm⁻³ H₂O in the organic form. The enhanced activity of both aminotransferases could be indicated by pathological lesions in livers of the birds. Their increased activity could have also been affected by other factors. The detailed *post-mortem* anatomopathological analysis did not demonstrate any adverse changes in the liver. It seems that in this case the enhanced activity of aminotransferases reflects enhanced biosynthesis of endogenous amino acids necessary for the synthesis of tissue proteins of turkeys. This is confirmed by the final body weight of the turkeys in the groups receiving the increased dose of copper, i.e. 20 mg Cu dm⁻³ H₂O.

Supplementation of feed mixes with copper was observed to have raised the content of total cholesterol in blood serum of the birds. Significant differences between the control and experimental birds did not appear in the case of birds administered 20 mg Cu dm⁻³ H₂O in the form of Cu-lysine

Table 5

The values of biochemical indices of turkeys' blood serum

Index	Group I	Group II	Group III	Group IV	Group V
	control	CuSO ₄	chelate Cu - Lys	CuSO ₄	chelate Cu - Lys
	-	10 mg Cu dm ⁻³ H ₂ O		20 mg Cu dm ⁻³ H ₂ O	
AST (U dm ⁻³)	592.36 ^b 119.13	526.25 ^b 91.33	712.75 ^a 153.69	632.67 ^a 129.95	525.70 ^b 58.75
ALT (U dm ⁻³)	18.18 ^b 4.51	16.25 ^c 4.65	21.50 ^b 6.76	20.92 ^b 4.64	27.00 ^a 7.44
CHOL (mg dl ⁻¹)	177.18 ^c 31.00	308.33 ^b 141.32	370.17 ^a 107.02	285.42 ^b 118.54	109.70 ^c 16.51
UA (mg dl ⁻¹)	8.05 ^a 2.38	6.35 ^b 0.87	7.71 ^a 2.01	7.70 ^a 1.17	4.94 ^c 0.97
TG (mg dl ⁻¹)	44.64 ^a 8.31	24.33 ^c 7.40	30.00 ^b 4.43	31.33 ^b 7.60	23.01 ^c 6.77
GLU(mg dl ⁻¹)	223.73 ^b 58.37	238.92 ^b 43.52	217.67 ^b 67.00	248.08 ^b 24.85	266.87 ^a 31.48

a, b – statistically significant difference at $p \leq 0.05$

chelate. Birds from all the experimental groups were characterized by a statistically significant decrease in the content of triacylglycerols. This is a desirable development as it is associated with the suppression of lipogenesis in the liver and adipose tissues, and at the same time confirms the role of copper in regulating the blood level of glucose. No significant changes were noted in the level of glucose, except the groups receiving the higher doses of copper.

It is worth mentioning that blood serum of the birds receiving Cu supplement, irrespective of its dose or chemical form, contained lowered levels of uric acid, which may be explained by Cu suppressing deamination processes of amino acids, which in turn seems to indicate their better utilization in the biosynthesis of tissue proteins.

Supplementation with copper preparations induced modification of the mineral composition of turkeys serum. The results of the analyses are presented in Table 6. Supplementation of feed mixes with copper, irrespective of its chemical form, was observed to induce insignificant changes in the serum level of Cu in the experimental turkeys compared to the control birds. A considerably higher level of Cu in blood serum was, in turn, observed in the group administered 20 mg Cu dm⁻³ H₂O in the organic form.

Table 6

The content of mineral elements in blood serum of turkeys receiving supplementation of 10 and 20 mg copper in different chemical forms

Index	Control	CuSO ₄	Chelate Cu - Lys	CuSO ₄	Chelate Cu - Lys
	group I	group II	group III	group IV	group V
	-	10 mg Cu dm ⁻³ H ₂ O		20 mg Cu dm ⁻³ H ₂ O	
Cu (mg dl ⁻¹)	0.37 ^a ± 0.07	0.31 ^a ± 0.02	0.39 ^a ± 0.09	0.36 ^a ± 0.13	0.14 ^b ± 0.06
Zn (mg dl ⁻¹)	1.56 ^b ± 0.28	2.17 ^a ± 0.38	1.47 ^c ± 0.56	2.04 ^{ab} ± 0.27	2.04 ^{ab} ± 0.27
Ca (mg dl ⁻¹)	10.13 ^c ± 1.37	10.10 ^c ± 1.19	10.44 ^b ± 1.21	10.66 ^a ± 1.06	11.05 ^a ± 1.26
Mg (mg dl ⁻¹)	2.24 ^b ± 0.48	2.30 ^b ± 0.47	2.58 ^b ± 0.43	2.68 ^a ± 0.45	2.89 ^a ± 0.66
P (mg dl ⁻¹)	8.05 ^a ± 0.97	7.52 ^a ± 1.21	8.86 ^b ± 1.44	7.90 ^a ± 1.73	8.40 ^b ± 1.66
Fe (µg dl ⁻¹)	362.18 ^a ± 39.11	277.42 ^c ± 49.58	367.00 ^b ± 79.01	332.17 ^a ± 75.89	370.11 ^b ± 75.60

a, b – statistically significant difference at $p \leq 0.05$

However, these results are inconsistent with findings of other authors, who reported increased concentrations of this mineral element in blood serum of reared birds (HARMS, BURESH 1986, EWING et al. 1998, WARD et al. 1998, POLONIS et al. 1999). Noteworthy is the accumulation of this element in the breast muscle and, above all, in the liver. Attention should also be paid to the low Fe level in the group receiving 10 mg of Cu in the inorganic form. Despite the reduced concentration of Fe, the level of haemoglobin in the blood serum of group II birds increased slightly compared to the birds not receiving supplementation.

In order to assess the accumulation of minerals in muscles of the birds receiving Cu supplements, chemical analyses were conducted on samples of their breast muscle. The results can be found in Table 7. They indicate that the level of Cu increased in the group receiving 20 mg Cu dm⁻³ H₂O in the form of CuSO₄ and in the one administered 10 mg Cu dm⁻³ H₂O as a chelate, in which the Cu concentration was the highest. In the other groups, the analyses demonstrated a decrease in the Cu concentration as compared to the control group.

Table 7

The content of mineral elements in turkeys' chest muscles

Index	Control	CuSO ₄	Chelate Cu - Lis	CuSO ₄	Chelate Cu - Lis
	group I	group II	group III	group IV	group V
	-	10 mg Cu dm ⁻³ H ₂ O		20 mg Cu dm ⁻³ H ₂ O	
Cu (mg kg ⁻¹)	1.20 ^{ab} ± 0.6	1.00 ^{ab} ± 0.1	1.70 ^a ± 0.1	1.40 ^{ab} ± 0.7	0.80 ^b ± 0.3
Zn (mg kg ⁻¹)	20.80 ^b ± 1.2	19.20 ^{bc} ± 0.3	19.50 ^c ± 0.4	19.40 ^c ± 0.5	30.40 ^a ± 3.7
Ca (%)	0.098 ^c ± 0.035	0.257 ^a ± 0.021	0.122 ^c ± 0.007	0.209 ^b ± 0.008	0.225 ^{ab} ± 0.036
Mg (%)	0.3124 ^{ab} ± 0.0099	0.3143 ^{ab} ± 0.0123	0.3129 ^{ab} ± 0.0047	0.3423 ^a ± 0.0094	0.2984 ^a ± 0.0324
Fe (mg kg ⁻¹)	10.70 ± 2.1	7.2 ± 0.7	10.20 ± 1.1	10.00 ± 3.3	9.8 ± 1.5
K (%)	2.82 ^c ± 0.19	3.47 ^a ± 0.05	2.97 ^{cb} ± 0.22	3.14 ^{ac} ± 0.071	2.83 ^c ± 0.27

a, b – statistically significant difference at $p \leq 0.05$

The liver serves a number of functions in the body's metabolism. It also aids excretion and secretion of metabolites. It is the site where detoxication processes occur and glucose is accumulated in the form of glycogen.

In order to determine the effect of the experimental preparations on the chemical composition of the turkey liver, samples of this organ were subjected to chemical determinations of the content of individual mineral elements. The results presented in Table 8 support the conclusion that Cu supplementation had a significant effect only on changes in Cu and Zn concentrations in a turkey's liver.

The application of copper, irrespective of its dose and chemical form, caused the enhanced accumulation of this element in livers of the turkeys. Despite the fact that copper competes with zinc for the site binding metallothioneins in cells of the intestinal mucosa (BRZOZOWSKA 1999, MAKARSKI, MAKARSKA 2009), the content of Zn was observed to increase significantly in the groups administered readily available Cu chelate with lysine.

The content of mineral elements in the turkey liver

Index	Control	CuSO ₄	Chelate Cu - Lis	CuSO ₄	Chelate Cu - Lis
	group I	group II	group III	group IV	group V
	-	10 mg Cu dm ⁻³ H ₂ O		20 mg Cu dm ⁻³ H ₂ O	
Cu (mg kg ⁻¹)	4.971 ^c ± 0.447	6.613 ^a ± 0.735	17.308 ^b ± 1.534	10.692 ^c ± 2.334	25.325 ^b ± 0.933
Zn (mg kg ⁻¹)	38.669 ^c ± 8.211	33.050 ^{bc} ± 4.290	61.683 ^a ± 10.938	38.124 ^c ± 4.263	50.083 ^b ± 6.512
Ca (%)	0.022 ^b ± 0.001	0.024 ^a ± 0.001	0.020 ^b ± 0.001	0.023 ^{ab} ± 0.001	0.021 ^b ± 0.002
Mg (%)	0.024 ^b ± 0.002	0.028 ^a ± 0.003	0.025 ^b ± 0.001	0.023 ^b ± 0.003	0.024 ^b ± 0.002
Fe (mg kg ⁻¹)	106.542 ^b ± 13.265	113.483 ^b ± 9.883	129.500 ^a ± 12.470	121.083 ^b ± 18.370	114.667 ^b ± 2.976
K (%)	0.345 ^a ± 0.016	0.326 ^a ± 0.018	0.338 ^a ± 0.017	0.338 ^a ± 0.014	0.283 ^b ± 0.029
Mn (mg kg ⁻¹)	2.992 ^{ab} ± 0.240	2.667 ^{ab} ± 0.436	2.765 ^{ab} ± 0.259	2.642 ^b ± 0.322	2.908 ^a ± 0.672
P (%)	0.274 ^c ± 0.018	0.359 ^a ± 0.037	0.303 ^b ± 0.014	0.294 ^{bc} ± 0.014	0.297 ^b ± 0.041

a, b, c – statistically significant difference at $p \leq 0.05$

CONCLUSIONS

1. Dietary supplementation of turkeys with Cu was observed to improve haematological blood markers, including RBC, Hb and Ht. These changes indicate improved health of the experimental turkeys.

2. The activity of transferase-group enzymes determined in the study proved that the supplementation did not cause any negative changes in internal organs.

3. The copper supplements added to drinking water were observed to significantly affect lipid markers in blood serum. The level of cholesterol was reduced only after the administration of increased doses (20 mg) of Cu in the organic form. In turn, the concentration of triacylglycerols in blood serum was positively affected by relatively low doses of this element. The above suggests the hypocholesterolemic properties of Cu.

4. The application of copper supplementation was found to reduce the concentration of uric acid.

5. The supplements did not cause any significant changes in the level of glucose. The level of this parameter was not raised until the highest, 20 mg dose of Cu in the organic form was applied.

6. Cu supplementation as a chelate and in a 20-mg dose caused enhanced accumulation of this element in the liver of turkeys.

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