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Effect of Different Dietary Copper Forms and Levels on Carcass Characteristics and Meat Quality Traits of Broilers Chickens

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Abstract

This study was carried out to evaluate the effects of dietary copper supplementation at a levels of 75, 100 and 125 ppm, from various forms, inorganic copper sulfate, (CuSo4) and copper nanoparticles (Cu-NP) supplementation on the live body weight, carcass characteristic and meat quality traits of broiler chickens. A total of 420 one-day-old Ros 308 chicks were randomly assigned to seven treatments. (n= 60 birds per each). The 1st group was fed a basal diet without any supplementation and considered as control group, the 2nd , 3rd and 4th groups were fed basal diet supplemented with 75, 100 and 125 ppm / kg diet of CuSo4, the 5th , 6th and 7th groups were fed basal diet supplemented with Cu-NPs at a level 75, 100 and 125 ppm / kg diet. Results showed that birds fed basal diet supplemented with inorganic or Cu-NPs had significantly better live body weight, carcass characteristics and meat quality while fat percentage was reduced compared with control group. However, the groups supplemented with Cu-NP showed significant improvement on carcass and meat quality traits compared with the other groups. Supplementation of dietary Cu from different forms significantly decreased meat content fat, PH, TVN and TBA. On the other hand, supplementation of dietary Cu from different forms significantly increased the levels meat sensory evaluation (color and Elasticity) compared with the control group. Dietary cu supplementation led to the total monounsaturated fatty acid (TMUFA) and total polyunsaturated fatty acid (TPUFA) content of muscles increased and total saturated fatty acids decreased compared with the control group. In conclusion, Cu supplementation with 125 ppm/ kg diet of Cu-NPs improved the live body weight, dressing percentage, and meat chemical examination of broiler chickens. Broilers fed Cu-NP had better growth and meat chemical examination than those fed CuSo4.

Keywords: copper, carcass characteristics, meat quality, nanoparticles, fatty acid, broilers

Introduction

A major issue in the meat industry is a decrease in the acceptability and nutritional quality of meat, as well as changes in flavor caused by the lipid oxidation process. As a result of changes and improvements in peoples eating habits, there is a growing interest in natural health and functional foods, including the development of new convenience meat products with natural flavor and taste (Choi *et al.,* 2010).

Copper (Cu) a crucial microelement required for proper physiological and biochemical processes, is frequently added to poultry diets at high concentrations at levels often exceed the birds requirements (Boa and Chocht, 2009; Świątkiewicz *et al*., 2014), copper as a possible alternative to an antibiotic growth promoters. It enhances animal performance, but an excess of Cu in the diet can also have adverse effects, including iron and calcium deficiency due to antagonism between those elements; this may cause a reduction in viability (Miroshnikova *et al.,* 2015) and increased toxicity (Cao *et al.,* 2016). The digestibility of Cu salts is very low, and approximately 80% of Cu is excreted in the feces (McDowell, 1992). Copper nanoparticles (Cu-NP) are relatively more bioavailable due to their small size and high surface to volume ratio. Although, there is limited research on the use of Cu-NP in the poultry industry. Some researchers have pointed out the importance of Cu-NP as an effective alternative of chemical, anti-bacterial agents, and growth promoters (Mroczek *et al.,* 2015; Joshua *et al.,* 2016; sharif *et al.,* 2021). It has been documented that Cu-NP has beneficial effects on animal performance and could be used to replace copper sulfate (CuSO4) (Wang *et al.,* 2011; Mroczek *et al., 2016*; Muralisankar *et al*., 2016; El-Basuini *et al.,* 2016). However, far less is known about the mechanism of action of Cu-NP in improving chicken performance, particularly regarding nutrient digestion and metabolism. Increasing Cu levels in the diet could reduce cholesterol and triglyceride levels in the blood of chickens (Rahman *et al.,* 2001; Skrivanova *et al*., 2000; Ibrahim *et al.,*2022). Therefore, this study aimed to investigate the effects of feeding different copper forms (CuSo4 and Cu-NPs) on carcass characteristics, meat quality traits (chemical composition - sensory evaluation, and fatty acids profile) of broiler chickens.

Materials and Methods

Experimental Location and Ethics approval

The Poultry Research Farm, Faculty of Agriculture at Benha University, Egypt served as the study's location. The Institutional Animal Care and Use Committee (IACUC) at Benha University

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authorized all experimental protocols. During the period from 21 May to 26 June 2021.

Experimental design and dietary treatments:

A completely randomized design involving a 2×4 factorial arrangement of treatments was used in this study. Four supplemental levels including 0, 75, 100 and 125 mg/kg copper from the two copper forms (copper sulfate and copper nanoparticles). Seven diet were formulated. Diet one without Cu supplementation and consider as a control diet. Diet 2-4 were basal diets supplemented with 75, 100, 125 mg/kg diet copper sulfate, respectively. While, Diet 5-7 were basal diet supplemented with 75, 100, 125 mg/kg diet Cu-NPs. Table 1 shows the basal and grower diets were formulated according to NRC (1994). The trial lasted 5 weeks. Mash diet and fresh water were provided *ad-libitum*. All chicks were reared under similar managerial and hygienic conditions.

Table 1. Feed ingredients and nutritional value of the basal starter and grower diet.

Ingredients (%)	Starter (1-21) days	Gower (22-35) days
Yellow Corn	58.0	63.0
Soybean (44% CP)[a]	28.2	24.9
Gluten meal (60% CP)[b]	7.00	6.00
Dicalcium phosphate	1.80	1.20
Limestone	1.30	1.30
Soybean oil	2.00	2.00
NaCl	0.30	0.30
L-Lysine hydrochloride	0.20	0.20
DL-Methionine	0.20	0.10
Mineral Premix*	0.50	0.50
Vitamin premix**	0.50	0.50
Total	100	100
Nutrient analysis		
ME (kcal/kg) [d]	3012	3069
Crude protein (%)	21.99	20.28
Calcium (%)	0.98	0.84
Total phosphor (%)	0.72	0.59
Methionine (%)	0.59	0.47
Methionine + Cystine (%)	0.95	0.80
Lysine (%)	1.14	1.06

[a;b]Crude protein. [c]Provided the following per kilogram of diet: 13,000 IU of vitamin A; 1,300 IU of vitamin D; 65 IU of vitamin E; 3.4 mg of menadione; 37 mg of pantothenic acid; 6.6 mg of riboflavin; 3.7 mg of folic acid; 39 mg of niacin; 1.0 mg of thiamine; 4.3 mg of vitamin B6; 0.23 mg biotin; 0.075 mg of vitamin B12: 43 mg of choline chloride. 170 mg of zinc; 140 mg of iron; 34 mg of manganese; 16 mg of copper; 0.29 mg of iodine; 0.29 mg of selenium. [d]Metabolizable energy.

A total of 420 one-day old male (Ross 308) chicks were individually assigned randomly to seven groups, each with three replicates of 20 birds each based on a completely randomized design. Thermo-neutral ambient temperature was maintained in accordance to standard brooding practices and adapted to the birds rearing stages. Light regime was regulated as follows 24 h light (1^{st}-5^{th} day) and 23h light and 1 h dark (6^{th}-35^{th} day) used in the present experiment. Floor brooder with gas heaters were used to provide chicks with heat needed for brooding. The brooding temperature was 32, 30, 29 and 23-26 C^{o} at 1-7, 8-14, 15-20 and 21-35 days of age, respectively (gradually decreased).

Slaughtering and carcass measurements

At the end of the experiment (35 days of age), 5 birds from each treatment were individually weighed, and slaughtered by severing the jugular vein with a sharp

knife near the first neck vertebra. Chickens were fasted for a period of 8-hours before slaughter, however, they had unlimited access to water. After slaughter and bleeding, the carcasses were de-feathered and eviscerated and intestine, gizzard, lungs, spleen, liver, heart and all internal organs were removed. The carcass and giblets (empty gizzard liver and heart) were separately weighed and expressed as a percentage of live body weight. The proportional weights to live weight of giblets, carcass and total edible parts were calculated as follows: giblets weight (%) = (GW/LW) ×100, edible parts (%) = ((EW+GW)/LW) ×100, whereas: LW = live weigh, EW= eviscerated weigh and GW= giblets weight. the breast and thigh meat was sampled. Part of the meat was immediately used for the determination of pH, moisture, protein, fat, and ash, while the remainder was frozen at −20 °C for subsequent analysis (total lipids and fatty acid profile).

Meat quality traits

Chemical composition

The examined samples of chicken fillets and sheish were analyzed for determination of their contents of moisture, protein, fat and ash by using the standard method recommended by Horwitz (2000) "AOAC". Keeping quality tests by determination of pH (Pearson 2006), total volatile nitrogen (TVN) was recommended by Food and Agriculture Organization FAO (1980) as follows: TVN/l00g = 26.88 x (2-T1). Where, T1 = volume of NaOH consumed in the titration. Thiobarbituric acid number (TBA) by Pikul *et al*., (1989) was applied as follow: TBA value= R x 7.8 (mg malonaldehyde /Kg). Where, R = Reading of sample against blank.

Sensory evaluation

The examined samples of chicken meat were analyzed for the quantification of the final sensory profile according to procedures of the World's Poultry Science Association by Mead (1987). Five trained panelists applied the proposed organoleptical method of raw chicken meat analysis. The different attributes were quantified on a rating scale from 1 to 3. The sensorial analyzed attributes were visual look (skin and meat color), meat consistency and elasticity and the odor.

Fatty Acids Profile of Meat

One hundred grams of the meat sample were placed in a 500 ml closed stopper flask then, 300 ml of n-hexane was added, and the flask was shacked for 30 min. using horizontal shaker and left for 24 hours at room temperature. The homogenated mixture was filtered and the residue was re-extracted as mentioned above. The combined filtrates were evaporated under reduced pressure, according to AOAC (2005). Fatty acids were determined in meat by Gas Chromatography technique (GC) according to Aura *et al.* (1995). The fats under study were saponified with ethanolic potassium hydroxide (40%, w/v) for 24 hours at room temperature according to the method of AOCS (1993).The aqueous layer (containing potassium salt of fatty acids and free from unsaponifiable matter) was acidified with HCL (0.5N), then it was extracted three time with petroleum ether. The petroleum ether extract was washed several times with distilled water and dried over anhydrous sodium sulphate. The obtained fatty acids were converted to methyl esters as follows: The extracted fatty acids were dissolved in anhydrous diethyl ether (0.5-1.0ml) and methylated by drop wise addition of diazomethane solution (Vogel, 1975) until the yellow color persisted. The mixture was then left at room temperature for 15 minutes and the solvent was evaporated on a water bath maintained at 60C. Finally, the methyl ester of fatty acids was dissolved in chloroform and aliquots of this solution were subjected to analysis by GC. The fatty acids methyl esters were analyzed by Hewlett Packard gas chromatography (5890 series) equipped with flame ionization detector. The chromatograph was fitted with FFAP (2.5m × 0.30µm film thickness and 0.32mm diameter).

Statistical analysis

Two-way ANOVA was used to examine the data, using the General Linear Models (GLM) method of (SAS, 2004). A factorial design (2×3) was used to assess the interaction between the main effects elements (dietary copper forms and amount). Duncan's multiple range test was applied to evaluate differences among treatments, where significant differences (Duncan 1955). According to the following liner model:

$X_{ijk} = \mu + S_i + L_j + (SL)_{ij} + e_{ijk}$

Whereas: Xijk = the observation of traits for ijkth birds; µ = the overall mean.; Si = the effect of the ith copper forms; L_j = the effect of the jth copper levels.; (SL)ij = the fixed effect of the interaction between the ith sources and the jth levels.; eij = random error assumed to be independently and randomly distributed.

Results and discussion

Live body weight and carcass characteristics.

Results of the proportional weights of carcass, giblets and total edible parts for broiler chickens as affected by copper forms, copper levels and the interaction between them are presented in Table (2). All copper forms and levels supplementation created no significant ($P \leq 0.05$) difference found in body weight (BW) at 5 wks of age on absolute wights of carcass, heart, and total edible parts. Which increased in chicks However, the previous treatments were superior for the groups fed diet supplemented with Cu -NPs compared with fed diets supplemented with copper sulfate.

Copper levels showed a significantly, ($P < 0.05$) increased body weight and carcass weight percentage at 125 mg/kg diet. In addition, broiler chickens fed diet supplemented with 100 mg/kg diet from either Cu -NPs significantly, ($P < 0.05$) increased absolute weight edible parts when compared with different levels applied and control group. Similar to our results, it was shown that supplementation with 100 mg/kg of Cu-NP significantly enhanced growth performance in piglets (Gonzales *et al.,* 2009; Wang *et al*., 2012). Furthermore, similar effects of Cu-NP on the final BW in fish were reported (El-Basuini *et al*., 2016).Our results are in agreement with a study on broilers (Scote *et al*., 2016), demonstrating that the improvement in broilers growth could be attributed to better energy digestibility in animals treated with Cu-NP than with $CuSO_4$.

Previously, we demonstrated that 125 mg/kg of Cu-NP had significant effects on the broiler dressing percentage and carcass content (Mroczek-Sosnowska *et al.*, 2015). The same authors reported that Cu supplementation reduced the heart weight. However, our results showed that the relative heart weight was not affected. Similar to our results, it was reported that the relative heart weight at 42 days age was not affected in birds treated with CuSO4 (Shahzad *et al.,* 2012) .The relative liver weight was affected by both forms of Cu and was significantly lower at higher concentrations of Cu in relation to the control group. The liver results are consistent with the results of Shahzad *et al*., 2012; Skrivan *et al*., 2000), while in other studies (Mroczek- Sosnowska et al., 2015; Payvastegan *et al.,* 2013; Upadhaya *et al*., 2016; Wang *et al*., 2011), the liver weight was not affected. It was reported that a high concentration of Cu-NP negatively affected the histology of the liver, kidneys and spleen, but not the heart and lungs in rats, and these changes were well supported by organ weight changes (Lee et al., 2016). Furthermore, it was demonstrated that the greatest accumulation of Cu was observed in the liver and spleen (Mroczek-Sosnowska *et al*., 2014).

Chemical examination of meat

Results presented in Table (3) showed that highly significant ($P < 0.05$) effect was found on moisture, protein, fat and ash, respectively due to copper forms. Concerning to the effect of the copper levels on meat chemical composition it is clearly found that there was highly significant ($P<0.001$) effect on protein, fat and ash of meat due to copper levels. Birds fed diets supplemented with CuSo4 and Cu-NPs at different levels had significantly ($P<0.001$) higher values of Moisture, protein, and ash % than the control group, with the higher fat % value observed in control group compared to the other treated groups (Table 3).

Meat sensory evaluation

PH, TVN and TBA increased significantly in meat samples produced from chickens fed diet supplemented Cu-sulfate compared with those produced from Cu-NPs. PH, TVN and TBA decreased significantly with increasing Cu levels, reaching its maximum decreasing at 125 mg / kg diet when compared with control group, which showed the higher values of the previously mentioned traits (table, 4)

Results in Table 4 and 5 showed significant ($P < 0.05$) effect on values of aspect, odor, color, elasticity and overall score values in sensory examination of broiler meat the higher values of color (2.77), elasticity (2.44) and overall score (9.88) were found significant Cu-NPs than Cu-So4 (Bianchi *et al.,* 2006 and Boni *et al.,* 2010). Highly significant ($P < 0.001$) effects on odor and overall score values in meat sensory examination were observed in the groups fed of Cu at a level of 100 and 125 mg/kg diet (table, 5). These results agree with those reported by Dadgar *et al*. (2010) who found that birds subjected to conditions of hypoxia before slaughter resulted in darker-colored breast meat .

The sensory evaluation results showed an overall improvement in order, color and overall. It could be ascribed to the antioxidant properties of different copper forms that inhibited lipid oxidation of meat, which is known to be the main reason behind meat quality spoiling resulting in rancidity and formation of unacceptable odors and flavors (Amaral et al., 2018). Generally, there was an improvement in meat elasticity expressed in response to copper forms.

Changes in Fatty Acid Composition

Fatty acid compositions of broiler thigh and breast muscle produced from dietary different copper forms and levels supplementation are presented in Table 6. There were some differences in the percentages of palmitoleic acid (C16:0) and palmitoleic acid (C16:1) among all treatments. Also, significant differences were observed in the percentages of myristic acid (C14:0), stearic acid (C18:0), Oleic (C18:1), Linoleic (C18:2), Linoleic (C18:3) and arachidonic acid (C20:4) among all treatments due to all factors studied. Overall percentages of oleic (C18:1), linoleic (C18:2), and linolenic acid (C18:3) significantly increased ($P < 0.05$). (Choi et al. (2010); López-Ferrer et al., 2001). Furthermore, there was a numeric decrease in the percentages of palmitic acid (C16:0) with incremental dietary levels of Cu-NP (100 and 125 mg/ kg diet) and this result was significant ($P < 0.05$) in the treatment with 125 Cu-NP compared with other treatment .The highest concentrations of unsaturated FAs (both MUFAs and PUFA) were present in the diet supplemented with Cu-NP a level of 100 and 125 mg. In contrast, the highest concentration of SFA was present in the diet supplemented without copper. There was important effect of Cu supplementation on the fatty acid profile of lipids of breast and thigh muscles, except minor changes in contents of some fatty acids. Thus, the reduction of total muscle lipids and cholesterol content was the main effect of Cu supplementation in chickens (Kim *et al*., 2005; Guo *et al.,* 2006).

Conclusions

The results can be summarized that the supplementation of Cu-NP and CuSo4 to broiler chicken diets improved body weight, carcass characteristics and meat quality traits. Birds fed diet with Cu-NP copper improved productive performance than other groups. Also, increasing the levels of Cu led to decreased total saturated fatty acid, and increased total monounsaturated fatty acid and total polyunsaturated fatty acid.

Table 2. Relative weights of carcass components as affected by the different levels of dietary copper supplementation (% of live body weight).

Items	Levels (mg/kg)	Live body weight	Carcass percentage	Gizzard (%)	Liver (%)	Heart (%)	Giblets (%)	Edible part (%)
Sources	Cu -NP	1958±.55	75.9±1.5	1.98±0.09	2.23±.0.08	0.55±0.03	4.77±0.13	80.7±1.4
	Cu sulfat	1938±55	74.8±1.5	2.14±0.09	2.27±0.08	0.54±0.03	4.96±0.13	79.7±1.4
Copper level	0	1875±63b	72.5±1.6c	1.85±0.11b	2.20±0.09	0.48±0.06	4.53±0.15	77.3±1.5c
	75	1936±.63a	72.5±1.6c	2.22±0.11a	2.13±.0.09	0.61±0.06	4.98±0.15	77.3±1.5c
	100	1877±63a	75.0±1.6b	1.97±0.11a	2.34±0.09	0.53±0.06	4.86±0.15	83.5±1.5a
	125	2032±63a	78.6±1.6a	1.97±0.11a	2.29±0.09	0.50±0.06	4.77±0.15	79.9±1.5b
Control	0	1847±.0.94	72.5±1.8	1.85±0.16b	2.20±.0.13	0.48±0.03b	4.53±.0.22	77.3±0.57c
Cu -NP	75	1918±0.94	72.9±1.8	2.20±0.16ab	2.09±0.13	0.54±0.03ab	4.92±0.22	77.8±0.84ab
	100	1898±0.94	75.7±1.8	1.79±0.16a	2.31±0.13	0.53±0.03ab	4.63±0.22	80.8±0.84a
	125	2060±.0.94	75.2±1.8	1.95±0.16a	2.29±.0.13	0.50±0.03ab	4.76±.0.22	80.3±0.84ab
CuSo4	75	1954±0.94	72.0±1.8	2.25±0.16ab	2.16±0.13	0.60±0.03a	5.03±0.22	76.8±0.84c
	100	1856±0.94	77.7±1.8	2.16±0.16ab	2.38±0.13	0.53±0.03ab	5.09±0.22	78.9±0.84abc
	125	2004±.0.94	74.8±1.8	1.99±0.16a	2.28±.0.13	0.50±0.03ab	4.78±.0.22	79.6±0.84abc

[a,b,c] Means with different superscript in the same column are significantly different at (P<0.05).
CuSo4 = Copper sulfate; Cu-NP = Copper nanoparticles.

Table (3): Least – square means and standard error for meet chemical examination (moisture, protein, fat and ash) as affected by the studied factors

Items	Levels (mg/kg)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Sources	Cu -NP	74.5±0.11a	20.2±0.18a	2.04±0.08b	2.03±0.05a
	Cu sulfate	74.3±0.11b	19.4±0.18b	2.42±0.08a	1.63±0.05b
Copper level	0	74.2±0.20a	18.90±0.35b	2.86±0.17a	1.43±0.14b
	75	74.5±0.14a	19.51±0.25ab	2.40±0.12b	1.71±0.10ab
	100	74.4±0.14a	19.86±0.25a	2.21±0.12b	1.83±0.10a
	125	74.3±0.14a	20.25±0.25a	2.08±0.12b	1.95±0.10a
Control	0	74.2±0.18a	18.9±0.29c	2.86±0.14a	1.43±0.09d

Cu -NP	75	74.6±0.18cd	19.8±0.29abc	2.23±0.14bcd	1.86±0.09bc
	100	74.2±0.18ab	20.20±0.29ab	2.03±0.0.14cd	2.03±0.09ab
	125	74.1±0.18a	20.7±0.29a	1.86±0.0.14d	2.20±0.09a
CuSo4	75	74.4±0.18de	19.2±0.29c	2.56±0.0.14ab	1.56±0.09d
	100	74.6±0.18cd	19.5±0.29c	2.40±0.0.14bc	1.63±0.09cd
	125	74.6±0.18bc	19.7±0.29bc	2.3±0.14bcd	1.70±0.09cd

[a-d] Means with different superscript in the same column are significantly different at (P<0.05).
CuSo4 = Copper sulfate; Cu-NP = Copper nanoparticles.

Table 4 Least – square means and standard error for meet chemical examination (Ph, TVN and TBA) as affected by the studied factors

	Levels (mg/kg)	pH	TVN (mg/Kg)	TBA (mg/Kg)
Sources	Cu -NPs	5.56±0.009b	3.13±.0.16b	0.11±0.005b
	Cu sulfate	5.63±0.009a	3.91±0.16a	0.15±0.005a
Copper level	0	5.67±0.02a	4.66±0.31a	0.19±0.18a
	75	5.62±0.01ab	3.91±0.22b	0.14±0.13b
	100	5.60±0.01b	3.51±0.22bc	0.13±0.13a
	125	5.57±0.01b	3.13±0.22c	0.11±0.13a
Control	0	5.67±0.01a	4.66±0.21a	0.19±0.01a
Cu -NP	75	5.60±0.01d	3.66±0.21bc	0.13±0.01bc
	100	5.56±0.01e	3.16±0.21cd	0.11±0.01bc
	125	5.53±0.01e	2.56±0.21d	0.09±0.01c
CuSo4	75	5.65±0.01ab	4.16±0.21ab	0.16±0.01ab
	100	5.63±0.01bc	3.86±0.21bc	0.15±0.01ab
	125	5.61±0.01cd	3.70±0.21bc	0.14±0.01abc

[a-d] Means with different superscript in the same column are significantly different at (P<0.05).
CuSo4 = Copper sulfate; Cu-NP = Copper nanoparticles.

Table 5. Least - square means and standard error for meet sensory evaluation (aspect, older, color and elasticity) as affected by the studied factors.

Items	Levels (mg/kg)	Aspect (3)	Oder (3)	Color (3)	Elasticity (3)	Overall (12)
Sources	Cu -NPs	2.77±.0.16	2.88±0.14	2.77±0.16a	2.44±.0.20a	9.88±0.36a
	Cu sulfate	2.55±0.16	2.66±0.14	2.44±0.16b	2.22±0.20b	9.88±0.36b
Copper level	0	2.33±0.29	1.66±0.26b	1.66±0.28b	2.00±0.38	7.66±0.67b
	75	2.50±.0.20	2.66±0.18a	2.33±0.20ab	2.16±.0.27	9.66±0.47a
	100	2.66±0.20	2.83±0.18a	2.66±0.20a	2.33±0.27	10.6±0.47a
	125	2.83±0.20	2.83±0.18a	2.83±0.20a	2.50±0.27	11.0±0.47a
Control	0	2.33±.0.19	1.66±0.02c	1.66±0.02b	2.00±.0.02	7.66±0.57c
Cu-NP	75	2.66±0.19	2.66±0.02b	2.33±0.02ab	2.33±0.02	10.00±0.57ab
	100	2.66±0.19	3.00±0.02a	3.00±0.02a	2.66±0.02	11.33±0.57ab
	125	3.00±.0.19	3.00±0.02a	3.00±0.02a	2.66±.0.02	11.66±0.57a
CuSo4	75	2.33±0.19	2.66±0.02b	2.33±0.02ab	2.00±0.02	9.33±0.57bc
	100	2.66±0.19	2.66±0.02b	2.33±0.02ab	2.33±0.02	10.00±0.57ab
	125	2.66±.0.19	2.66±0.02b	2.66±0.02a	2.33±.0.02	10.33±0.57ab

[a,b] Means with different superscript in the same column are significantly different at (P<0.05).
CuSo4 = Copper sulfate; Cu-NP = Copper nanoparticles.

Table 6. Effects of dietary copper supplementation on fatty acid composition in broiler chickens.

Items	Levels (mg/kg)	Myristic	Stearic	Palmitic	Palmitoleic	Oleic	Linoleic	Linolenic	Arachidonic	TSFAs	TMUFAs	TPUFAs
		14:0	18.0	16:0	16:1	18:1	18:2	18:3	20:4	------	------	-----
Sources	Cu -NP	47.3±4.0b	469±12.1	1174±21.0a	400±6.0a	1533±7.9a	469±12.1b	165±6.9a	151±4.8a	1714±36.0a	1934±15.8a	1136±19.1a
	Cu sulfate	70.6±4.0a	471±12.1	1230±21.0a	352±6.0b	1474±7.9b	617±12.1a	132±6.9b	117±4.8b	1806±36.0b	1838±15.8b	974±19.1b
Copper level	0	97.0±4.9a	621±8.6a	1386±12a	316±10.0c	1429±12c	584±9.9c	114±6.8c	110±7.5b	2152±20a	1745±22c	883.0±35c
	75	73.5±49b	508±8.6b	1273±12b	357±10.0b	1475±12b	620±9.9b	125±6.8bc	118±7.5b	1889±20b	1832±22b	962.5±35bc
	100	58.0±4.9bc	455±8.6c	1205±12c	374±10.0ab	1507±12ab	637±9.9ab	147±6.8b	134±7.5ab	1748±20c	1898±22ab	1064±35ab
	125	45.5±4.9c	447±8.6c	1128±12c	399±10.0a	1529±12a	665±9.9b	173±6.8c	149±7.5a	1644±20d	1928±22a	1139±35a
Control	0	97.0±0.57a	621±7.6a	1386±15.3a	316±7.1g	1429±14.2f	584±2.7g	114±2.7f	110±2.7f	2152±22a	1745±18.2c	883.0±12.4e
Cu -NPs	75	61.0±0.57d	493±7.6c	1246±15.3c	383±7.1c	1504±14.2c	643±2.7c	139±2.7d	128±2.7c	1830±22c	1887±18.2b	1024±12.4c
	100	45.0±0.57f	439±7.6f	1185±15.3e	399±7.1b	1541±14.2b	659±2.7b	167±2.7b	152±2.7b	1693±22e	1940±18.2a	1159±12.4b
	125	36.0±0.57g	475±.7.6d	1092±15.3g	419±7.1a	1556±14.2a	691±2.7a	189±2.7a	173±2.7a	1621±22g	1975±18.2a	1225±12.4a
CuSo4	75	86.0±0.57b	524±7.6b	1301±15.3b	331±7.1f	1446±14.2e	598±2.7f	112±2.7g	109±2.7f	1949±22b	1777±18.2c	901±12.4e
	100	71.0±0.57c	471±7.6e	1225±15.3d	349±7.1e	1474±14.2d	615±2.7f	128±2.7e	117±2.7e	1803±22d	1856±18.2b	970±12.4d
	125	55.0±0.57e	419±7.6g	1164±15.3f	378±7.1d	1503±.14.2c	639±2.7d	158±2.7c	125±2.7d	1667±22f	1881±18.2b	1053.±12.4c

[a–f] Means within the same column without common superscripts are significantly different ($P < 0.05$).

TSFAs = Total saturated fatty acid; TMUFAs = Total mono-unsaturated fatty acid; TPUFAs = Total poly-unsaturated fatty acid.

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تأثير التغذية علي اشكال ومستويات مختلفة من النحاس على خصائص الذبيحة وصفات جودة اللحم لدجاج التسمين

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يهدف هذا البحث إلى دراسة تأثير اضافة اشكال مختلفة من النحاس بمستويات 75 ، 100 و 125 مللجرام /كجم علف ، كبريتات النحاس الغير عضوية (CuSo4) حبيبات النحاس النانوية (Cu-NP) عي كلا من : وزن الجسم الحي وخصائص الذبيحة وجودة اللحم لدجاج التسمين. تم استخدام عدد 420 كتكوت عمر يوم من سلالة دجاج روس 308 وزعت عشوائيا علي 7 معاملات تجريبية (60 طائرًا لكل منها). تم تغذية طيور المجموعة الأولى على عليقة اساس بدون أي اضافت (مجموعة مقارنة) ، وتم تغذية المجموعات الثانية والثالثة والرابعة علي العليقة الاساسية مضاف اليها كبريتات النحاس الغير عضوية بمستويات 75 ، 100 و 125 جزء في المليون ، وتم تغذية المجموعه الخامسة والسادسة والسابعة على العليقة الاساسية مضاف اليها حبيبات النحاس النانوية Cu-NP بمستويات 75 و 100 و 125 جزء في المليون. أظهرت النتائج أن الطيور التي تم تغذيتها على العليقة الأساسية المضاف إليها النحاس الغير عضوي وحبيبات النحاس النانونية حسنت معنويا وزن جسم وخصائص الذبيحة وجودة اللحم بينما انخفضت نسبة الدهون مقارنة بمجموعة الكنترول. بينما ، أظهرت المجموعات المضاف اليها Cu-NP تحسنًا ملحوظًا في خصائص الذبيحة وجودة اللحم مقارنة بالمجموعات الأخرى. أدت إضافة النحاس باشكالة المختلفة علي العليقة إلى انخفاض معنوي في نسبة الدهون في اللحم ، ودرجة الحموضة ، و TVN و TBA. من ناحية أخرى ، أدت إضافة النحاس بصوره المختلفة ايضا إلى زيادة معنوية في مستويات التقييم الحسي للحوم (اللون والمرونة) مقارنة بمجموعة الكنترول .أدت اضافة النحاس للعليقة إلى زيادة محتوى العضلات من الأحماض الدهنية الأحادية غير المشبعة (TMUFA) والأحماض الدهنية المتعددة غير المشبعة (TPUFA) وانخفض إجمالي الأحماض الدهنية المشبعة مقارنة بمجموعة الكنترول. في النهاية ، أدت إضافة حبيات النحاس النانونية بمستوي 125 جزء في المليون لكل كيلو جرام عليقة إلى تحسين وزن الجسم الحي ونسبة التصافي والصفات الكميائية للحوم في دجاج التسمين. إظهرت الطيور التي تم تغذيتها على Cu-NPاعلي نموًا خصائص كيميائيّة للحوم عن تلك المغذاه على النحاس غير العضوي (كبريتات النحاس).