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Quality indicators of broiler chickens' meat under the influence of gadolinium and lanthanum orthovanadate nanoparticles

Alla Masliuk[1], Valerii Ushkalov[1], Oleksandr Orobchenko[2*], Olena Kurbatska[2], Roman Sachuk[3], Volodymyr Klochkov[4], Svitlana Yefimova[4]

[1]*Department of Epizootology, Microbiology and virology, National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony, 15, 03041 Kyiv, Ukraine.*
[2]*Laboratory of Toxicological Monitoring, National Scientific Center Institute of Experimental and Clinical Veterinary Medicine, Pushkinska, 83, 61023 Kharkiv, Ukraine.*
[3]*Department of Ecology, Geography and Tourism, Rivne State University for the Humanities, Plastova, 31, 3300 Rivne, Ukraine.*
[4]*Department of Nanostructured Materials named after Yu.V. Malyukin, Institute for Scintillation Materials NAS of Ukraine, prosp. Nauky, 60, 61001 Kharkiv, Ukraine.*

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***Correspondence:**

Corresponding author: Oleksandr Orobchenko
E-mail address: toxy-lab@ukr.net

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ABSTRACT

Nanotechnology is successfully used to ensure food quality, to enrich food with minerals, vitamins and antioxidants, and to improve the organoleptic properties of food. Nanoparticles of rare earth elements – gadolinium and lanthanum orthovanadates – have prospects for use in growing broiler chickens to improve meat quality, since their introduction in a therapeutic dose (0.2 mg/L of drinking water – on average, chickens received 0.09 (0.13-0.05) mg/kg body weight) for 10 days led to an increase in the mass fraction of protein and a decrease in the mass fraction of fat (gadolinium orthovanadate nanoparticles) and an increase in the mass fraction of dry matter during the administration period, along with an increase in the mass fraction of protein and ash (lanthanum orthovanadate nanoparticles and a mixture of gadolinium orthovanadate and lanthanum orthovanadate nanoparticles), which increases the energy value of meat.

Introduction

Poultry farming is the leading livestock industry in global agriculture due to its ability to quickly provide people with easily digestible healthy proteins contained in poultry meat (due to selection and intensive fattening, a broiler chicken can reach a slaughter weight of 2.5 kg in 6 weeks) (Mottet and Tempio, 2017; Kralik *et al*., 2018; Barbut and Leishman, 2022).

However, intensification of poultry production is often accompanied by violations of feeding and housing standards, which leads to stress in poultry and prevents the timely realization of genetic potential, resulting in a decrease in quantitative and qualitative productivity indicators and, in some cases, product safety (Masliuk *et al*., 2021; Melnyk *et al*., 2021; Zotsenko *et al*., 2021; Orobchenko *et al*., 2022).

To increase the stress resistance of broiler chickens, vitamin and vitamin-mineral feed additives are introduced into their diets (M'Sadeq *et al*., 2018; Alagawany *et al*., 2020), and natural anti-stress agents such as yeast fermentation products (Nelson *et al*., 2018), grape pressings (Haščík *et al*., 2020), flax and pumpkin (Čech *et al*., 2022) are searched for. In addition, inorganic (oxides, chlorides, nitrates) and organic (citrates) compounds of rare earth metals (cerium, lanthanum, and others) with recently proven antioxidant effects are used (Cai *et al*., 2015; Tariq *et al*., 2020).

However, scientific progress does not stand still, and substances in the nanoscale state are increasingly being introduced into the field of animal production: nanotechnology is successfully used to ensure food quality, enrich food with minerals, vitamins, antioxidants, and improve the organoleptic properties of food (Tsekhmistrenko *et al*., 2021).

Among rare earth element (REE) nanoparticles, cerium dioxide (CeO_2) is the most studied and tested. Cerium dioxide nanoparticles are potent antioxidants that currently hold great promise as potential treatments for diseases in which oxidative stress plays a significant pathological role (Estevez *et al*., 2019; Parra-Robert *et al*., 2019). In experiments on laboratory animals (white rats), gadolinium (NP $GdVO_4:Eu^{3+}$) and lanthanum (NP $LaVO_4:Eu^{3+}$) orthovanadate nanoparticles activated with europium, synthesized by Ukrainian scientists, showed good antistress and antioxidant effects (Klochkov *et al*., 2011; Klochkov *et al*., 2012): a safe and effective dose range (0.03-0.15 mg/kg body weight) was established (Masliuk *et al*., 2023a; Masliuk *et al*., 2023b). Our previous studies also showed that the live weight of chickens during a 10-day administration of the above REE NPs did not differ significantly from the control, but 5 days after stopping the administration of $GdVO_4:Eu^{3+}$ NPs, the tendency to increase the weight of chickens was 5.8%, $LaVO_4:Eu^{3+}$ NPs and a mixture of both types of nanoparticles – 3.0% (Masliuk, 2023). The results obtained were a prerequisite for conducting studies on the quality of broiler meat, which was the aim of this work.

Materials and methods

The work was planned at the National Scientific Center "Institute of Experimental and Clinical Veterinary Medicine", Kharkiv. The experiment was carried out at the vivarium of the State Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise, Kyiv. The synthesis of nanoparticles was carried out at the Institute for Scintillation Materials of the NAS of Ukraine, Kharkiv.

Experimental birds

Day-old broiler chickens of the Cobb 500 cross (n=150) were used as subjects. The birds were housed under optimal conditions: room temperature of 28.0±4.0°C with a relative humidity of 60-70 %; the day/night light cycle during the experiment was 15-9 h with an 18-fold change of air volume in the vivarium room per hour. According to the principle of analogs, 4 experimental and 1 control group of day-old broiler chickens (n=30) were formed: chickens of the first experimental group received a solution of NP $GdVO_4$: Eu^{3+} solution at a dose of 0.2 mg/L of drinking

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water, experimental group II – NP $LaVO_4:Eu^{3+}$ solution at a dose of 0.2 mg/L of drinking water, experimental group III – NP $GdVO_4:Eu^{3+}$ and NP $LaVO_4:Eu^{3+}$ at a dose of 0.2 mg/L of drinking water (on average, chickens received 0.09 (0.13-0.05) mg/kg body weight of NP) and chickens of the IV experimental group received the veterinary vitamin preparation Devivit Complex at a dose of 0.3 ml/L of drinking water with water to compare the antioxidant effect, chickens of the control group received drinking water without additives. After 10 days, the administration of NPs was stopped, and the chickens were observed for another 5 days. The total duration of the study was 15 days.

Bird experiments do not contradict the current legislation of Ukraine (Article 26 of the Law of Ukraine 5456-VI of 16.10.2012 "On protection of animals from cruel treatment") and "General ethical principles of animal experiments", adopted by the First National Congress of Bioethics and international bioethical standards (materials of the IV European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Purposes, Strasbourg, 1985) (Simmonds, 2017). The research program was reviewed and approved by the Bioethics Commission of the National Scientific Centre, Institute of Experimental and Clinical Veterinary Medicine in the current order.

Rations

The compound feed "PK 5 1-2 weeks Start Broiler" was used for feeding the chickens, the nutrient content of which was determined beforehand. The qualitative composition of the diet is shown in Table 1.

Characteristics of veterinary drugs and features of their use

In this work, we used prototypes of gadolinium orthovanadate nanoparticles (NP $GdVO_4:Eu^{3+}$) (spindle-shaped geometry, size 8×25 nm) and lanthanum orthovanadate (NP $LaVO_4:Eu^{3+}$) (rod-shaped geometry, size 8×80 nm) with the initial concentration of 1.0 g/L. The prototype nanoparticles were synthesized and standardized according to their stability and size in the Yu.V. Malyukin Department of Nanostructured Materials (Fig. 1).

Veterinary vitamin preparation Devivit Complex (manufactured by Devie LLC, Ukraine): one milliliter of the preparation contains the following active ingredients: vitamin A –15000 IU, vitamin D3 – 1000 IU, vitamin E – 20 mg, vitamins B1 – 10 mg, B2 – 0.5 mg, B3 – 25 mg, B5 – 35 mg, B6 – 3 mg, B12 – 30 mg.

Research methods

During CO_2 anesthesia, the experimental chickens were euthanized 5 and 10 days after the start of administration, and 5 days after the end of drug administration, 10 chickens per group were euthanized to take samples of thigh muscles for determination of quality indicators. The quality indicators of broiler meat (mass fraction of moisture and dry matter according to (SSU ISO 1442:2005), crude protein – (SSU ISO 937:2005), fat – (SSU ISO 1443:2005) and ash – (SSU ISO 936:2008), energy value) were determined after 24 hours of storage (maturation) in a refrigerator at a temperature of plus 4°C.

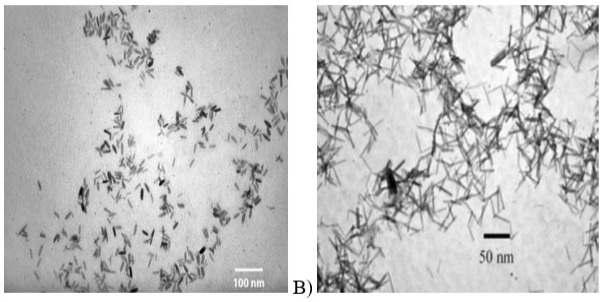

Fig. 1 Photograph (transmission electron microscopy, TEM-125K, Selmi, Ukraine) of nanoparticles: A) $GdVO_4:Eu^{3+}$; B) $LaVO_4:Eu^{3+}$ (Maliukin, 2017; Maliukina *et al*., 2018).

Statistical Analysis

The obtained results were processed by methods of variation statistics using the analysis of variance (ANOVA) software package StatPlus 7.6.5.0 (AnalystSoft Inc., USA). The reliability of the results was assessed by the Tukey's test (HSD difference of means) at a reliability level of 95.0% ($p<0.05$).

Results

During the study of the meat quality of the experimental broiler chickens, attention was paid to the indicators of dry matter and moisture, energy value, mass fraction of protein, fat, and ash. Thus, the mass fraction of dry matter in the thigh muscles of the broiler chickens of the first experimental group (treated only with NP $GdVO_4:Eu^{3+}$) tended to increase in relation to the control during the whole period of the study, i.e. no significant deviations were observed. In the thigh muscles of the second experimental group (administered only with $LaVO_4:Eu^{3+}$ NPs), an increase of 13.2% ($p<0.05$) in the dry matter mass fraction was observed after 5 days of administration compared to the control, while it increased after 10 days of administration and 5 days after cessation of administration. In the third experimental group (NP $GdVO_4:Eu^{3+}$ + NP $LaVO_4:Eu^{3+}$), after 5 days of administration, an increase in the mass fraction of dry matter was observed by 15.2% ($p<0.05$) in comparison with the control, while after 10 days there was a tendency to increase, and after 5 days after cessation of administration - to decrease. When the vitamin preparation Devivit complex was administered (experimental group IV), the mass fraction of dry matter in the thigh muscles of chickens after 5 days of administration

Table 1. Qualitative composition of the diet of broiler chickens (compound feed "PK 5 1-2 weeks Start Broiler").

Characteristics	Actually determined	Norm (SSU 4120 – 2002; Cobb500 Broiler Performance, 2022)	± to the norm
Carbohydrate, g/100 g	57,18	Not standardized	–
Energy value, kcal	376,09	290,00	+ 86,09
Mass fraction of fat, %.	6,69	Not standardized	–
Mass fraction of crude protein, %.	21,79	21,00-22,00	Normal
Mass fraction of crude fiber, %.	2,80	No more than 3.0	Normal
Vitamin B_2, mg/kg	8,28	9,00	– 0,72
Vitamin A, IU/kg	7920,00	10000,00-13000,00	– 2080
Vitamin E, mg/kg	212,50	80,00	+ 132,50
Selenium, mg/kg	0,172	0,35	– 0,178
Copper, mg/kg	38,67	15,00	+ 23,67
Zinc, mg/kg	144,99	100,00	+ 44,99

was 9.1% higher than in the control, while on the 10th day and 5 days after cessation of administration only an upward trend was observed (Fig. 2).

Obviously, the opposite pattern was observed with respect to the mass fraction of moisture (Fig. 3). Thus, the mass fraction of moisture in the thigh muscles of broiler chickens of the first experimental group (administered only with $GdVO_4:Eu^{3+}$ NPs) tended to decrease relative to the control throughout the study period, i.e. no significant deviations were observed. In the thigh muscles of experimental group II (injected only with $LaVO_4:Eu^{3+}$ NPs), a decrease of 4.2% in the mass fraction of moisture was observed after 5 days of administration ($p<0.05$), while only a decreasing trend was observed after 10 days of administration and 5 days after cessation of administration. In the third experimental group (NP $GdVO_4:Eu^{3+}$ + NP $LaVO_4:Eu^{3+}$), after 5 days of administration, a decrease in the mass fraction of moisture compared to the control was observed by 4.9% ($p<0.05$), while after 10 days of administration, a decreasing trend was observed, and after 5 days of cessation of administration, an increase was observed. When the vitamin preparation Devivit complex (experimental group IV) was administered, the mass fraction of moisture in the thigh muscles of chickens after 5 days of administration was 2.9% lower than the control, while on the 10th day and 5 days after cessation of administration, only a decreasing trend was observed (Fig. 3).

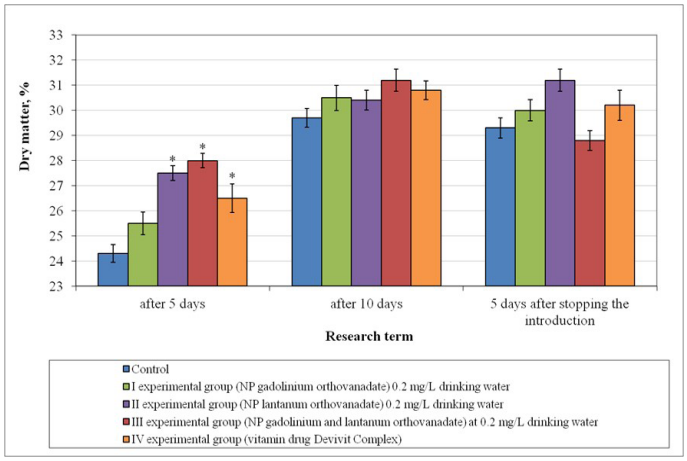

Fig. 2. Dynamics of dry matter content in the thigh muscles of broiler chickens under conditions of administration of different doses of antioxidants with water (M±m, n=5, *- p<0.05 - compared with the control group).

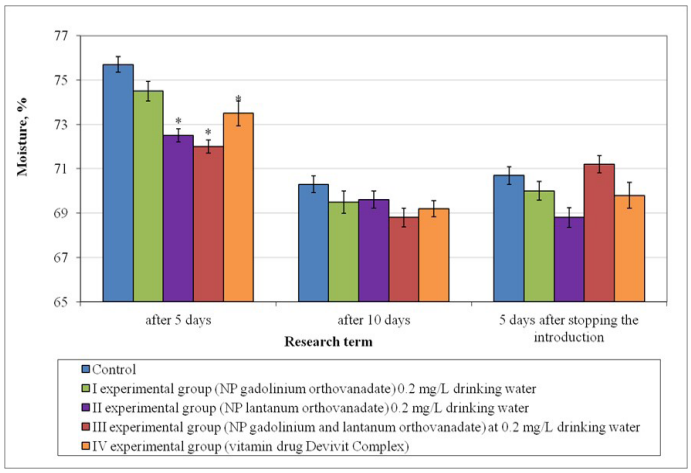

Fig. 3. Dynamics of moisture content in the thigh muscles of broiler chickens under conditions of administration of different doses of antioxidant drugs with water (M±m, n=5, *- p<0.05 - compared with the control group).

The energy value of the thigh muscles of broiler chickens of the first experimental group (NP $GdVO_4:Eu^{3+}$) during the administration period did not show significant deviations from the control (on the 5th day there was a tendency to increase the index in relation to the control, and on the 10th day – to decrease it), while 5 days after the end of administration a significant ($p<0.05$) increase in the energy value by 5.6% was recorded.

In the femoral muscles of chickens of the second experimental group (NP $LaVO_4:Eu^{3+}$), after 5 days of administration, an increase in energy value of 9.7% was observed ($p<0.05$), while after 10 days of administration, an upward trend was observed, and 5 days after cessation of administration, the energy value again exceeded the control by 7.8% ($p<0.05$). The energy value of the thigh muscles of broilers of experimental group III (NP $GdVO_4:Eu^{3+}$ + NP $LaVO_4:Eu^{3+}$) exceeded the control value only after 5 days of administration by 8.1% ($p<0.05$), while at the end of the experiment there was a tendency to increase. When the vitamin preparation Devivit complex was administered (experimental group IV), the energy value of the chicken thigh muscles tended to increase during the administration period and exceeded the control value by 13.8% ($p<0.05$) 5 days after the end of administration (Fig. 4).

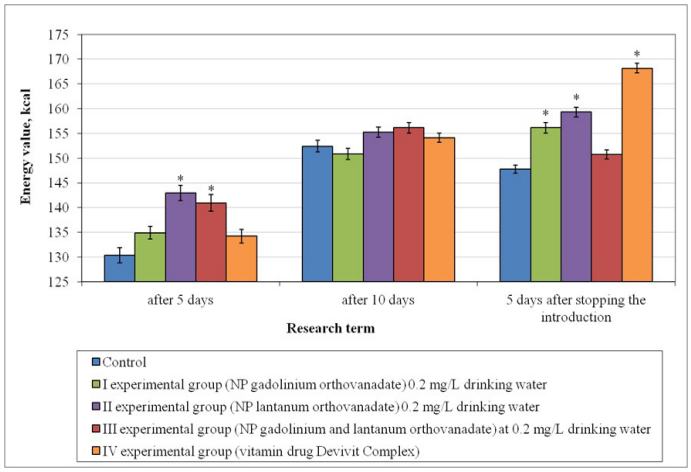

Fig. 4. Dynamics of the energy value of the thigh muscles of broiler chickens under conditions of administration of different doses of antioxidant drugs with water (M±m, n=5, *- p<0.05 - compared with the control group).

The mass fraction of protein in the thigh muscles of chickens of all experimental groups after 5 days of administration of antioxidant drugs significantly exceeded ($p<0.05$) the control by 6.9, 5.8, 10.7 and 5.5 %, respectively, in groups I, II, III and IV. A similar picture was observed after 10 days of administration: in the thigh muscles of chickens of groups I, II, III and IV, the mass fraction of protein exceeded the control ($p<0.05$) by 9.8, 4.8, 4.8 and 6.1%, respectively. Whereas 5 days after the end of the administration, the mass fraction of protein in the thigh muscles of chickens of experimental groups I and II tended to increase, in experimental group III it significantly decreased ($p<0.05$) compared to the control by 5.1 % and did not differ from the control after the administration of the vitamin preparation Devivit complex (experimental group IV) (Fig. 5).

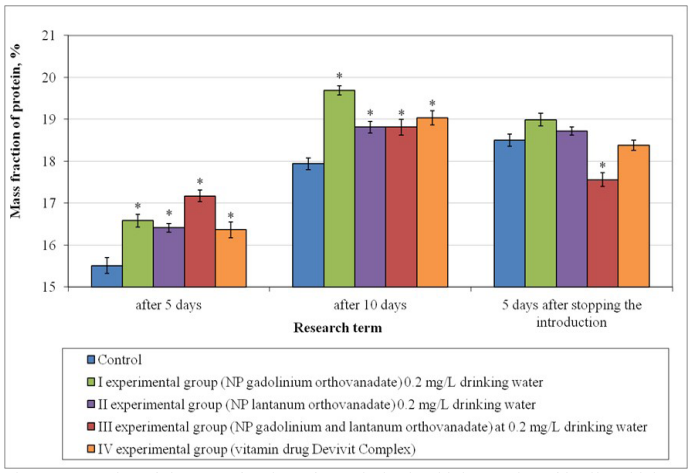

Fig. 5. Dynamics of the mass fraction of protein in the thigh muscles of broiler chickens under conditions of administration of different doses of antioxidants with water (M±m, n=5, *- p<0.05 - compared with the control group).

In the thigh muscles of chickens of the first experimental group (NP

$GdVO_4:Eu^{3+}$) after 5 days of administration, the index of the mass fraction of fat was almost the same as in the control, after 10 days of administration it decreased by 10.6% ($p<0.05$), and 5 days after the end of administration a significant increase of the mass fraction of fat by 8.7% ($p<0.05$) was observed. In the femoral muscles of chickens from experimental groups II and III NP $LaVO_4:Eu^{3+}$) and (NP $GdVO_4:Eu^{3+}$+ NP $LaVO_4:Eu^{3+}$), an increase in the mass fraction of fat of 13.2 and 5.8%, respectively, was observed after 5 days of administration compared to the control ($p<0.05$), while after 10 days of administration the indicators were almost the same as the control, and 5 days after the end of administration the indicators of the mass fraction of fat again exceeded the control ($p<0.05$) by 14.4 and 9.0 %, respectively. When the vitamin preparation Devivit complex (experimental group IV) was administered during the administration period, no significant deviations in the mass fraction of fat from the control were observed, while 5 days after the end of administration the mass fraction of fat exceeded the control by 28.3% ($p<0.05$) (Fig. 6).

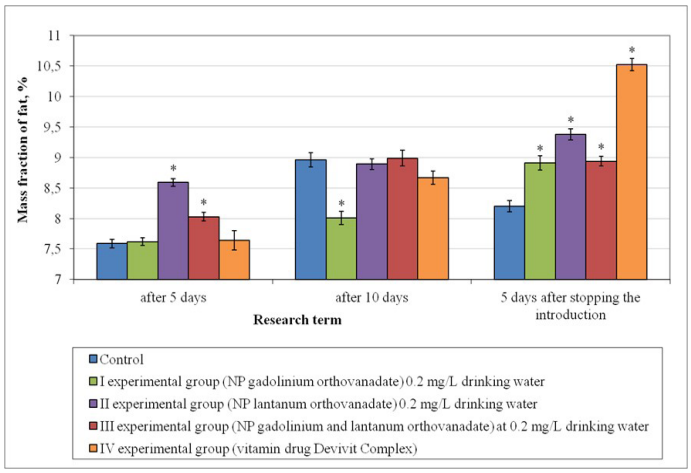

Fig. 6. Dynamics of the mass fraction of fat in the thigh muscles of broiler chickens under conditions of administration of different doses of antioxidants with water (M±m, n=5, *-$p<0.05$ - compared with the control group).

The mass fraction of ash in the thigh muscles of broiler chickens of the first experimental group (NP $GdVO_4:Eu^{3+}$) did not differ significantly from the control during the administration period, and 5 days after the end of administration it decreased by 19.2% compared to the control ($p<0.05$). In the thigh muscles of the second experimental group (NP $LaVO_4:Eu^{3+}$), after 5 days of administration, a 2.1 times increase in the mass fraction of ash was observed compared to the control ($p<0.05$), while after 10 days of administration, a decreasing trend was observed, and 5 days after the end of administration, the mass fraction of ash increased again by 19.2% ($p<0.05$). In femoral muscles of chickens of experimental group III (NP $GdVO_4:Eu^{3+}$+ NP $LaVO_4:Eu^{3+}$), after 5 and 10 days of administration, an increase in the mass fraction of ash was observed in 2.3 times and 21.4%, respectively, compared with the control ($p<0.05$), while 5 days after cessation of administration, the mass fraction of ash tended to decrease. After administration of the vitamin preparation Devivit complex (experimental group IV) in the thigh muscles of chickens, after 5 days of administration, a 2.1 times increase in the mass fraction of ash was observed by ($p<0.05$) compared to the control, after 10 days only a tendency to increase was observed, while 5 days after cessation of administration the mass fraction of ash decreased by 50.0% ($p<0.05$) compared to the control (Fig. 7).

Discussion

Nanomaterials occupy an intermediate position between individual atoms (molecules) and macrostructures and have unique physical and chemical properties due to their small size, chemical composition, structure, large surface area and shape, which are radically different from the properties of such substances in the form of macroscopic dispersions (Kutsan *et al*., 2016). The scientometric analysis conducted by Idamokoro and Hosu (2022) of global trends in the study of the use of nanotechnology to increase meat production for 1985-2020 (a total of 656 papers from the Web of Science and Scopus scientometric databases) indicates a growing trend in research (with an annual growth rate of 25.18%) aimed at developing meat production using nanotechnology. Similarly, there is growing evidence that research on nanotechnology in meat production has the potential to positively influence research decisions and collaborations, thereby increasing the production of meat and meat products in the future.

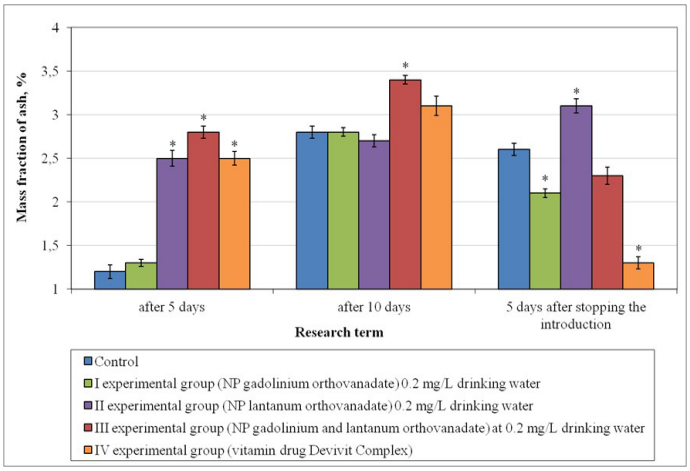

Fig. 7. Dynamics of the mass fraction of ash in the thigh muscles of broiler chickens under conditions of administration of different doses of antioxidants with water (M±m, n=5, *-$p<0.05$ - compared with the control group).

For comparison, literature data on the use of inorganic and organic forms of REE are presented. Thus, the addition of REE (38.7% of rare earth oxides: La_2O_3, Ce_2O_3, Nd_2O_3) at 300.0, 400.0, and 600.0 mg/kg of feed improved the live weight gain of broiler chickens by 20.3, 18.6, and 6.6%, respectively, compared to the control group (Abdelnour *et al*., 2019). The addition of REE-enriched feed yeast (42.3 mg/kg La and 70.65 mg/kg Ce) at a dose of 1500.0 mg/kg improved nutrient absorption and meat quality in broiler chickens (Cai *et al*., 2015). And when a mixture of REE chlorides ($LaCl_3$ 380.0 mg/kg; $CeCl_3$ 520.0 mg/kg; $PrCl_3$ 30.0 mg/kg and chlorides of other REEs 70.0 mg/kg) at a dose of 40.0 mg/kg feed and a mixture of REE citrates (La-citrate 210.0 g/kg; Ce-citrate 670.0 g/kg; Pr-citrate 120. 0 g/kg) at a dose of 70.0 mg/kg feed, it was found that the mixture of REE citrates improved body weight gain by 5.0%, while the addition of REE chlorides did not show a significant improvement compared to the control (Tariq *et al*., 2020). If we make certain mathematical calculations regarding the intake of REE in the body of broiler chickens, the introduction of REE orthovanadate nanoparticles allows at least a 30-fold reduction in the effective dose for improving meat quality compared to their inorganic or organic forms (in the case of minimal administration of REE, the dose is about 2.53 mg/kg body weight, and for the introduction of orthovanadates – about 0.09 mg/kg body weight).

This effect is probably due to the fact that REEs are able to activate the metabolism of proteins and other nutrients by stimulating the activity of hormones, especially growth hormone and triiodothyronine (Tsekhmistrenko *et al*., 2019), which is consistent with our data: administration of NP $GdVO_4:Eu^{3+}$ increases the mass fraction of proteins in chicken meat. The decrease in the mass fraction of lipids in meat after administration of NP GdVO4:Eu3can be explained by the antioxidant effect of nanoparticles, which leads to a decrease in the total amount of lipids in the body (Masliuk *et al*., 2023a). REEs, especially cerium and lanthanum, have similar properties to calcium (Hu *et al*., 2004; He *et al*., 2010), which can explain the increase in the mass fraction of dry matter and ash in chicken meat during the 10-day administration period of NP NP $LaVO_4:Eu^{3+}$ and the mixture of NP $GdVO_4:Eu^{3+}$+ NP $LaVO_4:Eu^{3+}$. On the other hand, the biological activity of REE orthovanadate nanoparticles can be enhanced

by the influence of vanadium, an element that attracts considerable attention of researchers with a wide range of positive effects in biological systems (Goc, 2006; Gruzewska *et al*., 2014; Scibior *et al*., 2020).

Conclusion

Ten-day administration of NP $GdVO_4$:Eu^{3+} at a therapeutic dose (0.2 mg/L of drinking water – on average, chickens received 0.09 (0.13-0.05) mg/kg body weight) does not significantly affect the content of dry matter and moisture, as well as ash in meat, but it contributes to an increase ($p<0.05$) in the mass fraction of protein (on average by 8.4%) and a decrease in the fat mass fraction (10.6% on the 10th day of administration), which allows maintaining the energy value at the level of the control and comparison groups. The administration of NP $LaVO_4$:Eu^{3+} as well as a mixture of $GdVO_4$:Eu^{3+} + NP $LaVO_4$:Eu^{3+} at a therapeutic dose leads to an increase ($p<0.05$) in the mass fraction of dry matter (on average by 14.2%) during the administration period, together with an increase in the mass fraction of protein (on average by 6.5%) and ash (on average by 2.0 times) and the maintenance of the fat at the level of the control and comparison drug, which allows to increase the energy value of the meat. After cessation of administration, an increase in the energy value of meat was observed in the groups receiving mono-orthovanadates due to an increase in the mass fraction of fat, but somewhat lower than in the case of the comparison drug (Devivit Complex).

Conflict of interest

The authors declare that they have no conflict of interest.

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