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TISSUES CHEMICAL COMPOSITION AND QUALITY IN BROILER CHICKENS WHEN USING AN ADAPTOGENIC COMPLEX

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Abstract
To study the effect of a newly developed adaptogenic complex on the chemical composition of muscle and bone tissues, as well as on the quality and process characteristics of the broiler chickens breast and thigh muscles, an experiment was conducted on 3 groups of the broiler chickens in the physiological ward of the Federal Research Center for Animal Husbandry named after Academy Member L. K. Ernst (n = 40, N = 120) (1 control group and 2 experimental groups) under conditions of increased stocking density. The poultry from the experimental groups received the DHQEC complex with their diet (the 2nd experimental group started receiving it from the 22nd day of life, i.e., from the day of the onset of simulated overcrowded environmental conditions; the 3rd experimental group started receiving it from the 7th day of their life). On the day 34th (n = 10, N = 20) and 52nd (n = 10, N = 20) of age, the samples of the breast and thigh muscles and the tibia bones were collected. The chemical composition, as well as several quality and process properties of the meat were determined. The administration of DHQEC for 34 days of the poultry life contributed to an increase in fat content in the breast muscle from 0.74 % in the control group up to 1.03 % and 1.17 % in the experimental groups, respectively; an increase in the pH of muscle tissue; an increase in the water-holding capacity (WHC) of the breast ($p < 0.01$) and thigh ($p < 0.01$) tissues; and elevated levels of reduced glutathione (at $p < 0.05$ and $p < 0.01$) and superoxide dismutase (at $p < 0.01$) compared to the control group values. In the liver of the poultry that received DHQEC, an increase in the level of water-soluble antioxidants was observed, whereas in the cardiac muscle, conversely, a decrease was noted. At the 52nd day of age, the trend of differences between the groups persisted. A significant difference was found in phosphorus content (it was lower in the control group) ($p < 0.05$) and magnesium content (it was lower in the 3rd experimental group) ($p < 0.05$), which may be associated with the impact of stress and its mitigation by the DHQEC complex. The most pronounced effect of the complex was observed when it was introduced into the diet from the 7th day of the poultry life. The obtained data open broad prospects for the inclusion of the DHQEC complex into broiler chicken diets, particularly during periods of stress exposure from the first days of life.

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Introduction

The increase in meat production volumes in the Russian Federation and globally is driven, among other factors, by advances in breeding achievements in the development of modern fast-growing poultry crosses. For instance, 50 years ago, a carcass weight of 2.5 kg was achieved by the age of 3 months, whereas today such live body weight in broiler chickens can be obtained as early as 5–7 weeks of age [1]. Worldwide, poultry meat production is increasing, which is mainly associated with advances in genetics and breeding technologies [2]. This has led to a significant increase in growth rates, meat yield (especially breast meat), and feed conversion efficiency.

Intensive growth, as well as the conditions of feeding and housing technology, negatively affect the quality of poultry meat products, which is manifested in the emergence of various pathologies and the deterioration of process properties. The main mechanism influencing meat quality is the occurrence of oxidative stress in the cells and tissues of the body, which results from reduced immunity and impaired health [3]. For example, studies have shown that oxidative stress can increase shear force and decrease the pH value in the breast meat of the broilers [4].

A way to reduce the negative impact of stress of various etiologies on animal health and, consequently, on product quality is the use of various nutritional factors — adaptogens and their complexes [5,6]. Adaptogens are defined as natural compounds or plant extracts aimed at increasing the adaptability and survival of living organisms exposed to stress conditions [7]. The term “adaptogen” was first introduced by Nikolai Lazarev in 1947, when the effect of 2-benzylbenzimidazole against damage to the nervous system and its ability to increase nonspecific resistance to adverse environmental conditions were described [8]

Plant extracts as feed additives not only contribute to enhancing resistance to diseases but also positively influence zootechnical performance — growth parameters and feed conversion. It has been noted that plant-based adaptogens can improve product safety by reducing the content of drug residues in the organism [9]. For example, adding *Ampelopsis grossedentata* extract to poultry diets promotes the digestion and absorption of feed nutrients and increases average daily weight gain and total weight gain [10].

Adaptogens included in the diets of both animals and humans are capable not only of modulating the immune system and various physiological processes but also of influencing reproductive function. Although the latter fact has not been extensively studied, positive effects of natural adaptogens on spermatogenesis and folliculogenesis have been reported, either through direct mechanisms or via the suppression of oxidative stress and inflammation. A significant role in this process is attributed to the regulation of neuroendocrine-immune interactions [11].

Despite the wide range of biological effects of adaptogens on living organisms, our interest is focused on their influence on the composition, quality, and safety of livestock and poultry products, particularly meat. Since these products are an integral part of the human diet and affect the health and well-being of the primary consumer.

In our earlier studies, the use of melanin in the diet of broiler chickens at a dose of 1.42 mg/kg body weight at 45 days of age contributed to an increase in the antioxidant content in the breast and thigh meat and an increase in the activity of antioxidant enzymes in the breast meat [12].

Essential oil extracted from *Lippia origanoides* improved bone mineralization in the *tibia* bones of the chickens subjected to cyclic heat stress by increasing calcium absorption and reducing bone resorption [13]. A similar positive effect on the improvement of bone microstructure and mineral density was observed by researchers when thymol was included in chicken diets [14], which was explained by an increase in osteoblast activity and a decrease in osteoclast activity [15].

Betaine supplementation increases bone mineral density and improves bone microstructure, which may prevent fractures and enhance skeletal health by increasing the digestibility of minerals such as calcium and phosphorus [16].

The combined use of adaptogens is the most appropriate approach. For example, it has been reported that the inclusion of a herbal mixture based on ginseng and artichoke into chicken diets led to improved breast muscle quality, increased redness of the breast meat, enhanced water-holding capacity, and reduced abdominal fat. The authors attributed the observed changes in the experimental group precisely to the synergistic effect of the components. Thus, the redness of the breast meat is explained by improved muscle oxygenation under the influence of ginseng, while the reduction in abdominal fat is associated with the lipid-lowering effect of both components of the complex [17].

A complex of feed additives with eco-antioxidants, based on beet powder and grape pomace, applied in poultry diets, contributed to a reduction in the amount of abdominal fat in the carcasses [18].

An adaptogen complex was developed, comprising the reference antioxidant dihydroquercetin (DHQ), obtained by extraction from the shredded wood or bark of Dahurian larch (*Larix dahurica*) ("Ekostimul-2", Ametis JSC, Russia; DHQ content 72–73 %), along with vitamins E and C [19].

In previous experiments on monogastric animals (piglets), the DHQEC complex contributed to the activation of metabolic processes and antioxidant defense, as well as to an increase in the adaptive capacity of the organism under intensive fattening technology conditions [20].

The purpose of this study was to investigate the effect of an adaptogenic complex on the chemical composition of muscle and bone tissues, as well as on the quality and technological characteristics of the pectoral and femoral muscles of broiler chickens of the domestic cross Smena 9.

Objects and methods

The experiment was conducted on 3 groups of the broiler chickens of the domestic cross Smena-9 in the physiological ward of the Federal Research Center for Animal Husbandry named after Academy Member L. K. Ernst ($n = 40$, $N = 120$) (1 control group and 2 experimental groups). As the main ration for chickens of all groups, full-fledged compound feeds were used, appropriate to the growing periods: from start up to 11 days of life — starter compound feed was used, after that grower (12–26 days), and finisher (27–52 days) feeds were used. The feeds were purchased from Mayskie Prostory LLC, Sergiev Posad city. The poultry were kept in the cages; all microclimate parameters complied with the requirements for this poultry cross[1]. The stocking density of birds in both the control group and experimental groups was increased by 10 % starting from the 21st day of life compared to the recommended values in the above-mentioned Guidelines. This was necessary to create simulated overcrowding stress conditions for the poultry. Stocking density was adjusted using movable plywood partitions as the birds grew (weekly). All three chicken groups did not differ in housing conditions, but differed in adding of 0.025 % of the developed nutritional antioxidant complex DHQEC to the diets of the broiler chickens in the experimental groups. Moreover, the additive was introduced into the diets of the chickens in the 1st experimental group from the onset of stocking density stress (from the 22nd day), and into the 2nd experimental group starting from an

[1] Efimov, D.N., Egorova, A.V., Emanuilova, Zh.V., Ivanov, A.V., Konopleva, A.P., Zotov, A.A. et al. (2020). Manual for working with poultry of meat cross-breed "Smena 9" with autosexing maternal parent form. Sergiev Posad: All-Russian Research and Technological Poultry Institute, 2020

earlier age, from the moment of the poultry transfer from brooders to cages (from the 7th day of life).

At the 34th ($n = 10$, $N = 20$) and 52 ($n = 10$, $N = 20$) day of age, the chickens were slaughtered and samples of the breast muscle, thigh muscle, and *tibia* bone were collected from the right side of the carcass. The following chemical composition parameters of the pectoral and femoral muscles were determined: dry matter (GOST 33319-2015[2]), fat (GOST 23042-2015[3]), and ash (GOST 31727-2012 (ISO 936:1998)[4]). Crude protein content was calculated. The concentrations of calcium, phosphorus, and magnesium in the bone were determined according to the appropriate methodology[5]. Meat quality parameters were determined according to the following methods: meat pH — by GOST 31476-2012[6]; GOST R 57879-2017[7]; water-holding capacity (WHC) — by samples pressing according to Grau and Hamm method, as modified by Volovinskaya; the amount of water-soluble antioxidants (AWSA) — with a Tsvet-Yauza-01-AA device using the amperometric method. This parameter was determined not only in the breast and thigh meat but also in the cardiac muscle and liver. The activity of glutathione peroxidase, catalase, and the concentration of reduced glutathione were measured using commercial Elabscience kits by a Photometer Immunochem-2100 device.

Studies carried out with approval by the bioethical commission (No. 3, May 27, 2022). The experiments were carried out in accordance with the requirements of the Federal Law of the Russian Federation[8], the Declaration of Helsinki[9], the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes[10].

Mathematical and statistical processing of the results was done using Microsoft Office Excel 2003, STATISTICA 10 (Statistica 13RU, StatSoft, USA) with the methods of variance and factor analysis, using the Dunnett's test and Tukey's test, t-test. The differences believed as statistically significant at $p < 0.05$, highly significant at $p < 0.01$; $p < 0.001$.

Results and discussion

Chemical composition of muscle tissue, namely the content of fat, protein, and moisture, serve as criterion for determining the nutritional value of raw material. It is generally considered that thigh meat contains lower protein content than breast meat in both crosses. Thigh meat features higher intramuscular fat content but lower protein content compared to breast meat.

Table 1 presents the chemical composition of thigh and breast meat, as well as the mineral composition of the *tibia* bone at the 34th day of age. It should be noted that the most substantial intergroup differences are observed in the fat content of breast meat. Thus, feeding the developed complex contributed to a significant increase in fat content in the breast from 0.74% in the control group up to 1.03% and 1.17% in the experimental groups No. 2 and No. 3, respectively. Other researchers have also drawn attention to the effect of plant adaptogens on lipid metabolism in the body. For instance, the addition of *Eucommia* leaf extract to piglet feed regulated the distribution of free amino acids and fatty acids in pork, thereby contributing to improved meat quality [21].

Table 1. Chemical composition of meat and bones of the broilers at the 34th day of age, % ($M \pm SEM$, $n = 10$)

Parameter	Group			*p*-value
	1-Control	2-Experimental	3-Experimental	
Breast meat				
Moisture	74.72 ± 0.19	74.93 ± 0.22	74.66 ± 0.14	0.31
Protein	23.34 ± 0.25	22.84 ± 0.20	23.01 ± 0.15	0.35
Fat	0.74 ± 0.12^C	1.03 ± 0.07	1.17 ± 0.10^A	*0.001*
Ash	1.20 ± 0.04	1.20 ± 0.05	1.16 ± 0.03	0.32
Calcium	0.06 ± 0.001	0.06 ± 0.001	0.05 ± 0.002	0.40
Phosphorus	0.18 ± 0.003	0.15 ± 0.003	0.16 ± 0.003	0.40
Magnesium	0.026 ± 0.0011	0.026 ± 0.001	0.029 ± 0.001	*0.04*
Thigh meat				
Moisture	74.34 ± 0.29	73.61 ± 0.41	73.57 ± 0.44	0.16
Protein	19.16 ± 0.23	19.25 ± 0.28	19.21 ± 0.08	0.91
Fat	5.40 ± 0.33	6.07 ± 0.42	6.19 ± 0.47	0.20
Ash	1.1 ± 0.04	1.1 ± 0.04	1.03 ± 0.02	0.07
Calcium	0.05 ± 0.001	0.05 ± 0.003	0.05 ± 0.006	0.12
Phosphorus	0.15 ± 0.003	0.15 ± 0.003	0.15 ± 0.003	0.50
Magnesium	0.04 ± 0.02	0.02 ± 0.001	0.02 ± 0.0001	0.45
Bone				
Ash	11.26 ± 0.60	10.17 ± 0.49	9.38 ± 0.50	0.06
Calcium	3.84 ± 0.24	3.43 ± 0.19	3.17 ± 0.16	0.08
Phosphorus	1.74 ± 0.09	1.58 ± 0.08	1.44 ± 0.08	0.07
Magnesium	0.12 ± 0.009	0.11 ± 0.006	0.11 ± 0.01	0.04

Note: the differences are significant at: Significant differences according to Tukey's test compared to the group 1 (control): A — $p < 0.05$, AAA — $p < 0.001$. Significant differences according to Tukey's test compared to the group 2 (experimental): B — $p < 0.05$, BB — $p < 0.01$, BBB — $p < 0.001$. Significant differences according to Tukey's test compared to the group 3 (experimental): CC — $p < 0.01$, CCC — $p < 0.001$.

[2] GOST 33319-2015 "Meat and meat products. Method for determination of moisture content". Moscow: Standartinform, 2019. Retrieved from https://docs.cntd.ru/document/1200123927 Accessed May 17, 2025 (In Russian).

[3] GOST 23042-2015 «Meat and meat products. Methods of fat determination». Moscow: Standartinform, 2019. Retrieved from https://docs.cntd.ru/document/1200133107. Accessed May 17, 2025 (In Russian).

[4] GOST 31727-2012 (ISO 936:1998) «Meat and meat products. Determination of total ash». Moscow: Standartinform, 2013. Retrieved from https://docs.cntd.ru/document/1200098742. Accessed May 17, 2025 (In Russian).

[5] Drozenko, N.P., Kalinin, V.V., Raetskaya, Yu. I. (1981). Methodological recommendations for chemical and biochemical studies of livestock products and feed. Dubrovitsy, 1981.

[6] GOST R 57879-2017 «Agricultural pedigree cattle. Methods for determination of pigs productivity parameters» Moscow: Standartinform, 2020. Retrieved from https://docs.cntd.ru/document/1200157536 Accessed May 17, 2025 (In Russian).

[7] GOST R 57879-2017 «Agricultural pedigree cattle. Methods for determination of pigs productivity parameters» Moscow: Standartinform, 2020. Retrieved from https://docs.cntd.ru/document/1200157536 Accessed May 17, 2025 (In Russian).

[8] Federal Law of the Russian Federation dated December 27, 2018 No. 498FZ "On the responsible treatment of animals and on amendments tocertain legislative acts of the Russian Federation."Retrieved from https://docs.cntd. ru/document/552045936. Accessed May 17, 2025 (In Russian).

[9] WMA Declaration of Helsinki — ethical principles for medical research involving human subjects Retrieved from https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/ Accessed May 17, 2025.

[10] ETS No. 123, Strasbourg, 1986) (European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes. Retrieved from https://rm.coe.int/168007a67b. Accessed May 17, 2025.

The difference is significant between the control group and the experimental group that received DHQEC from an earlier age. A tendency toward an increase in magnesium level can also be noted in the 3rd experimental group compared to the control group parameters ($p = 0.04$). This parameter also tends to change in the 3rd experimental group compared to the control group, but in the direction of a decrease (from 0.12 to 0.11% at $p = 0.04$).

Analyzing the quality parameters, including the antioxidant parameters of chicken meat at age of 34 days (Table 2), it can be noted that the use of the adaptogenic complex contributes to an increase in the pH of muscle tissue, water-holding capacity (WHC) of the breast ($p < 0.01$), WHC of the thigh ($p < 0.01$), reduced levels of glutathione (at $p < 0.05$ and $p < 0.01$), and superoxide dismutase (SOD) (at $p < 0.01$) compared to the values in the control group. It should also be noted that when the adaptogenic complex was introduced at the onset of the stress factor, a decrease in catalase activity in the breast meat was observed compared to the control group ($p < 0.05$), whereas with longer-term feeding of DHQEC, an increase in catalase activity was noted ($p < 0.05$). This demonstrates an increased expenditure of enzymatic antioxidant defense factors in response to simulated stress under short-term adaptogenic feeding. With prolonged use of DHQEC (the 3rd experimental group), the organism of the chickens adapts to environmental conditions and, conversely, promotes the accumulation of antioxidant enzymes in muscle tissue. This demonstrates an increase in the adaptive capacity of the organism of intensively growing chickens under simulated environmental conditions.

In studies by other authors, the adaptogenic quercetin, fed to the broiler chickens at a dose of 0.2–1 g/kg of feed, also contributed to the adaptation of the organism exposed to stress conditions. The authors attribute the mechanism of action of this adaptogen to the activation of antioxidant enzymes, either through the stimulation of transcription factors that enhance the antioxidant defense status. Feeding quercetin at the prescribed dosages promotes increased expression of antioxidant defense genes [22], a decrease in malondialdehyde (MDA) concentration and an increase in glutathione activity [23], including under conditions of oxidative stress [24].

The addition of 2 g/kg of cinnamon bark powder to the diet of broiler chickens leads to an improvement in the physicochemical characteristics of poultry meat [25]. As a result of the other study, it was found that the addition of the adaptogen sanguinarine to the diet can increase pH levels and improve the tenderness and flavor of chicken breast and thigh meat. The authors also noted changes in blood lipid metabolism markers in the poultry, in particular, a decrease in triglyceride levels and higher concentrations of high-density and low-density lipoproteins, which influenced fat deposition [26]. Fermented Ginkgo biloba leaves added into the diet can promote lipid metabolism, reduce lipid peroxidation, and improve the meat quality of the broilers [27].

The pH value determines the process characteristics, quality, and consumer properties of meat, and directly influences such characteristics as tenderness, water-holding capacity (WHC), color, juiciness, and shelf life. For example, pH is determined by the postmortem formation of lactic acid during glycolysis. The longer the meat is stored, the lower its pH becomes, and the more the activity of proteolytic enzymes is inhibited, which in its turn determines meat tenderness [28]. A decrease in pH also affects the rate of denaturation of myosin and actin in muscle fibers, thus reducing their hydrophilic function [29]. In connection with the important biological role of pH in the formation of meat quality, regulation of this parameter is crucial in poultry farming and processing. Proper preslaughter handling and minimization of stress during slaughter (appropriate transportation, careful treatment, rest) play a very important role in pH management. Feed antioxidants and adaptogens can also contribute not only to minimizing stressful situations [30, 31], but also to the

Table 2. Quality characteristics of broiler meat at the 34th day of age ($M \pm SEM$, $n = 10$)

Parameter	Group			p-value
	1-Control	2 -Experimental	3-Experimental	
Breast pH-45	6.10 ± 0.02	6.18 ± 0.04	6.22 ± 0.05	0.12
Breast pH-24	5.49 ± 0.04	5.59 ± 0.07	5.70 ± 0.07	0.42
Thigh pH-45	5.91 ± 0.08	6.03 ± 0.09	6.07 ± 0.04	0.38
Thigh pH- 24	5.65 ± 0.04^{ACCC}	5.67 ± 0.06^{CCC}	5.91 ± 0.03^{AAABBB}	0.0004
AWSA in the breast, mg/g	0.090 ± 0.04	0.084 ± 0.006	0.089 ± 0.006	0.75
AWSA in the thigh, mg/g	0.213 ± 0.01	0.207 ± 0.01	0.209 ± 0.013	0.98
AWSA in the liver, mg/g	0.941 ± 0.06	0.834 ± 0.07	0.860 ± 0.08	0.48
AWSA in the heart, mg/g	0.272 ± 0.03	0.289 ± 0.03	0.289 ± 0.02	0.82
TAS, mM/L	0.109 ± 0.02	0.116 ± 0.02	0.160 ± 0.02	0.80
Reduced glutathione in breast meat, μM/g	67.24 ± 2.49^{BCCC}	91.63 ± 3.38^{A}	101.33 ± 3.65^{AAA}	0.005
SOD in breast meat, U/g	10.65 ± 2.11^{CC}	13.69 ± 0.38^{CC}	22.18 ± 0.62^{AABB}	0.0006
Catalase in breast meat, U/g	20.07 ± 2.75^{BC}	17.38 ± 2.77^{AC}	34.16 ± 5.31^{A}	0.03
WHC of breast meat, %	58.33 ± 0.45^{BBBCCC}	63.23 ± 1.50^{AAAC}	67.46 ± 1.11^{AAAB}	0.000003
WHC of thigh meat, %	56.96 ± 1.31^{BBBCCC}	62.95 ± 0.97^{AAA}	65.60 ± 0.86^{AAA}	0.00007

Note: the differences are significant at: Significant differences according to Tukey's test compared to the group 1 (control): A — $p < 0.05$, AAA — $p < 0.001$. Significant differences according to Tukey's test compared to the group 2 (experimental): B — $p < 0.05$, BB — $p < 0.01$, BBB — $p < 0.001$. Significant differences according to Tukey's test compared to the group 3 (experimental): CC — $p < 0.01$, CCC — $p < 0.001$.

reduction of oxidative stress [32]. The rate of post-slaughter cooling also plays a role in pH regulation, as it can slow down glycolysis, thereby reducing the rate of pH decline. Temperature, humidity, and other parameters during the transportation and storage of poultry meat also play an important role in stabilizing pH levels [33].

Water-holding capacity (WHC) is a crucial factor determining meat juiciness and tenderness. It is considered that approximately 90 % of water is bound to proteins within muscle tissues, located inside the cell between actin and myosin, while the remaining 10 % is located between myofibrils [34]. It is known that a number of factors influence WHC. For example, there is a close relationship between WHC and pH. Changes in pH reduce the number of active sites available for water-protein binding. When pH reaches isoelectric point values (where the number of positive and negative charges is equal), proteins are unable to bind to charged groups of water [35]. This leads to a decrease in WHC. Another factor influencing WHC is energy deficiency during meat aging. This results in a reduction of WHC due to the aggregation of actin complexes within the muscles and a decrease in the space between myofibrillar proteins. On the other hand, WHC itself affects the color of broiler breast muscles, as changes in water content within the muscles alter light reflection on their surface [36]. One of the main factors influencing WHC is apoptosis, which can disrupt the structural integrity of muscle cells, leading to a decrease in water-holding capacity [37]. It is known that oxidative stress damages cell membranes and proteins, leading to a decrease in the water-holding capacity of muscle tissue. Therefore, the increase in WHC of both the breast and thigh muscles of broiler chickens fed with the antioxidant complex may indicate an enhancement of the body's antioxidant defense, with longer-term administration of DHQEC exerting the most significant effect.

For example, supplementing the broilers' diet with vitamin E has been shown to increase the brightness of breast muscle [38], and to increase muscle pH [39].

At the day 52 of age (Table 3), the muscle pH level in the chickens of the 3rd experimental group was higher than that in the 2nd experimental group ($p < 0.05$), indicating a positive and cumulative effect of adaptogens on meat quality parameters. The most pronounced effect was observed when the complex was used in the diet from day 7 of the poultry life. The highest moisture content was found in the breast meat of the chickens from the 3rd experimental group (74.33 %, $p < 0.01$ compared to the 2nd group). A significant difference was observed between the control and the 3rd experimental groups in phosphorus content (lower in the control) ($p < 0.05$) and magnesium content (lower in the 3rd experimental group) ($p < 0.05$), which may be associated with the impact of stress and its mitigation by the DHQEC complex.

In the liver of birds receiving DHQEC, an increase in the level of water-soluble antioxidants (AWSA) was observed ($p < 0.001$) compared to the control group and the 2nd experimental group. In the cardiac muscle, conversely, feeding the adaptogen complex resulted in a significant decrease in the accumulation of water-soluble antioxidants. It is known that the liver is an important and central

Table 3. Chemical composition of meat and bones of broilers at the 52nd day of age, % (M ± SEM, n = 10)

Parameter	Group			*p*-value
	1-Control	2-Experimental	3-Experimental	
Breast meat				
Moisture	73.26 ± 0.22^{CC}	73.87 ± 0.18	74.33 ± 0.25^{AA}	*0.016*
Protein	24.34 ± 0.16^{C}	23.78 ± 0.14	23.42 ± 0.27^{A}	*0.04*
Fat	1.02 ± 0.15	1.19 ± 0.09	1.09 ± 0.08	0.44
Ash	1.19 ± 0.01	1.17 ± 0.01	1.16 ± 0.02	0.44
Calcium	0.056 ± 0.002	0.058 ± 0.05	0.056 ± 0.002	0.85
Phosphorus	0.168 ± 0.03^{C}	0.160 ± 0.002	0.171 ± 0.004^{A}	*0.027*
Magnesium	0.031 ± 0.001^{C}	0.030 ± 0.001	0.027 ± 0.001^{A}	*0.029*
Thigh meat				
Moisture	73.11 ± 0.80	74.59 ± 0.36	74.63 ± 0.28	0.15
Protein	20.21 ± 0.21	19.75 ± 0.15	19.74 ± 0.15	*0.01*
Fat	5.65 ± 0.64	4.64 ± 0.35	4.61 ± 0.25	0.11
Ash	1.03 ± 0.02	1.02 ± 0.01	1.02 ± 0.01	0.41
Calcium	0.052 ± 0.004	0.049 ± 0.003	0.048 ± 0.001	0.78
Phosphorus	0.141 ± 0.004	0.139 ± 0.003	0.150 ± 0.005	*0.03*
Magnesium	0.024 ± 0.0003	0.025 ± 0.001	0.023 ± 0.001	0.28
Bone				
Ash	10.36 ± 0.47	10.65 ± 0.52	10.10 ± 0.56	0.46
Calcium	3.50 ± 0.19	3.50 ± 0.18	3.40 ± 0.20	0.45
Phosphorus	1.37 ± 0.07	1.38 ± 0.07	1.46 ± 0.0	0.11
Magnesium	0.09 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.83

Note: the differences are significant at: Significant differences according to Tukey's test compared to the group 1 (control): A — $p < 0.05$, AAA — $p < 0.001$.
Significant differences according to Tukey's test compared to the group 2 (experimental): B — $p < 0.05$, BB — $p < 0.01$, BBB — $p < 0.001$.
Significant differences according to Tukey's test compared to the group 3 (experimental): CC — $p < 0.01$, CCC — $p < 0.001$.

coordinator of the body's antioxidant defense. Its role involves the synthesis, storage, metabolism, and distribution of key antioxidant defense factors throughout the organism. Various liver dysfunctions negatively affect the overall oxidative status [40]. It can be assumed that liver tissues, playing a key role in the implementation of antioxidant defense, accumulate the relevant substances. Evidence of this, as well as an indirect indication of increased adaptive capacity of the organism, is the increase in the total antioxidant status of meat (from 0.14 mM/L in the control to 0.188 and 0.208 mM/L in the 2nd and 3rd experimental groups, respectively, at $p = 0.10$).

In another study, the addition of a herbal preparation consisting of a mixture of the following plant species: *Ichnocarpus frutescens, Terminalia chebula, Sida cordifolia, Terminalia arjuna, Phyllanthus emblica, Tephrosia purpurea, Fumaria indica, Andrographis paniculata, Azadirachta indica, Tinospora cordifolia, Achyranthes aspera, Boerhavia diffusa, Solanum nigrum, Citrullus colocynthis, Eclipta alba, Aphanamixis polystachya u Phyllanthus niruri* exerted a positive effect on chicken growth and liver protection [41]. The application of a nutritional adaptogen complex based on ginger powder and ginger essential oil reduced the level of malondialdehyde (MDA) in liver and blood serum samples [42]. Supplementation of broilers diet with a mixture containing 5% carvacrol, 3% cinnamaldehyde, and 2% capsicum oleoresin at a dose of 100 mg/kg of feed exerted a positive effect on the concentration of antioxidants in the liver [43].

Conclusion

The chemical composition of broiler chicken muscle tissue determines its nutritional value, while quality parameters — pH and WHC — determine the process characteristics, quality, and consumer properties of the meat. Intensive growth, as well as the conditions of feeding and housing technology, negatively affect the quality of poultry meat products, which is manifested in the emergence of various pathologies and the deterioration of process properties. Stress of various etiologies affecting the chicken's organism also influences the quality of the resulting meat products. One strategy for improving the quality of meat raw materials is using of various adaptogens in the nutrition of intensively growing broiler chickens.

The DHQEC complex we developed, based on the synergistic effect of the referenced antioxidant DHQ and vitamins E and C, contributes to an increase in breast fat content, an increase in muscle tissue pH, an increase in the water-holding capacity (WHC) of the breast and thigh, the elevated levels of reduced glutathione and superoxide dismutase in muscle tissue, and the accumulation of water-soluble antioxidants in the liver. The most pronounced effect is observed when the complex is used in the diet starting from the 7th day of the poultry's life. The obtained data open broad prospects for the inclusion of the DHQEC complex in broiler chicken diets, particularly during periods of stress exposure from the first days of life.

Table 4. Quality characteristics of broiler meat at the 52nd day of age (M ± SEM, n = 10)

Indicator	Group			p-value
	1-Control	2-Experimental	3-Experimental	
Breast pH –45	5.55 ± 0.06	5.65 ± 0.04	5.68 ± 0.06	0.31
Breast pH 24	5.44 ± 0.11^{C}	5.70 ± 0.10	5.78 ± 0.04^{A}	*0.033*
Thigh pH –45	5.95 ± 0.03^{C}	6.05 ± 0.03	6.07 ± 0.02^{A}	*0.04*
Thigh pH 24	5.52 ± 0.06	5.69 ± 0.05	5.77 ± 0.04	*0.003*
AWSA in the breast, mg/g	0.149 ± 0.01	0.145 ± 0.01	0.134 ± 0.01	0.74
AWSA in the thigh, mg/g	0.196 ± 0.02	0.212 ± 0.01	0.229 ± 0.01	0.56
AWSA in the liver, mg/g	0.121 ± 0.02^{BBBCCC}	0.658 ± 0.03^{AAA}	0.703 ± 0.04^{AAA}	*0.000001*
AWSA in the heart, mg/g	0.455 ± 0.02^{BBBCCC}	0.312 ± 0.02^{AA}	0.308 ± 0.02^{AAABB}	*0.00001*
TAS, mM/L	0.140 ± 0.02	0.188 ± 0.03	0.208 ± 0.15	0.10
Reduced glutathione in breast meat, μM/g	58.49 ± 14.53	85.54 ± 6.73	117.39 ± 26.75	0.28
SOD in breast meat, U/g	11.80 ± 0.94	13.96 ± 2.14	15.35 ± 2.68	0.34
Catalase in breast meat, U/g	22.16 ± 3.22	24.39 ± 2.62	28.52 ± 0.33	0.37
WHC of breast meat, %	56.29 ± 0.75	58.42 ± 1.03	58.67 ± 0.62	0.19
WHC of thigh meat, %	55.32 ± 1.48^{BC}	61.38 ± 1.39^{A}	63.41 ± 1.17^{A}	*0.0005*

**Note: the differences are significant at: Significant differences according to Tukey's test compared to the group 1 (control): A — $p < 0.05$, AAA — $p < 0.001$.
Significant differences according to Tukey's test compared to the group 2 (experimental): B — $p < 0.05$, BB — p < 0.01, BBB — $p < 0.001$.
Significant differences according to Tukey's test compared to the group 3 (experimental): CC — $p < 0.01$, CCC — $p < 0.001$.
Significant differences according to Tukey's test compared to the group 4 (experimental): D — $p < 0.05$, DD — $p < 0.01$, DDD — $p < 0.001$.**

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