



## Hematological blood profile of pigs fed with protein powder extracted from the black soldier fly (*Hermetia illucens*)

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The search for alternatives to traditional soybean meal, a significant share of the protein components of pig feed, is particularly relevant. Using insect-based protein products is one of the most promising solutions in this area. The research was carried out on hybrid young pigs for 70 days. The young pigs of the control group were fed a nutrient-balanced diet, while the second group was fed a black soldier fly (*Hermetia illucens*) larvae-based protein powder supplement in 20 kg per tonne of feed. Using the protein supplement in the piglet diet increased piglet survival and live weight gain, proving the supplement's effectiveness in improving pig production. An increase in average daily live weight gain of 23.3% with an improved feed conversion of 11.7% indicates improved nutrient absorption and increased efficiency of protein metabolism. Biochemical tests showed a higher level of total protein, an increase in globulin concentration, and a decrease in albumin, indicating a more active metabolism and a stronger immune response. A slight increase in the De Ritis ratio is still within the physiological norm. A 24.8% improvement in calcium-phosphorus metabolism caused by an increase in calcium concentration and a decrease in phosphorus shows the supplement's impact on the formation of the musculoskeletal system. Higher glucose levels indicate improved energy metabolism. The morphological composition of the blood shows changes in the hemopoiesis and immune system: an increase in mean corpuscular hemoglobin and an increase in segmented neutrophils with a decrease in the level of lymphocytes and monocytes indicate the adaptation of the body to the conditions of feeding from insect protein powder.

**Keywords:** piglets; insects; protein powder; live weight gain; blood; biochemical parameters.

### Introduction

Pork is one of the world's rapidly growing livestock industries, leading to increased attention to the efficiency of production processes and cost reduction. Feed is the main cost item in pig production, which accounts for up to 70% of total costs. Protein components play a unique role in the feed structure, as they are critical for ensuring high growth rates and animal health (Ivanova et al., 2017). Protein feeds account for 60–70% of the total cost of the diet.

The search for new approaches to optimizing feed resources will increase the economic efficiency of the industry (Razanova et al., 2023; Montironi et al., 2024). Fishmeal and soybean meal are traditional sources of protein in the pig industry. Fishmeal is known for its high protein content and balanced amino acid composition, but its use is associated with high costs and limited resources. Overfishing and the reduction of land and water resources for growing crops have increased the cost of these protein ingredients. The price of soybean meal fluctuates due to competition with the food industry. In such a situation, finding alternative solutions to provide production animals with feed protein sources is becoming crucial for agricultural development. Considering the rising costs of protein sources, particularly soybean meal, measures to reduce the protein content of animal feeds while maintaining optimal productivity levels are being actively taken (Vieira et al., 2016). da Cruz et al. (2024) believe that using asparagine protease in feeds with reduced crude protein and amino acid content causes more efficient nutrient absorption, reducing the need for high-protein ingredients. Optimal animal growth and productivity are achieved through improved protein and amino acid digestibility. This contributes to increased economic profitability and ensures greater environmental sustainability of the industry, reducing the negative impact on the environment by reducing nitrogen emissions. Consumption of various dietary supplements helps to increase pig growth rates, improves the digestibility of the main components of the diet, maintains the health of the digestive system, and contributes to the economic efficiency of production (Zhang et al., 2024).

Cheng et al. (2024) conducted a study aimed at addressing the shortage of high-quality protein resources by examining the effect of replacing soybean meal with different levels of enzymolysis-fermentation compound protein feed in the diets of pigs (Duroc × Landrace × Yorkshire) during the growing and finishing stages. The study focused on growth performance, nutrient digestibility, carcass traits, and meat quality. Ahn et al. (2019) also confirm the positive effect of the usage of fermented soybean meal in pig feeding on these parameters.

More and more attention is being paid to using insects as a protein source in the search for alternative solutions (DiGiacomo & Leury, 2019). Insects are highly nutritious, rapidly renewable resources that have the potential to become a major feed component in the future. Insects are characterized by high protein content, which exceeds the level of plant protein, contain 18 types of amino acids, including all the essential ones, and are a valuable source of vitamins and minerals (MacEvilly, 2000). According to numerous studies, using insect protein feeds in animal and poultry feeding provides better results than traditional protein sources (Barkar & Trybuntsova, 2022). Experiments with the partial replacement of fish meal and soybean meal with insect protein products have positively affected pig performance and economic efficiency (Altmann et al., 2019). Sánchez-Muros et al. (2014) also report that insects are actively used as an alternative source of feed ingredients in the livestock industry.

The larvae of the black soldier fly (*Hermetia illucens*) and the yellow mealworm beetle (*Tenebrio molitor*) are among the most suitable insect species for fodder use. These insects are characterized by high nutrient content, ease of breeding, and environmental sustainability (Ramos-Elorduy et al., 2002) and have nutritional value (Sánchez-Muros et al., 2014).

Animal productivity depends on many factors, including health, growth rates, and the ability to digest feed efficiently (Kouamo et al., 2015; Razanova et al., 2023). Numerous studies prove that a balanced diet of essential nutrients significantly impacts pig performance and hematological parameters (Ghomsi et al., 2024; Poberezhets et al., 2023). Higher productivity can be achieved by maintaining good ani-

mal health, often assessed by analyzing hematological and biochemical parameters (Perri et al., 2017; Palova et al., 2019; Martins et al., 2020). The changes in pig metabolic dynamics can be assessed by blood tests, which, despite the constancy of physiological norms, make it possible to trace the influence of the studied factor on metabolic processes (Friendship et al., 1984; Zynoviev, 2014). Blood tests assess various metabolites and other components in the animal body, which are crucial factors in determining the physiological (Khan & Zafar, 2005), nutritional, and pathological status of the organism (Aderemi, 2004; Doyle, 2006) and their relationship with the environment (Ovuru & Ekweozor, 2004; Isaac et al., 2013). Hematological studies can be used to monitor nutritional stress (Togun & Oseni, 2005). Thus, according to the available data, the effect of insect larvae protein supplementation on weaned piglets remains insufficiently studied.

The study aimed to investigate the morphological and biochemical parameters of pig blood when fed with black soldier fly (*Hermetia illucens*) larvae-based protein powder supplement in three-phase liquid feeding of piglets from growing up to the age of 70 days.

## Materials and methods

All experimental procedures were carried out following the General Ethical Principles for Experiments on Animals (Ukraine, 2001), which complies with the provisions of the Law of Ukraine On the Protection of Animals from Cruelty (No. 3447-IV of 21.06.2006, as amended on 15.07.2021) (<https://zakon.rada.gov.ua/laws/show/3447-15#n8>) and the provisions of the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (ETS No. 123, Strasbourg, 1986) (<https://rm.coe.int/168007a67b>).

The experiment was conducted on hybrid young pigs of the F2 generation, obtained by crossing Camborough pigs (Large White × Landrace) with boars of the PIC 337 line at LLC SPE Globinsky Pig Complex (Ukraine). The experiment lasted for 70 days, during which growth performance and biochemical and morphological parameters of blood were evaluated. To experiment, we selected 104 piglets with an average initial live weight of at least 4.5 kg, divided into two groups of 52 heads each. The distribution was carried out using analog groups, taking into account the origin, age, sex, and live weight, which ensured homogeneity of the experimental conditions.

The study examined the effect of black soldier fly (*Hermetia illucens*) larvae-based protein powder supplement. A high nutrient content characterizes this supplement; in particular, it contains 56-57% protein, 9-10% fat, 4% moisture, and 7% ash. For the study, we used complete feed; its composition met the pigs' requirements and provided them with all the necessary nutrients. In the control group, piglets were fed according to the standard scheme from the beginning of

growing up: pre-starter 0-9, pre-starter 9-12, and starter ration 12-25. Feed was prepared at the HydroMixPro feed kitchen, which ensured the following of the recipe and feeding curve adopted by the farm. This ensured a stable and balanced diet for the piglets before transitioning to the fattening unit. The experimental group was fed with pre-starter 0-9 using a similar scheme and the same feed kitchen. From day 18 to day 20, pre-starter 9-12 was introduced into the piglet diet with the addition of protein powder in the amount of 20 kg per ton of feed. The transition was carried out gradually: on the first day, 30% of pre-starter 9-12 and 70% of pre-starter 0-9 were used; on the second day, 50%/50% were used; and on the third day, 70%/30% were used. On day 21, the feed contained a full 9-12 pre-starter with the addition of insect larvae protein powder. On day 32, all piglets were fed starter 12-25 with the same protein powder. The transition to the new feed lasted three days, with a similar gradual increase in the share of new feed. The feed consisted of corn, wheat, barley, soybean meal and oil, soy protein concentrate, protein, vitamin and mineral supplements. The diet's nutritional value in digestible protein was 18.8 g for pre-starter 9-12 and 18.3 g for starter 12-25.

The maintenance and feeding of the pigs were the same in both groups. All piglets had free access to feed and water throughout the research period. In both groups, veterinary treatments were carried out according to a single scheme, which ensured no influence of different treatment measures on the experiment results. This approach ensured the correctness of comparing the effectiveness of other diets. It allowed us to objectively assess the effect of protein powder supplementation on piglets' growth, development, and physiological condition.

The material for hematological studies was pig blood collected on day 70. The anticoagulant heparin was used to prevent blood clotting. The blood of ten pigs was analyzed: five head of the experimental and five head of the control group. Biochemical and morphological parameters of blood were carried out in the laboratory of the Research Center for Biosafety and Environmental Control of Agricultural Resources of Dnipro State Agrarian and Economic University (UBCC certificate No. LB 13/22 of 26.12.2022) following approved methods.

Statistica software analyzed statistical results, calculating the mean value ( $\bar{x}$ ) and standard deviation ( $\pm$  SD). One-way ANOVA analysis of variance was used to determine statistically significant differences between the mean values for the respective groups of pigs. The results at  $p < 0.05$  were considered statistically significant.

## Results

Adding a black soldier fly (*Hermetia illucens*) larvae-based protein powder supplement to the piglet diet positively affected productivity. When piglets were fed with a protein supplement from insect larvae, they gained more live weight. In this group, the absolute increase in live weight was 23.1% higher ( $P < 0.001$ , Table 1).

**Table 1**  
Productive parameters of suckling piglets fed with protein powder from larvae of *Hermetia illucens* ( $\bar{x} \pm$  SD,  $n = 52$ , experiment duration 70 days)

Parameter	Main diet	Protein powder from larvae of <i>H. illucens</i> (20 kg per ton of feed)
Piglet survival rate at the end of the experimental period, %	97.8 $\pm$ 3.1	98.5 $\pm$ 2.8
Absolute gain during the supplement feeding period, kg	19.12 $\pm$ 0.82	23.53 $\pm$ 0.69**
Piglet average daily live weight gain during the supplement feeding period	374 $\pm$ 9	461 $\pm$ 8***
Piglet live weight gain during the supplement feeding period, %	127 $\pm$ 2	136 $\pm$ 2***
Feed conversion	1.62 $\pm$ 0.07	1.43 $\pm$ 0.05***

Note: \* –  $P < 0.05$ , \*\* –  $P < 0.01$ , \*\*\*  $P = 0.001$ .

Furthermore, using protein powder contributed to better piglet live weight gain and positively affected average daily weight gain. The average daily live weight gain of the piglets was 23.3% higher ( $P < 0.001$ ), with an 11.7% better feed conversion during the supplement feeding period. Piglet survival during the experimental period was slightly better in the experimental group, where this parameter was 0.68% higher than in the control group. This increase in survival rate resulted in an increase in the total number of pigs at the end of the

experiment, providing for a higher output. Thus, this supplement positively affected piglet productivity, leading to further research and implementation to improve pig production efficiency.

Differences between the groups were found when the biochemical blood test parameters were analyzed. The experimental groups fed a protein supplement of insect larvae protein powder as part of the diet had a slightly higher total protein content due to an increase in the rate of metabolic processes (Table 2).

**Table 2**The blood biochemical parameters of pigs fed with protein powder from larvae of *Hermetia illucens* for 70 days ( $x \pm SD$ ,  $n = 5$ )

Parameter	Main diet	Protein powder from larvae of <i>H. illucens</i> (20 kg per ton of feed)
Total protein, g/L	62.2 ± 0.9	62.3 ± 0.8
Albumins, g/L	34.1 ± 0.4	32.8 ± 0.5*
Globulins, g/L	28.2 ± 0.5	29.6 ± 1.3
Protein coefficient, units	1.204 ± 0.026	1.112 ± 0.039*
Urea, mmol/L	2.961 ± 0.133	3.261 ± 0.194*
Blood Urea Nitrogen, mg / %	5.661 ± 0.103	6.240 ± 0.223**
Creatinine, µM/L	60.0 ± 1.6	71.2 ± 2.3***
Aspartate aminotransferase (AST), mmol/L	37.8 ± 1.7	47.8 ± 2.1***
Alanine aminotransferase (ALT), mmol/L	48.6 ± 1.5	57.2 ± 2.2***
De Ritis ratio, units	0.783 ± 0.049	0.841 ± 0.048*
Alkaline phosphatase, units/L	637 ± 25	867 ± 43***
Glucose, mM/L	5.38 ± 0.15	5.72 ± 0.10**
Calcium, mmol/L	2.681 ± 0.037	2.803 ± 0.063*
Inorganic phosphorus, mmol/L	2.463 ± 0.051	2.022 ± 0.078***
Ca/P, units	1.091 ± 0.031	1.360 ± 0.037***

Note: see Table 1.

Changes in the concentration of protein fractions in the blood serum were found when piglets were fed a protein supplement; namely, the albumin content decreased by 3.8% due to more intensive growth, and the globulin content increased by 4.9% ( $P < 0.05$ ). Still, the protein coefficient was lower than the control by 7.6% ( $P < 0.05$ ). Urea nitrogen in the blood serum of the experimental group of pigs was higher by 10.2% ( $P < 0.05$ ). There were significant changes in the creatinine concentration in the experimental group, an increase of 18.7% ( $P < 0.01$ ). The variability of urea in the experimental group was the highest at 13.3%. According to the research results, the content of alanine aminotransferase and aspartate aminotransferase in the blood plasma of experimental pigs was higher by 26.4% and 17.7%, respectively, at  $P < 0.01$  compared to control pigs. The obtained parameters impacted the De Ritis ratio increase in the experimental group by 7.7%, but no reliable confirmation of such an increase was found. The De Ritis ratio variability in the control group was relatively high (14.2%), while in the experimental group, it was 12.6%. The level of inorganic phosphorus of the experimental piglets was lower

by 7.9% ( $P < 0.01$ ), and calcium, on the contrary, was higher by 4.5%; it had a particular effect on the calcium-phosphorus metabolism being higher by 24.8% in this group ( $P < 0.01$ ). The obtained data indicate that the consumption of a black soldier fly (*Hermetia illucens*) larvae-based protein powder supplement increased blood glucose by 5.9% ( $P < 0.05$ ) over the control. Considering the limits of standard biochemical pig parameters, no pathologies were found in the blood of the experimental animals, which is essential when feeding the recommended supplement.

We have found that the level of hematopoiesis parameters depends on the piglet feeding characteristics. Consumption of insect protein powder supplement by the experimental group of pigs caused a slight increase in hemoglobin, a decrease in erythrocytes and hematocrit, color index, and erythrocyte sedimentation rate (ESR).

In the experimental group, we noted a 4.0% mean corpuscular hemoglobin increase and a 2.7% mean corpuscular hemoglobin concentration increase ( $P < 0.05$ ) compared to the control group (Table 3).

**Table 3**Blood morphological composition of pigs fed with protein powder from larvae of *Hermetia illucens* for 70 days ( $x \pm SD$ ,  $n = 5$ )

Parameter	Main diet	Protein powder from larvae of <i>H. illucens</i> (20 kg per ton of feed)
Hemoglobin, g/L	113.0 ± 4.3	113.4 ± 1.1
Haematopoiesis, %	35.1 ± 0.7	34.0 ± 0.9
Erythrocytes, T/L	6.61 ± 0.10	6.45 ± 0.11
MCV (mean corpuscular volume), fL	53.2 ± 1.6	54.1 ± 0.3
MCH (mean corpuscular hemoglobin), pg	17.4 ± 0.3	18.1 ± 0.1**
MCHC (mean corpuscular hemoglobin concentration), *10 g/L	32.5 ± 0.3	33.4 ± 0.1*
Color index, units	0.838 ± 0.029	0.872 ± 0.005*
ESR, mm/hr	4.22 ± 0.37	4.61 ± 0.24
Platelets, G/L	301.2 ± 13.7	441.2 ± 5.7***
Leukocytes, G/L	22.4 ± 0.8	24.7 ± 1.6*
Leukogram, %:		
basophils, %	0	0
eosinophils	3.60 ± 0.24	3.60 ± 0.51
banded	3.01 ± 0.45	1.81 ± 0.19***
segmented	36.8 ± 1.1	41.2 ± 0.6***
lymphocytes	58.0 ± 2.0	53.8 ± 0.6***
monocytes	4.4 ± 0.4	3.2 ± 0.3***

Note: see Table 1.

The analysis of the leukogram showed an increase in the percentage of segmented neutrophils by 11.9% ( $P < 0.01$ ), a decrease in the percentage of banded neutrophils by 40.0% ( $P < 0.01$ ), lymphocytes by 7.2% ( $P < 0.05$ ), monocytes by 27.3% ( $P < 0.05$ ). The level of eosinophils was the same as that of the control. The coefficient of variation of the percentage of banded neutrophils in the control group was 33.3%; in the experimental group, it was slightly lower, 24.9%. High limits of variation were also found in the number of monocytes (20.3–26.2%).

## Discussion

The use of insects as an ingredient in animal feed has not attracted much interest recently. However, the industry increasingly seeks

alternative protein sources as global prices for traditional feed ingredients rise. Interest in replacing expensive protein ingredients has grown significantly. The black soldier fly, housefly, yellow mealworm beetle, silkworm, and several species of grasshoppers are among the most promising insect species for industrial use. Their high efficiency is due to their rapid growth, rich nutritional composition, and ability to convert organic waste into valuable feed protein.

The use of insect-based feed supplements positively affects animal breeding results. Including such components helps increase growth performance, improve nutrient absorption, and improve the biochemical and hematological parameters of the blood. Insect feed additives are becoming a promising ingredient for balanced diets that ensure healthy growth and development of animals due to the high content of easily digestible protein, fatty acids, and trace elements

(Barkar & Trybuntsova, 2022). The results indicate that experimental group pigs had better adapted to feed with protein powder of the black soldier fly (*Hermetia illucens*) insects, contributing to a decrease in feed consumption by 11.7% per unit of gain.

Tengan et al. (2012) found no significant differences in hematological parameters in research analyzing the growth, hematological profile, and carcass characteristics of pigs fed diets with different soy milk residue contents. These observations demonstrate the importance of rational feed choice in increasing nutrient utilization efficiency. Replacing 50% of fermented soybean meal during the growing and finishing period improves pig growth performance without affecting the blood profile. It does not lead to significant changes in serum biochemical parameters (Ahn et al., 2019). The intensity of metabolic processes, as well as redox reactions that determine the overall level of metabolism in pigs, depends on the indicators of the morphological and biochemical composition of the blood (Petrenko, 2014).

Serum biochemical parameters are essential indicators of nutrient metabolism and functionality of animal tissues and organs. They give helpful information about pigs' physiological state and health, contributing to the effective monitoring and correction of their diet and housing conditions (Bindiuh, 2013; Pundyk & Tesak, 2021; Lu et al., 2022). Blood parameters are essential during active piglet growth, as this stage is characterized by intensive metabolic processes requiring optimal protein supply. Total serum protein is one of the key parameters reflecting the state of protein nutrition. Its concentration is considered to be an indicator of the completeness of the diet in terms of protein content and the efficiency of absorption of nutrients necessary for the normal development of animals. Insufficient protein levels indicate protein deficiency, negatively affecting growth and development. An increased total protein concentration indicates improved protein metabolism and the body's supply of important nutrients. The research conducted by Abonyi et al. (2018) showed no significant differences in the total serum protein levels in two pig breeds.

In the current study, the amount of total protein in the blood serum of piglets fed with protein powder from larvae of the black soldier fly was slightly higher (62.4 vs. 62.5 g/L in the control). It is caused by improved absorption of nutrients, which ensures more efficient use of protein from the feed. As a result, the animal body receives sufficient amino acids necessary for protein synthesis, which positively affects muscle tissue formation and overall performance.

Optimization of protein metabolism provides favorable conditions for the active growth of young animals, increasing the rate of live weight gain and strengthening physiological functions, which is confirmed by a higher average daily live weight gain of 23.3% ( $P < 0.001$ ). In addition, animals' general health and resistance to technological stress and diseases improve livestock survival.

It proves that using insect protein supplements from *H. illucens* contributes to the adaptive capabilities of pig improvement, which is an important factor for effective livestock production in modern production conditions. Furthermore, serum biochemical parameters included the assessment of urea and creatinine. Urea is the main nitrogenous end product formed by the catabolism of amino acids not used for pigs' biosynthetic processes (Perri et al., 2017). Thus, its concentration reflects the degree of muscle loss and changes in protein intake and utilization efficiency (Orororo et al., 2014; Pawlowsky et al., 2017). The research results show an insignificant increase in the urea content in the blood of the experimental pigs. Creatinine is a product of biochemical reactions that occur in muscle tissue. Creatinine levels in the blood of pigs vary depending on their feeding habits. This tendency is confirmed by current research.

In the weaned piglet blood profile results, a decrease of blood urea nitrogen and an increase of insulin-like growth factor were observed as dried mealworm was increased in the diet. However, the supplementation of dried mealworms did not significantly affect blood IgG and IgA concentration as an immune response (Jin et al., 2016). Dried mealworm supplementation increased feed intake and nutrient digestibility without harming immune response. The obtained results on feeding the supplement of protein powder from *H. illucens* revealed an increase of blood urea nitrogen by 10.2% and globulins by 4.9% ( $P < 0.05$ ), which are essential components of the immune

system. Analyzing the obtained results, higher activity of transamination enzymes, such as alanine aminotransferase (ALT) and aspartate aminotransferase (AST) in the blood serum of piglets of the experimental group, should be noted.

Mineral elements are key in ensuring normal growth and development of young animals. Calcium and phosphorus are particularly important, being the main components of bone formation and contributing to regulating muscle contractions and maintaining other vital body functions. Considering the importance of these elements for physiological processes, the current study focused on assessing the effect of the feed supplement on mineral metabolism, mainly by assessing the concentration of calcium and phosphorus in the blood serum of experimental piglets. This approach makes it possible to evaluate the supplement's effectiveness in improving mineral nutrition and the general physiological state of animals. High activity of alkaline phosphatase and increased inorganic phosphorus content is found in the piglets' blood, probably due to intensive growth and development processes at this age. Increased alkaline phosphatase levels are typical for young animals, as this enzyme is actively involved in bone formation. This fact is confirmed by Levchenko et al. (2002), who point to a correlation between the activity of alkaline phosphatase and the growth rate of young animals, which makes it essential to control these biochemical parameters to assess the physiological state of animals.

Phosphorus is key in the body's metabolic processes, involving bone formation, energy metabolism, and cell membrane function. According to Yefimov et al. (2010), its concentration in blood serum varies depending on the animals' age and physiological state. These values can vary considerably in young pigs due to intensive growth, increased use of phosphorus for bone mineralization, and other developmental processes. These fluctuations ensure optimal diet phosphorus levels, promoting healthy development and high animal performance. The feed supplement E-selenium affects calcium-phosphorus metabolism, which is probably due to an indirect effect on the processes of bone renewal, which are activated by increased body weight gain. The mechanism may explain the increase in total calcium concentration and the bone isoform of alkaline phosphatase, an enzyme marker of bone cell activity. The correlation between the activity of alkaline phosphatase and live weight gain was confirmed by Kuzmenko (2012). The research results proved that *H. illucens* protein powder added to the diet increased the calcium level in the blood of the experimental group piglets by 4.5% ( $P < 0.05$ ) compared to the control group. This indicates a positive effect of the feed supplement on the calcium absorption processes and the improvement of mineral metabolism.

The increased concentration of this element in the blood may be caused by the increased bioavailability of nutrients in the body. This optimization of metabolism contributes to the harmonious development of the piglet's musculoskeletal system, which is essential for forming a strong skeleton and normal muscle function. As a result, it improves productivity and increases animal adaptivity. In the current study, consuming insect protein powder by piglets increased calcium-phosphorus metabolism by 24.8% ( $P < 0.01$ ).

Glucose levels are the primary source of energy for metabolic processes in animals. Optimal glucose concentration supports the normal functioning of vital organs and systems. In the study, the glucose level was 5.9% higher in the blood of the experimental pigs.

According to Abonyi et al. (2018), serum albumin levels, as an important blood transport protein, do not differ significantly between pig breeds. According to the results of the current study, albumin levels were normal in both groups. However, its concentration was higher in the experimental group of pigs fed additionally by insect protein powder supplementation. The morphological profile of pig blood is an essential indicator of the body, as it is closely related to its vital activity. It reflects changes in physiological processes and is a key indicator for assessing adaptive responses that ensure the maintenance of homeostasis and stable functioning of body systems under various factors. Analyzing these parameters allows the timely detection of metabolic disorders and the effectiveness of feed supplements affecting animal productivity and health.

Novakovska (2020) found an increase in hemoglobin by 8% and erythrocytes by 14% during the fattening period of pigs due to adding cellulose amyolytic supplement to the diet. There was a high correlation between the number of erythrocytes in the blood and the weight of muscle tissue, with a correlation coefficient of +0.72. This indicates a close correlation between the volume of circulating blood and the level of carcass meatiness, allowing these indicators to be used to assess the productivity of pigs.

Thus, the morphological and biochemical composition of the blood are essential markers of the physiological state of animals, reflecting the efficiency of their feeding, metabolism, and adaptive capacity (Khalak et al., 2024). Various biologically active supplements are added to the pig diet to increase their body's resistance.

In particular, the use of the drug Jodis-concentrate makes it possible to increase the number of red blood cells in the blood of animals (Karpovskiy et al., 2013), the use of "E-selenium" causes changes in specific biochemical parameters, and a decrease in serum activity of AST, creatine kinase and alkaline phosphatase (Yefimov, 2015). In the current study, adding insect protein powder of the black soldier fly (*Hermetia illucens*) to the piglet diet caused a slight increase in blood hemoglobin and a decrease in red blood cells.

The health of animals can be assessed by the concentration of leukocytes in the blood because they play a key role in the body's immune system. Leukocytes provide an immune response to infectious pathogens. The mean corpuscular hemoglobin is an essential indicator of the efficiency of oxygen transport to tissues. This parameter measures the hemoglobin saturation level of red blood cells, characterized by mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC). Optimal or high saturation levels ensure efficient oxygen transportation. The mean hemoglobin concentration in the blood of the experimental piglets in the study was 2.7% higher, MCHC was higher by 3.9%, and the MCH by 3.9% ( $P < 0.05$ ) compared to the control.

We proved that when young pigs consumed the protein powder of black soldier fly (*Hermetia illucens*), the number of leukocytes in the blood was 10.2% higher ( $P < 0.05$ ), indicating an increase in animal immunity.

Platelets are important in blood clotting processes and are responsible for the body's immune system. They keep the vascular wall intact and are activated in response to tissue damage, a key mechanism for preventing blood loss and protecting the body from infections. The blood of the experimental pigs contained 46.5% ( $P < 0.01$ ) more platelets.

No signs of pathologies were found in the experimental animals, considering the normal limits of biochemical and morphological blood parameters for pigs. This indicates that feeding the recommended supplement does not affect the physiological processes in the body of animals and is safe for their health. This result demonstrates the importance of choosing the right feed supplements to ensure the proper physiological state of pigs.

## Conclusions

Using *Hermetia illucens* larvae-based protein powder supplement in piglet feeding increased livestock safety, average daily live weight gain by 23.3%, and feed conversion efficiency by 11.7%.

Adding *H. illucens* larvae-based protein powder supplement to the piglet diet had a positive effect on protein and mineral metabolism, reflected in an increase of total protein, globulins, creatinine, and glucose in the blood, as well as in the improvement of calcium-phosphorus metabolism strengthening the musculoskeletal system of the piglets. The morphological analysis of the blood showed adaptive changes in the hemopoiesis and immunity system, in particular, an increase in mean corpuscular hemoglobin and an increase in segmented neutrophils, indicating an increase in immune response without detecting pathological changes in animals.

The authors declare no conflicts of interests.

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