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Influence of Activated Shungite on Quail Productivity and the Biometrical Parameters and Chemical Composition of Quail Eggs

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ABSTRACT

Poultry farming is key to providing the population with high-quality, affordable products. The successful development of this industry is directly dependent on the rational use of available feed resources. The study aims to explore the influence of different concentrations of activated Shungite as part of compound feed on the productivity of quail and the quality and chemical composition of quail eggs. The experiment was conducted on a quail farm owned by the SalemQus LLC in Almaty region, Kazakhstan. The study subjects were three groups of quail of the meat breed Texas, 50 animals each, selected by random sampling. The control group received a standard diet without additives, while groups 2 and 3 were supplemented with activated Shungite in doses of 3 and 5%, respectively. After 120 days of the experiment, the influence of activated Shungite on the egg productivity of laying quail hens produced a significant difference. Adding activated Shungite into the diet of laying hens in 5% of their main feed improved their egg-laying indicators, increasing gross egg production by 2.82% and egg-laying rate by 98.8%. The average egg weight increased by 6.50% and egg mass yield by 9.48%. An improvement was also observed in the morphometric parameters of eggs. The phosphorus and iron content in the eggs rose by 5.1 and 7.25%. This study confirms the effectiveness of activated Shungite in poultry feeding and substantiates the need for further research to optimize the dosages and study long-term effects.

Key words: Feed additives, Shungite, Quail, Productivity, Quality assessment, Mineral composition.

INTRODUCTION

Quail farming is now actively developing in Kazakhstan, becoming a prominent direction in industrial poultry farming (Musafirova 2019). This sector helps meet the needs of domestic consumers for quail meat and eggs (Mnisi and Mlambo 2018; Bektimirov et al. 2020).

In recent years, researchers and dieticians have been paying increased attention to the nutritional value and potential advantages of quail eggs for human health (Proskurina 2018; Startseva and Naumov 2018; Ali and Abd El-Aziz 2019; Boiago et al. 2019; Sadaf et al. 2022). Mathieu et al. (2015) emphasized the unique properties that make quail eggs a valuable raw material for the European cosmetics industry. Owing to their unique qualities, quail eggs are used in the formulations of cosmetic masks and shampoos. Egg whites are used in the dairy industry to pasteurize milk due to their high content of lysozyme enzymes; purified lysozyme is also exported. Egg yolks are used in the food industry to make creams and liqueurs and the shells and whole eggs are used to make edible cookies. Researchers also note that quail eggs are 97% digestible by the human body.

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Gogaev et al. (2017) demonstrated that quail meat contains high levels of fat-soluble and water-soluble vitamins and micro and microelements, such as copper (Cu), iron (Fe) and cobalt (Co). This meat is particularly valued for its nutritional value and constitutes one of the highest-quality protein sources. It has a strong aroma, soft texture and pleasant taste.

Smolina and Vasileva (2018) and Czerwonka et al. (2024) found quail eggs significantly more nutritious than chicken eggs. Quail eggs contain twice as much vitamin B12 and three times as much iron as chicken eggs. Therefore, quail eggs are especially beneficial for people suffering from anemia and other diseases associated with deficiencies of these nutrients.

Bayomy et al. (2017) also described the nutritional properties of quail eggs and their functional benefits. The contents of vitamins, minerals, antioxidants, and other biologically active components in quail eggs were evaluated. The results show that quail eggs contain high concentrations of vitamins A, B1 and B2 and minerals, such as iron and phosphorus, making them a valuable nutrition source. In addition, the antioxidant activity of quail eggs was found to protect cells from oxidative stress and potentially support overall health.

Edilbekova (2024) reviewed scientific findings on the influence of quail eggs on human health. The review examines the potential therapeutic properties of quail eggs, including their anti-allergic and immunomodulatory effects. A key conclusion is that quail eggs may reduce the risk of allergic reactions and support the normal functioning of the immune system. Researchers discuss the potential benefits of quail eggs for people with cardiovascular diseases and diabetes owing to the healthy fats and antioxidants they contain.

Umera et al. (2018) studied the dietary effects of quail eggs on blood glucose and lipid levels in diabetic rats. Thirty-six diabetic rats were administered quail eggs and divided into nine groups of four rats each. The rats that received two raw quail eggs exhibited the most remarkable ability to lower blood glucose levels and reduce weight gain compared to rats that received insulin. Blood glucose tests at specific time intervals (d7, d14, and d21) showed that quail eggs could be used for medium to long-term diabetes treatment. Iakovleva (2020) showed that quail eggs positively affect bodily functions and memory. Furthermore, quail eggs are high in protein and low in calories, aiding in weight management and obesity prevention.

The search for effective feed additives for industrial poultry farming, particularly for quail, remains urgent today. Mineral nutrition is key in poultry diets, providing the necessary balance of nutrients and contributing to their health and productivity (Nys et al. 2018; Alagawany et al. 2021). Among natural minerals, Shungite, which has unique adsorption and antibacterial properties, is the most promising (Swiderska-Mocek et al. 2024).

Shungite is an intermediate form between amorphous carbon and crystalline graphite, containing carbon (30% of the mass), silicon dioxide (45%) and layered silicate (around 20%). Shungite carbon is a fossilized organic material of Precambrian sediments with a high level of carbonization, containing fullerene-like regular structures (Skrypnik et al. 2021; Shevchenko et al. 2023).

In recent years, several significant studies have confirmed the positive effect of Shungite and feed additives based on their effect on egg quality, productivity and the amino and fatty acid composition of poultry eggs. Balykina et al. (2024) evaluated the composition and properties of natural adaptogens (Shungite and fucus powder) for feed additives. The highest chicken survival rate was observed in the experimental group (97.69%), which was 7% greater than the control group. The additives positively affected the number of normoflora in the blind intestine, the weight and quality of eggs, the digestibility of amino acids, hemoglobin levels, and immunity.

Biktashev et al. (2018) demonstrated that high-dispersion Shungite and zeolite sorbents prevent cadmium accumulation and lead in broilers' liver and muscles. Introducing Shungite at a dose of 0.5% in non-contaminated feeds increased broiler productivity by 10.2% and reduced feed conversion to 1.45kg/kg gain. Zeolite does not produce a similar effect. Balykina et al. (2022) observed a positive effect of the Black feed Plus feed additive based on Shungite (1.0kg/t of compound feed) on the performance of laying hens of the industrial crossbreed Brown Nick. The additive reduced stress caused by mycotoxins and was recommended for use on egg farms, especially in the 3rd-stage diets of laying hens.

Kishniaikina et al. (2024) tested the effectiveness of the Mustal adsorbent developed based on Shungite in the feed of parent stock chickens of the Ross 308 crossbreed. In the experimental group, which received the adsorbent at a dose of 1.5kg/t of compound feed, gross egg production and the yield of eggs fit for incubation were 0.24 and 0.20% higher than the control group. Furthermore, the output of desired chicks increased by 0.8%, and the survivability rate grew by 0.02%. Profit from product sales in the experimental group was 2.21% higher.

Biktashev (2018) examined the composition and structural qualities of the amorphous, noncrystallizing, fullerene-like carbon-containing mineral Shungite from the Zazhoginsky deposit in Karelia. The study found Shungite to have high adsorption, catalytic, and bactericidal activity. Based on the data, Biktashev (2018) emphasized the prospects of using Shungite as a sorbent for water treatment and purification and its efficiency in animal and poultry diets.

Trukhachev et al. (2022) considered the use of heat-treated Shungite presented in the Black feed Plus supplement in the diets of Brown Nick laying hens. Mycotoxicosis, often occurring in poultry farming, negatively affect poultry productivity and safety, leading to economic losses. The study showed a positive effect of the additive on the productivity of hens, especially in the conditions of egg poultry farms and in the diets of laying hens at the 3rd stage of egg laying. It also revealed a high sorption capacity of Shungite about mycotoxins, including non-polar ones. Egorov et al. (2021) studied the effectiveness of a combination of sorbents in reducing the impact of imidacloprid on broiler chicks. In their experiment, the researchers used zeolite and Shungite. This combination of mineral sorbents positively affected growth rate, metabolism and other indicators. The study demonstrated that, owing to their sorption capacity, the studied sorbents reduced the toxic influence of imidacloprid and improved the health of chicks. For more objective results, it was recommended to experiment with other neonicotinoids and bird species (Egorov et al. 2021). Balykina et al. (2024) demonstrated that Shungite-based mineral supplements can effectively reduce *Campylobacter jejuni* infection in poultry, improving survival rates and growth performance despite the presence of the pathogen.

Our study aimed to explore the influence of various concentrations of activated Shungite in quail feed on their productivity, biometric indicators and the chemical profile of their eggs.

MATERIALS AND METHODS

Ethical approval

The Kazakh National Agrarian University Ethics Committee examined and approved the study on birds (Minutes 77 of September 18, 2023).

Research location and subjects

The experimental economics study was conducted from October 2022 to February 2023 in SalemQus LLC in Eskeldi district, Almaty region, Kazakhstan. Laboratory analyses of quail eggs were performed at the Research Institute of Food Safety at Almaty Technological University.

The study subjects were quail of the Texas breed. The rearing period was 120 days. Three groups were formed, each consisting of 150 seven-week-old quail. The chicks were kept in isolated 0.90×1.54m battery cages with a mesh floor, maintaining optimal bird density. All cages were equipped with automatic feeders and nipple drinkers, allowing chicks to feed and drink water freely. The birds' background, live weight, and general condition were considered.

Management of experimental quail

The feeding, weight control, and housing of the quail as part of the experiment were consistent with cage housing standards. The chicks were reared in cages on deep litter with a partially netted floor, which provided free access to feed and water. All birds received the farm's standard complete compound feed, consisting of the same components.

Birds in group 1 (control group) were fed the basic diet. Group 2 received activated Shungite in addition to the basic diet in the amount of 3.0% of the dry matter of the feed. Birds in group 3 received activated Shungite in 5.0% of the basic feed. The basic diet included corn, wheat, sunflower cake, barley, soybean meal, fish meal, salt, baking soda, limestone, choline chloride, methionine, lysine, threonine, and mineral and vitamin premixes. The nutritional value per 100g of compound feed was as follows: 270kcal of metabolizable energy, 17.03g crude protein, 3.82g crude fat, 4.97g crude fiber, and 12.48g crude ash. The diet was formulated according to the nutritional requirements provided by the farm's recommendations. The diet composition for the control and experimental groups of quail is presented in Table 1.

Composition of activated shungite

The carbon-mineral raw material to produce activated Shungite was Shungite rock (hereinafter source Shungite), which was found as a contact ore in the mining of polymetallic ore at the Bakyrchik deposit, Kazakhstan. Activated Shungite was obtained in two stages. In the first stage, Shungite materials were stabilized by flotation enrichment performed using an FM-0.2M machine (Mining Machines JSC, Russia) to ensure uniform distribution of carbon. Before this, source Shungite was crushed to a fraction up to 0.3mm and enriched by carbon froth flotation. The flotation process was conducted in one stage in an aqueous medium. The obtained carbon concentrate of Shungite was dried at 105±5°C for 3 hours while being stirred periodically, which resulted in a moisture content of no more than 3.0%, and then the carbon concentrate was briquetted. Chemical wood tar and coal tar were used as the binder mass, and the extruder bushing diameter was 1.7mm. In the second stage, the obtained carbon Shungite concentrate was subjected to additional drying, carbonization (in an argon medium) at 700-750°C, and activation with sharp water vapor at 850-900°C.

Table 1: Composition of diets for the control and experimental groups of quail

Ingredients (%)	Groups		
	1 (Control)	2 (Experimental)	3 (Experimental)
Wheat	10.00	10.00	10.00
Fodder corn	46.00	46.00	46.00
Barley	14.00	14.00	14.00
Soybean meal	8.50	8.50	8.50
Sunflower cake	6.50	6.50	6.50
Baking soda	1.00	1.00	1.00
Shungite	0.00	3.00	5.00
Fishmeal	5.00	5.00	5.00
Lysine	0.40	0.40	0.40
Methionine	0.40	0.40	0.40
Threonine	0.20	0.20	0.20
Salt	0.50	0.50	0.50
Mineral premix[1]	1.00	0.00	0.00
Vitamin premix[2]	1.00	1.00	1.00
Limestone	2.00	0.00	0.00
Choline chloride	3.50	3.50	1.50
Total	100	100	100

[1]Mineral premix composition (mg/kg): zinc – 50; copper – 12; iodine – 0.3; cobalt – 0.2; iron – 100; selenium – 0.1; manganese – 110. [2]Vitamin premix composition: vitamin A – 12 000ME; vitamin D_3 – 2500ME; vitamin E – 30ME; vitamin K_3 – 2mg; thiamine – 2.25mg; riboflavin – 7.5mg; pyridoxine – 3.5mg; cobalamin – 0.02mg; niacin – 45mg; pantothenic acid – 12.5mg; biotin – 0.125mg; folic acid – 1.5mg.

The elemental composition of source Shungite from the Bakyrik deposit was C – 17.7; S – 0.2; N – 0.3; H – 0.02; SiO_2 – 52.0; Na_2O – 1.4; MgO – 2.2; K_2O – 0.1; CaO – 1.1; $Fe2O_3$ + FeO – 4.2; Al_2O_3 – 16.3; TiO_2 – 0.7 (Bulegenova et al. 2014). The elemental composition of the obtained activated Shungite was C – 22.5; S – 0.0; N – 0.0; H – 0.0; SiO_2 – 40.1; Na_2O – 0.7; MgO – 1.9; K_2O – 4.7; CaO – 2.5; $Fe2O_3$ + FeO – 10.3; Al_2O_3 – 16.4; TiO_2 – 0.9.

The elemental analysis of the studied Shungite suggests that after flotation enrichment of the source Shungite, carbon content increased significantly and then decreased in the activated Shungite, which effectively lacks sulfur, hydrogen, and nitrogen. Compared to the source Shungite, activated Shungite has lower carbon, SiO_2, and Na_2O concentrations and notably higher content of metal oxides of K, Ca, Fe, Al and Ti.

Quail eggs quality assessment

The selection and analysis of egg samples were conducted according to GOST 31655-2012 "Food eggs (turkey, guineafowl, quail, ostrich)." A total of 120 egg samples were examined. Veterinary and sanitary testing was conducted in the Department of Veterinary and Sanitary Examination and Hygiene laboratory of Kazakh National Agrarian University.

Egg quality assessment consisted of several stages. First, the cleanliness of the shell was evaluated visually. The smell of the contents of quail eggs was determined through an organoleptic study. The egg white and color concentration were assessed visually after the eggs were poured onto a smooth surface. The eggs were ovoscoped using a PK-10 device (Vetzootekhnika, Russia) to check the height and condition of the air chambers, yolk position, shell integrity, and defects. Physical indices determined the weight of the egg and its yolk and white. For this purpose, egg mass was measured on laboratory electronic scales VM-153 (Vesta, Russia). The dimensions of the shell were measured with a caliper with an accuracy of 0.1mm.

Analysis of the chemical composition of eggs

Laboratory tests on quail meat were performed in the Research Institute of Food Safety laboratories at Almaty Technological University. Total moisture in muscle tissue was determined by drying the sample in a ShS-80-01 SPU drying cabinet (production in Smolensk SKTB SPU, Russia) at 103±2°C as per GOST 33319-2015. Fat content was determined via GOST 23042-2015. Protein content was determined using the Kjeldahl method according to GOST 25011-2017. Ash content was determined by heating the sample in a muffle furnace at 550°C for four hours following GOST 31727-2012 (ISO 936:1998).

Determination of macro and microelements

Sodium, potassium, magnesium and manganese were measured using a KFK-3 spectrophotometer (NV-Lab, Russia) according to GOST 55484. They were determined via flame atomic absorption. The contents of iron, calcium, and zinc were determined following GOST 26929.

Preparation of samples

Sample preparation for the decomposition of organic matter to analyze toxic elements was conducted according to GOST 51482-99.

Amino acid determination

The amino acid composition of meat was studied according to ND MU 04-38-2009, "Determination of proteinogenic amino acids." The technique used was measuring the mass fraction of amino acids by capillary electrophoresis using the Kapel capillary electrophoresis system (Lumex, Russia).

Determination of fatty acid composition

The composition of fatty acids in meat was determined according to GOST 30418-96 "Vegetable oils, Method for determination of fatty acid content." Chromatographic separation was performed using an Agilent Technologies 7890A gas chromatograph (USA) equipped with a flame ionization detector (FID) and a 30m long capillary column with an inner diameter of 0.32mm. The liquid phase in the column was Supelcowax 10 with a 0.25μm thick film.

The separation conditions were as follows: carrier gas – helium, flow rate – 1 mL/min, detector temperature – 250°C, injector temperature – 230°C, column temperature – 195°C. The methyl esters of acids were identified by retention time and compared to a reference mixture of methyl esters of fatty acids (Supelco 37 Component FAME Mix, 10mg/mL in methylene chloride). The percentage shares of fatty acids were calculated in the Chemostation. The results were expressed in relative percentages (%) to the total content of fatty acids in the meat samples.

The eggs were cracked by hand for testing, separating the whites from the yolks. Yolk lipids were extracted using the standard methods using chloroform and methanol in the ratio of 2:1 (by volume). The methylation method determined the composition of fatty acids in yolk lipids. For this purpose, 100mg of the extracted yolk lipid was put into a glass test tube with a lid, then 4cm³ of 2M NaOH solution was added to it, and the tube was heated on a heating block; after 10min, 5cm³ of boron trifluoride-methanol complex were added and the heating continued. We added 3cm³ of isooctane to the boiling mixture and continued heating for one more minute. After removing the tube from the heat source, 20cm³ of NaCl solution was added without letting it cool down. The top 2cm³ of isooctane was then poured into a container, adding a small amount of anhydrous sodium sulfate.

Data analysis

The results were subjected to variation-statistical processing using Microsoft Excel. The reliability of the data was assessed using variation statistics using the Student's t-test. Differences were considered statistically significant at $P<0.05$.

RESULTS

Egg production and morphometric indicators of quail eggs

The analysis of laying quail performance indicators conducted to study differences between the concentrations of activated Shungite shows mixed results (Table 2). Group 3, which received activated Shungite in 5% of the basic feed, showed significantly better results than the control group.

We recorded that quail in the control group produced 8,076 eggs, while the experimental groups 2 and 3 produced 8,268 and 8,304 eggs, respectively. Thus, gross egg production in the two experimental groups was 2.38 and 2.82% higher compared to the control group ($P<0.05$). Egg production per average laying hen is 67.3±1.5 eggs in the control group, while in the experimental groups 2 and 3, it amounts to 68.9±1.3 (+2.38%) and 69.2±1.5 (+2.82%) eggs, respectively ($P<0.05$). The age of peak egg production is 16 weeks in the control group and 17 weeks in the experimental groups.

The egg-laying rate was 96.1% in the control group, 98.4% (+2.40%) in group 2, and 98.8% (+2.81%) in group 3. The average egg mass was 11.23±0.94g in the control group, 11.82±1.13g (+5.26%) in group 2, and 11.96±0.83g (+6.50%) in group 3. Egg mass yield reaches 90.7kg in the control group, 97.73kg (+7.77%) in group 2, and 99.3kg (+9.48%) in group 3. Egg mass per female quail was 755.8g in the control group, 814.4g in group 2, and 827.5g in group

Table 2: Experimental Economic Parameters of Quail (Hens) and the Effects of Activated Shungite on Egg Production, Egg Mass Output, and Survivability

Parameters	Units	Groups		
		1 (Control)	2 (Experimental)	3 (Experimental)
Average number	Number	120	120	120
Gross egg production	Number	8076	8268	8304*
Egg production per average laying hen	Number	67.3±1.5	68.9±1.3*	69.2±1.5*
Age of peak egg production	Weeks	16	17	17
Egg-laying rate	%	96.1	98.4	98.8
Average egg weight	g	11.23±0.94	11.82±1.13	11.96±0.83
Egg mass yield§	kg	90.7	97.73	99.3
Egg mass	g	755.8	814.4*	827.5*
Survivability, %	%	93.3	93.3	96.6

Values bearing asterisk differ significantly (P<0.05) in a row. In each group, there were 150 seven-week-old quail of the Texas breed. §Egg Mass Yield, also referred to as Egg Mass Output (EMO), is measured in kilograms (kg) of egg mass produced per day for the entire flock. This metric represents the total weight of eggs produced by all laying hens over a specific period rather than the mass of eggs per individual bird

3 (P<0.05). The latter parameter is 7.74 and 9.49% higher in the two experimental groups than in the control. Finally, survivability reaches 93.3% in the control and group 2 and 96.6% in group 3.

The study thus demonstrates that the addition of activated Shungite into the diet of quail positively affects their productivity. Gross egg production, egg production per average laying hen, and egg-laying rate are higher in the experimental groups compared to the control. The average egg mass is also more significant in the two experimental groups, especially in group 3, pointing to a favorable effect of activated Shungite. Egg mass yield and egg mass per hen are significantly higher in the experimental groups, which supports the effectiveness of using Shungite. The survivability of quail in group 3 is significantly higher than in the control group and group 2, suggesting the potential benefits of activated Shungite for poultry health and productivity.

The morphological parameters of eggs are economically important in poultry production (Popoola 2015). In this study, quail diets with different doses of Shungite resulted in significant changes in the morphological parameters of eggs (Table 3).

The weighing of the eggs confirmed that all groups met state standards, with an average egg weight exceeding 10g. The average egg weight was 11.23±0.94g in the control group, 11.82±1.13g in group 2, and 11.96±0.83g in group 3 (P≥0.05). While group 3 showed a numerical increase of 7.05% and group 2 an increase of 4.8% compared to the control, the overlapping confidence intervals indicate that these differences are not statistically significant (P>0.05). Therefore, a trend toward increased egg weight is observed.

In the tests to determine the weight of whites and yolks, all experimental groups of quail fed with Shungite show higher values than the control group. The mass of egg white is 0.38g greater (5.3%) in group 2 and 0.58g greater (7.9%) in group 3 compared to the control group. The mass of the yolk is also increased by 0.14g (3.9%) in group 2 and by 0.06g (1.7%) in group 3 (P≥0.05).

Quail eggs from group 3, with the addition of activated Shungite to the main diet, have the highest mass and the best shell thickness and density (P≥0.05). The mass of shells is 0.07g (5.8%) higher in group 2 and 0.09g (7.4%) higher in group 3 (P≥0.05) compared to the control group.

Shell strength is an important indicator of egg quality. In the control group, the average shell thickness is 0.19±0.02mm. In contrast, group 2, with 3% of activated Shungite, reaches 0.24±0.01mm, 0.05mm, or 20.8% greater than the control. In group 3, with 5% of activated Shungite, shell thickness was 0.28±0.02mm, 32.1% greater than in the control group (P≥0.05). These results indicate a significant increase in the thickness and density of eggshells among quail that received Shungite as a supplement to their basic diet. In production settings, these improvements are economically significant. Therefore, feeding Shungite can be considered an effective preventive measure to reduce the number of defective eggs and increase the overall efficiency of production.

Egg quality assessment in the control and experimental groups of quail

To assess the quality of quail eggs when using different concentrations of Shungite, we conducted an organo-physiological examination. First, we assessed the eggs' appearance, the eggshells' color, smell, taste, and firmness of egg contents, and the condition of the shells.

Table 4 provides the results of organic food tests of quail eggs from the experimental groups compared to the control group. The appearance and color of eggs in all the groups satisfy hygienic quality requirements. The shells of eggs in all three groups were pale yellow with bluish-black or brown spots and light blue on the underside. The contents of the eggs were pale yellow, uniform in appearance and color. The smell and taste of the eggs were distinctive and pleasant, with no extraneous odors. No aftertaste was observed in any of the groups. The consistency of the eggs was watery, without lumps, blood, spots, or other foreign bodies. The inspection showed that all quail eggs had clean shells, a rounded shape, and no stains, excrement, damage, or defects.

An important egg quality indicator is its freshness, determined based on the position of the air chamber (Kuleshova 2017). Quail eggs with a chamber height below 2mm are considered edible. In our study, the height of the air chamber ranged between 1 and 2mm in all quail eggs. The yolks of all the eggs were dense, barely visible, with an indistinguishable outline, occupying the center and not moving. The whites of the eggs were dense and translucent white.

The study thus confirms that the quality of quail eggs in the control and experimental groups satisfies the criteria of GOST 31655-2012.

Table 3: Morphometric and quality indicators of quail eggs in the control and experimental groups

Parameters	Units	Groups		
		1 (Control)	2 (Experimental)	3 (Experimental)
Mass of eggs with shells	g	11.23±0.94	11.82±1.13	11.96±0.83
Egg density	g/cm^3	0.79±0.002	0.83±0.002*	0.85±0.001*
Shape index	%	73.1±1.12	75.6±1.05	77.4±1.13
Haugh Unit		93.01±0.82*	92.23±0.65	92.06±0.72*
Mass of egg whites	g	6.71±0.18	7.09±0.16	7.29±0.21
Mass of egg yolks	g	3.40±0.14	3.54±0.11*	3.46±0.13
Mass of eggshell	g	1.12±0.31	1.19±0.12*	1.21±0.08*
Shell thickness at the pointed end	mm	0.19±0.02	0.24±0.01*	0.28±0.02*

Values bearing asterisk differ significantly (P<0.05) in a row.

Table 4: Results of organoleptic examination of eggs

Indicator	Groups		
	1 (Control)	2 (Experimental)	3 (Experimental)
Shell color and condition	Light yellow, with bluish-black or brown spots. Rounded shape, without mechanical damage and dirt		
Egg contents smell	Specific, odorless		
Egg contents taste	Specific, pleasant		
Egg contents consistency	Watery, free of lumps and blood spots		
Condition of the air chamber and its height	Fixed, no more than 2mm		
Condition and position of the yolk	Firm, barely noticeable, but no outline visible, occupying a central position and not moving.		
Density and color of the white	Dense and transparent white		

Table 5: Chemical and mineral composition of egg yolk and eggshells in the control and experimental groups

Parameters	Units	Groups		
		1 (Control)	2 (Experimental)	3 (Experimental)
Eggs				
Mass fraction of moisture	%	74.88±0.93	72.17±0.15	71.98±0.75*
Mass fraction of protein	%	12.15±0.14	12.26±0.15*	12.60±0.15*
Mass fraction of fat	%	15.33±0.18	15.15±0.17	15.68±0.13
Mass fraction of ash	%	0.87±0.01	0.88±0.01*	0.90±0.01*
Iron (Fe)	mg/100g	2.95±0.02*	3.03±0.03*	3.11±0.03*
Calcium (Ca)	mg/100g	48.77±0.55	49.48±0.57	51.17±0.61*
Magnesium (Mg)	mg/100g	14.71±0.17	14.09±0.15*	14.65±0.15*
Sodium (Na)	mg/100g	158.15±1.89	159.05±1.93	158.22±1.90
Phosphorus (P)	mg/100g	191.16±2.03	197.72±2.37	193.55±2.19*
Potassium (K)	mg/100g	141.64±1.69*	143.28±1.72*	149.69±1.88*
Zinc (Zn)	mg/100g	1.19±0.02	1.07±0.01	1.16±0.02
Iodine (I)	mg/100g	0.021±0.001	0.020±0.001	0.023±0.001
Nitrogen (N)	mg/100g	2.02±0.03	1.94±0.03	1.96±0.03
Eggshells				
Mass concentration of calcium	%	27.40±0.33	27.46±0.32*	27.83±0.34*
Mass concentration of magnesium	%	0.51±0.006	0.55±0.007	0.50±0.006*
Mass concentration of phosphorus	%	0.193±0.002*	0.203±0.002*	0.207±0.002*
Mass concentration of silicon	%	0.057±0.001	0.061±0.001	0.061±0.001

Values bearing asterisk differ significantly (P<0.05) in a row.

Chemical and mineral composition of eggs

As indicated in Table 5, the average moisture content of quail meat in the control group amounts to 74.88±0.93%; in group 2, this indicator is somewhat lower at 72.17±0.15%; in group 3, the moisture content is the lowest, reaching only 71.98±0.75% (P<0.05). Thus, in the two experimental groups, the moisture content in quail meat is 3.6 and 3.8% lower compared to the control group.

In our study, the average protein content in the control group amounts to 12.15±0.14%; in group 2, this parameter is higher at 12.26±0.15%; finally, in group 3, crude protein content is 12.60±0.15%, which is 3.5% greater than in the control group and 2.6% higher compared to group 2 (P<0.05).

Regarding fat content, the control and experimental groups have no significant differences. The fat content of quail eggs ranges between 15.15±0.17 and 15.68±0.13%. The content of ash in the control group amounts to 0.87±0.01%. In group 2, it is insignificantly higher at 0.88±0.01%. In group 3, ash content is 0.90±0.01%, 3.3% higher than in the control group (P<0.05). More excellent ash content in the experimental groups can be associated with adding Shungite. Since ash typically contains calcium, phosphorus, magnesium and other microelements, it can increase the total content of minerals in the bird's body and, consequently, in its eggs.

Phosphorus accounts for the bulk of the macronutrients in quail eggs, with an average content of 197.72±2.37mg/100g of eggs in group 2, with 3% activated Shungite (P<0.05). Sodium ranks second with a content of about 158mg/100g in the control group and group 2. The highest potassium content is found in group 3 (149.69±1.88mg/100g); the average calcium content in eggs from group 1 (control) is 48.77±0.55mg/100g, 4.6% lower than in group 3 (P<0.05). Magnesium content reaches about 14 mg/100g in all the groups.

The content of iron in quail eggs in the control group (1) averages at2.95±0.02mg/100g, which is 2.6% lower than in group 2 and 5.1% lower than group 3 (3.11±0.03mg/100g) (P≥0.05). The second most abundant microelement is zinc, whose content reaches 1.16±0.02mg/100g in group 3, 2.5% higher than the control group. Iodine content averages 0.023±0.001mg/100g in group 3, which is 8.6% greater than in the control group. The addition of activated Shungite to the diet of quail in the experimental groups positively affected the content of mineral substances in eggs.

Our study demonstrates that the addition of Shungite to quail diets not only improves productivity but also affects the composition of eggshells. Our analysis of the mineral composition of shells indicates that the calcium content in eggshells is also higher in the two experimental groups. In the control group, the mass concentration of calcium in shells averages 27.40±0.33%; in group 2, this indicator is 0.2% higher compared to the control, reaching 27.46±0.32%; in group 3, the concentration of calcium is 27.53±0.34%, which is 1.5% higher than the control (P<0.05). The mass concentration of magnesium in eggshells ranges between 0.50 and 0.55%.

The mass concentration of phosphorus in eggshells in experimental groups 2 and 3 is 5.18 and 7.25% higher compared to the control group. The mass concentration of silicon in the shells is also elevated in the experimental groups, with an increase of 7.02% in both groups compared to the control. These findings testify to the positive influence of Shungite on the mineral composition of the shells of quail eggs.

Amino acid composition of quail eggs

The analysis of the amino acid composition of quail eggs suggests that the eggs of group 3 are preferred the most (Table 6). Comparing the results, we can note that the content of essential amino acids (EAAs) in eggs remains high in both experimental groups. The threonine content in the control group averages 0.79±0.02mg/100g. In group 2, it remains the same; in group 3, the concentration of threonine drops to 0.74±0.02mg/100g, which is 6.3% less than in the control group and group 2. This may indicate that higher concentrations of the additive do not result in a significant additional increase in threonine levels.

Valine shows the most significant increase, especially in group 2, which highlights the significant influence of Shungite on the content of this amino acid. In the control group, the average valine content is 1.07±0.04mg/100g, 2.7% lower than in group 2. Isoleucine levels remain the same in the control group and group 3, indicating that the experimental conditions do not affect this amino acid; in group 2, however, isoleucine averages at 0.68±0.02mg/100g, which is 0.27mg/100g higher (P<0.05) compared to group 3. A significant increase in leucine is observed in group 3, its content reaching 0.77±0.02mg/100g (P<0.05). This indicates that increased concentrations of the additive have a positive effect.

Both experimental groups show a minor but significant increase in phenylalanine levels, more pronounced in group 2. The difference in valine level between the control and group 2 is 0.16mg/100g, with a 15.2% higher value in the experimental group; in group 3, the level of phenylalanine is increased by 0.94mg/100g, reaching a 5.3% higher value than the control (P<0.05). The effect is more pronounced at higher concentrations of the supplement.

The concentration of methionine is 0.08mg/100g higher in the control group than in group 2. Tryptophan level is somewhat lower in group 2 (0.82±0.01mg/100g) compared to the control group (0.63±0.01mg/100g), yet group 3 shows a 0.6mg/100g higher level (1.23±0.01mg/

Table 6: Mass fraction of essential and nonessential amino acids (%) in quail eggs

Parameters	Group		
	1 (Control)	2 (Experimental)	3 (Experimental)
Essential amino acids			
Threonine	0.79±0.02	0.79±0.03*	0.74±0.02
Valine	1.07±0.04	1.10±0.04	0.99±0.03
Isoleucine	0.43±0.01	0.68±0.02	0.41±0.01
Leucine	0.64±0.01	0.55±0.02	0.77±0.02*
Phenylalanine	0.89±0.02	1.05±0.03*	0.94±0.02*
Methionine	0.51±0.01	0.43±0.01	0.44±0.01
Tryptophan	0.63±0.01	0.82±0.01*	1.23±0.01*
Lysine	1.12±0.03	0.88±0.02	0.84±0.02
Amount of EAAs	6.08±0.15	6.30±0.18	6.32±0.14
Nonessential amino acids			
Arginine	1.40±0.05	1.58±0.06	1.68±0.06*
Histidine	0.56±0.02	0.61±0.03*	0.59±0.02
Aspartic Acid	0.84±0.02	0.97±0.02*	1.03±0.03*
Serine	1.16±0.03*	0.92±0.02	0.89±0.03
Glutamic Acid	0.47±0.02	0.48±0.02	0.50±0.02
Tyrosine	0.65±0.01*	0.66±0.01*	0.59±0.01
Cystine	0.31±0.01	0.53±0.01	0.88±0.02
Proline	1.03±0.02	1.05±0.02	1.23±0.03
Glycine	1.40±0.04	0.74±0.02*	0.89±0.03*
Alanine	0.79±0.02	0.88±0.02*	0.99±0.02*
Amount of NAAs	8.61±0.24	8.35±0.23	9.27±0.27
The total amount of all AAs	14.69±0.39	14.65±0.41	15.59±0.41
Mass fraction of EAAs	41.39	43.01	40.54
Mass fraction of NAAs	58.61	56.99	59.46

Values bearing asterisk differ significantly (P<0.05) in a row.

100g) than the control. Comparing the content of lysine in the studied groups, we observed that group 1, with 1.12±0.03mg/100g, shows a 21.4% higher level compared to group 2; in group 3, the level of lysine drops significantly by 4.5%, hitting 0.84±0.02mg/100g.

We obtained the following results by considering the content of nonessential amino acids (NAAs) in eggs in the control and experimental groups. The concentration of arginine in the control group averages 1.40±0.05mg/100g, which is 11.3% lower than in group 2 and 16.6% lower than in group 3. The concentration of histidine in the control group is 0.56±0.02mg/100g, whereas groups 2 and 3 show an average increase of 0.60±0.02mg/100g, outperforming the control group by 6.7%.

The aspartic acid content in the control group is 0.84±0.02mg/100g. In group 2, the level of this NAA is 0.97±0.02mg/100g, 13.4% higher than in the control; group 3 has 1.03±0.03mg/100g of aspartic acid, which is 18.4% more than the control group ($P<0.05$). Serine content in group 2 is 0.92±0.02mg/100g, or 20.6%, lower than in the control group (1.16±0.03mg/100g). Group 3 has a serine content of 0.89±0.03mg/100g, 3.2% lower than group 2.

The content of tyrosine and proline in the control group is 0.65±0.01 and 1.03±0.02mg/100g, respectively. These levels are 1.5 and 1.9% lower compared to group 2. The concentration of cystine in the control group is 0.31±0.01mg/100g, group 2 shows a higher level of 0.53±0.01mg/100g, outperforming the control group by 41.5%; finally, in group 3, the level of cystine reaches 0.88±0.02mg/100g, 64.7% higher than in the control group.

The control group's alanine content is 0.79±0.02mg/100g, 10.2% lower than group 2 and 20.2% lower than group 3. These results suggest that the concentrations of most amino acids are significantly greater in the two experimental groups (2 and 3) compared to the control (1). The greatest changes are observed in the content of alanine, glycine, arginine, and aspartic acid.

The share of EAAs in eggs amounts to 41.39% in the control group, 43.01% in group 2, and 40.54% in group 3. NAAs account for 58.61% in the control group, a 2.7% lesser share in group 2, and 59.46%, 1.4% more than in the control group 3 ($P<0.05$).

The average total content of amino acids in eggs in the control group is 14.69±0.39mg/100g. In group 2, their concentration amounts to 14.65±0.41mg/100g; in group 3, it reaches 15.59±0.41mg/100g, 5.7% greater than the control and 6.0% higher than in group 2.

Fatty acid composition of quail eggs

Quail eggs contain a wide range of fatty acids, including saturated, monounsaturated, and polyunsaturated. The dynamics of changes in the influence of Shungite on the fatty acid composition of quail eggs is illustrated in Fig. 1. The content of butyric acid in the control group is 0.99%, the level in group 2 is 0.50% lower, and in group 3 it rises to 0.69%. This increase can indicate a significant change in lipid metabolism in response to alterations in quail' diets.

Myristic acid is important to support the structure of cell membranes and participates in lipid metabolism and hormone synthesis. In the two experimental groups, its content ranges from 0.6% to 0.7%. The content of palmitic acid in the control group averages at 22.5%, which is 0.7% and 1.6% lower than in groups 2 and 3, respectively.

The stearic acid content in the experimental groups exceeds that in the control group by 0.21% in group 2 and 0.07% in group 3. This indicates a positive influence of changes in diets on the level of this saturated fatty acid, which does not increase blood cholesterol levels and may have a favorable effect on skin health.

The content of margaric acid reaches 0.15% in the control group and 0.12% in group 2, while group 3 shows a level of 0.17%, somewhat higher than group 2. The concentration of oleic acid in experimental groups is significantly different. Specifically, relative to the control group, group 2 demonstrates a 1.5% increase, and group 3 – a 3.3% increase ($P<0.05$).

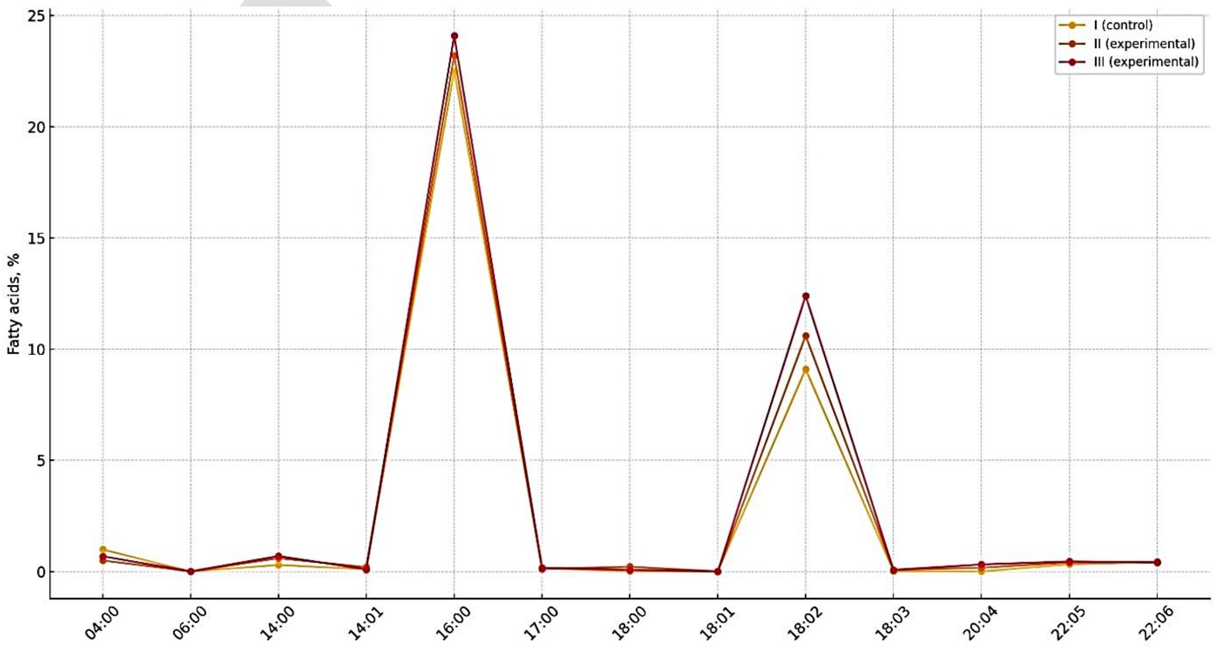

Fig. 1: Diagram of the concentration of fatty acids in quail eggs.

The linoleic acid content is virtually the same in the experimental groups, while the control group has a 0.07% lower level. Group 3 has the greatest content of arachidonic acid, 0.32%, while group 2 has a somewhat lower content (0.17%). The level of docosapentaenoic acid, which is involved in forming cell membranes and protecting nerve cells, is 0.09% higher in group 2 and 0.15% higher in group 3 compared to the control. This increase may indicate improved metabolic activity and changes in lipid metabolism with alterations to quail' diets.

DISCUSSION

The findings convincingly confirm the positive influence of activated Shungite on quail eggs' productive and biochemical parameters. The increase in all key productivity indicators in the Shungite-supplemented groups, especially in the 5% group, emphasizes the effectiveness of activated Shungite. These results are consistent with data from other studies. Buryakov et al. (2023) and Sallam et al. (2023) also demonstrate significant improvements in the productivity of poultry when mineral supplements are used.

The 6.5% increase in egg weight and 9.48% increase in egg mass yield compared to the control group show improved egg quality characteristics. This can bring significant economic benefits in industrial poultry farming, as the increased weight and number of eggs directly lead to higher income (Anang et al. 2023). Consistent with the findings from our study, the use of processed avocado seed, fermented banana peel, and soybean milk dregs in quail rations in this study similarly enhanced egg production, further demonstrating the potential of alternative feed ingredients to optimize poultry performance and reduce feed costs (Ciptaan et al. 2024; Djulardi et al. 2024). The improvement of quail survivability in the group with activated Shungite testifies to the positive effect of this additive on the overall health of poultry. These results align with the findings of Kochish et al. (2022), who also attribute increased egg mass and yield to additives affecting metabolism in poultry. Better survivability among quail in the groups supplemented with Shungite supports the conclusions of Mishina et al. (2018), who point to the positive effect of additives on the natural resistance and average daily weight gain of poultry. Lokapirnasari et al. (2024) admitted that including probiotics combined with organic acidifiers significantly improved various aspects of late-laying quail performance, including egg mass, production efficiency, and the chemical composition of egg yolk.

Changes in the morphological indicators of eggs, such as increased shell thickness and density, suggest greater strength, which is important for minimizing losses during transportation and storage. Previous studies also support this conclusion. Hamilton and Bryden (2021) emphasized that shell thickness is critical in determining the egg's strength and resistance to mechanical damage. In our study, the thickness of eggshells in the experimental groups was 28% greater than in the control group, consistent with the results of similar research. Nurkholis et al. (2023) found that tobacco additives significantly improved yolk color and shell thickness in quail eggs while not impacting egg weight, egg shape index, shell weight, and Haugh unit, indicating safety up to 2% tobacco addition.

Quail eggs contain large amounts of macro and microelements. The addition of activated Shungite to the quail diet positively affected the mineral composition of eggs and shells. The phosphorus content in the eggs of the experimental groups reached 197.72±2.37mg/100g in group 2, which is a high content, and the content of iron and zinc also increased compared to the control group. The highest potassium content was observed in group 3, and the calcium level in group 3 was 4.6% higher than in the control. Increased content of macro and microelements, such as phosphorus, calcium, and silicon, in eggs and eggshells confirms the positive effect of Shungite on their mineral composition. These findings are consistent with the results of Świątkiewicz et al. (2018) and Ghasemi et al. (2022), who also report an improvement in the mineral composition of eggs with the addition of various supplements to poultry diets. The calcium content in eggshells in group 3 was 1.5% higher than in the control group, confirming the positive influence of Shungite on mineral metabolism. The findings of this study align with those of Naligwu et al. (2024) and Utrami and Akbar (2025), where the supplementation of fermented leaf meal (FLM) similarly resulted in better egg quality and mineral content, suggesting that various feed additives can have synergistic effects on quail productivity and nutritional value.

The biochemical analysis shows an increase in the content of protein and fat in eggs, supporting previous findings, for example, Cartoni Mancinelli et al. (2022) and Vlaicu et al. (2021), indicating the importance of polyunsaturated fatty acids and antioxidants for the nutritional value of eggs. According to the literature, crude protein content in quail eggs reaches 11-14%. This value may vary depending on the age of the quail and feeding and rearing conditions (Dymkov et al. 2019). Increased levels of oleic and docosapentaenoic acid in group 3 confirm the positive effect of Shungite on lipid metabolism and the improved nutritional properties of eggs, which may have a favorable effect on consumer health. Similarly, Ali and Abd El-Aziz (2019) reports that quail eggs are rich in polyunsaturated fatty acids and antioxidants, which benefit cardiovascular and general health. Wang et al. (2022) admitted that oleic acid, which is the primary monounsaturated fatty acid and is contained in quail eggs, is renowned for its beneficial properties: lowering cholesterol levels, antioxidant effects, and reducing inflammation.

Our findings, consistent with previous studies, confirm that activated Shungite improves quail productivity and quail eggs' quality and nutritional value. The introduction of Shungite into the poultry diet is an effective method for increasing the efficiency of poultry farming and improving the quality of products.

Conclusion

The study demonstrated that the addition of activated Shungite into the diet of quail positively affects their productivity and the quality indicators of their eggs. The introduction of activated Shungite into the feed mixture leads to a significant improvement in egg production, increased egg mass, and greater shell strength. The increased amino acid and fatty acid content of eggs indicate an improvement in their nutritional value, making such eggs more beneficial to consumers.

It is also worth noting the positive effect of Shungite on quail survivability, which may suggest its general health-improving effect. Thus, activated Shungite can be considered a promising additive to poultry diets that can increase the economic efficiency of quail egg production and improve their quality.

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