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The influence of hermanium and iron nanocomposites on saturated fatty acid levels in pig blood, depending on vegetative regulation

Svitlana Kravchuk
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0008-0767-9032

Olena Zhurenko
Doctor of Veterinary Sciences, Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-4933-0372

Dmytro Kryvoruchko
PhD in Veterinary Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-1788-6090

Vitaly Zhurenko
PhD in Veterinary Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-2097-9212

Ihor Hryshchuk*
Doctor of Philosophy, Assistant Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-2571-6876

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**Corresponding author*

Abstract. The study's relevance is related to developing new methods for increasing pig productivity by balancing metabolic processes in the body. The main objective was to determine changes in saturated fatty acid levels in pigs when using a feed supplement of nanoaquachelates, taking into account individual characteristics of the body. The experimental groups of animals were formed using a pulsometric study, which resulted in three groups of 10 pigs, which were then divided into two groups, control and experimental, with five animals each. The experimental group was given a mixture of nano-compounds of iron in a dose of 3 mg/day and germanium in a dose of 0.01 mg/day. The content of saturated fatty acids was assessed using gas chromatography. The results of the study showed that the blood of pigs in the control group with normotonia had increased levels of saturated fatty acids: myristic ($P < 0.01$), heptadecanoic ($P < 0.05$), and behenic ($P < 0.01$). In the blood of pigs in the experimental group with sympathicotonia, the content of saturated fatty acids decreased: myristic ($P < 0.01$), pentadecanoic ($P < 0.01$), heptadecanoic ($P < 0.01$), and behenic ($P < 0.01$). In the blood of pigs in the control group with vagotonia, the content of saturated fatty acids increased compared to the experimental group. It was found that fatty acids with the highest proportion in experimental normotonic pigs, such as palmitic acid, were 12.1% lower, and stearic acid was 10.7% lower ($P < 0.01$). In control pigs with sympathotonics, the palmitic acid content was 15.4% higher ($P < 0.01$) and stearic acid was 17.8% higher ($P < 0.001$). In experimental pigs with vagotonia, the palmitic acid content was lower by 14.8% ($P < 0.01$) and stearic acid by 11.8% ($P < 0.001$). The results of the study showed a positive effect of the mixture of iron and germanium nanocomposites on the indicators of saturated fatty acid metabolism and the formation of pigs following the individual characteristics of the organism, which improved the accuracy of the data obtained

Keywords: metabolism; nanopreparation; productive animals; autonomic nervous system; lipids

Introduction

Modern pig breeding and fattening farms have a well-established system for producing animal raw materials based on cyclicality and stable livestock productivity. Proper regulation of this system requires a balanced diet that is adjusted at all stages of pig rearing. However, this technology has a significant drawback: when attempting to reduce the time needed for an animal to reach the required body weight, problems arise with metabolic processes in its body. This leads to a significant decline in productivity and further economic losses for the farm. Attempts to solve this problem involve adding feed additives to the pigs' diet to improve the stability of homeostasis in the animal and compensate for the adverse effects of intensive metabolism.

S. Rao *et al*. (2023) identified several methods for identifying factors related to the animal and how much and what feed additives it needs to consume to improve body weight gain. This chain omits one point: it does not consider the individual characteristics of pigs, which reduces the effectiveness of the feed additives. Z.X. Rao *et al. (*2023) proved that feed additives in pig farming are in high demand. Many different feed additives exist, including various acidifiers, probiotics, minerals, etc. The composition of these feed additives varies widely and theoretically affects the growth rate of animals and improves homeostasis. Despite such positive prospects for using these additives in pig feed, their cost must be economically viable for the farm. In addition, they are also designed to help pigs adapt to the effects of negative environmental factors, which is especially important during weaning, regrouping and relocation to new places depending on the rearing cycle.

Several factors contribute to increased pig productivity: diet, genetics, housing conditions, metabolic rate and individual characteristics. Q. Tang *et al.* (2023) found that maintaining stable pig productivity largely depends on lipid metabolism, especially fatty acids. It has been proven that animals need a significant amount of amino acids for active muscle growth. Still, with insufficient energy metabolism, fatty acids are used as fuel, reducing the herd's productivity. To prevent this, it is necessary to adjust lipid metabolism. The main goal of increasing pig productivity is stabilising lipolysis and lipogenesis, with particular attention paid to fatty acids.

Y. Feng *et al.* (2023) studied the effectiveness of feed additives in lipid metabolism in pigs. It was established that the primary goal was to improve lipid metabolism and use non-traditional feed, which would be economically beneficial for the farm. Grape seed extract was used for pigs during the fattening period. The positive results included improved productivity ($P < 0.05$), increased high-density lipoprotein content, and reduced triacylglycerol and total cholesterol levels in the animals ($P < 0.05$). At the same time, the antioxidant protection status improved. Y. Liu *et al.* (2024) studied the usage of various feed additives to improve pig productivity and ensure a high level of antioxidant protection. According to these authors, using more natural feed additives rather than artificially created ones is better. Therefore, it is proposed that flavonoids from mulberry leaves be used as an alternative feed additive. The use of flavonoids from mulberry leaves contributed to increased pig productivity, which was reflected in body weight gain, better feed conversion, and improved lipid metabolism.

M. Han *et al.* (2024) used the feed supplement *Eucommia ulmoides* to improve metabolic processes in pigs. It was found that the extract from the leaves of this plant is highly effective in stimulating animal growth and stabilising lipid metabolism and antioxidant protection. Using *Eucommia ulmoides* in pigs for 60 days helped regulate lipid metabolism, resulting in normalised liver enzyme activity and reduced lipogenesis, including increased antioxidant protection.

V.O. Ivanov *et al.* (2024) investigated the effect of the feed supplement Nanoverm on pig performance. The results showed an increase in the body weight of pigs that additionally consumed the feed supplement and an increase in total protein content on the 28^{th} day of use due to the albumin fraction. The authors noted the economic feasibility of using Nanoverm and its positive effect on the pig organism.

The study of ways to increase pig productivity is of great interest to the scientific community. The development of methods to improve lipid metabolism in pig farming is more relevant than ever, and the study of using nanoaquachelate preparations, taking into account the individual characteristics of the animal organism, opens up new horizons for researchers. The study aimed to determine the effect of nanoaquachelate preparations on pigs regarding the tone of the autonomic nervous system and the levels of saturated fatty acids in blood plasma lipids.

Literature Review

The balanced lipid breakdown processes make animal weight gain stable and productive. With sufficient energy, the body uses amino acids more efficiently to build muscle mass. Many factors influence maintaining a stable lipid metabolism, including ambient temperature, diet, breed, age, sex, activity of regulatory systems, and others. Considering the extensive list of variables that directly or indirectly play a role in balancing homeostasis in pigs, it can be seen that modern methods of improving lipid metabolism take the above factors into account.

N. Khan *et al.* (2025) found that lipid metabolism is an essential link in the development of pigs. C.G. Yao *et al.* (2021) proved that any direction in the study or improvement of lipid metabolism begins with the alimentary pathway, i.e., the diet. Further, in most cases, the issues concern the microflora of the animal's intestines and the subsequent distribution of digested components to their locations in the body. At the same time, the state of the nervous system, particularly the autonomic nervous system, is often not considered. This peripheral nervous system component plays a leading role in regulating homeostasis, which also applies to lipid metabolism.

J. Imai & H. Katagiri (2022) argued that the autonomic nervous system, which has afferent and efferent nerve fibres, communicates between peripheral organs and the central nervous system. This feature helps analyse metabolic processes in pigs and compensate for energy deficiencies on time, which is essential for stimulating metabolism. An example of this is regulating the hepatoportal system by the vagus nerve, which helps regulate glucose levels, namely its synthesis and breakdown. In addition, the efferent nerve endings of this nervous system are involved in the control of energy metabolism by promoting lipolysis in white adipose tissue and enhancing thermogenesis in brown adipose tissue. M. Hardoňová *et al.* (2021) established a significant relationship between the content of triacylglycerols in the body and the sympathetic nervous system. According to the data obtained, different types of neurons that express melanocortin and the hormones leptin and insulin are modulated by the peripheral nervous system, namely the autonomic nervous system, thereby controlling the metabolism of triacylglycerols. Lipolysis processes depend on the activity of the sympathetic nervous system, reflecting the catabolic role of this type of autonomic nervous system. Therefore, studying autonomic regulation in lipid metabolism is fundamental in analysing the body's homeostasis.

T. Teng *et al.* (2023) studied the energy balance in pigs under the influence of heat. First, it was found that during the colder months, the metabolism of high-molecular compounds increases to produce energy. This causes the release of significant amounts of both glucose and lipids, which are then broken down. At the same time, the gut microbiota is crucial as it helps digest feed and form short-chain fatty acids, which are then used to synthesise triacylglycerols. H. Ohorodnichuk & V. Zagamula (2022) conducted comprehensive research on improving pigs' metabolism to obtain high-quality products and ensure their productivity growth. The scientists used a complex feed additive called "MikoStop", which positively affected pigs' body weight gain. Z. Xu *et al.* (2021) studied the effect of low temperatures on the body of pigs. The researchers found that exposure to low temperatures reduces the concentration of triacylglycerols in animals by maintaining thermogenesis. The opposite transport of cholesterol occurs with the help of high-density lipoproteins and their subsequent conversion to bile acids. Thus, with short-term modulation of the effect of low temperatures on the pig organism, changes in the fatty acid composition were found, namely in the total content of saturated and unsaturated fatty acids.

Z. Tian *et al.* (2021) studied the inclusion of probiotics as feed additives in pigs' diet to improve amino acid and fatty acid metabolism. According to the results, using a probiotic based on Lactobacillus reuteri one positively affected the content of glutamic and inosinic acids. The authors claimed that protein synthesis in pigs was likely to increase and the fatty acid profile to change due to improved feed digestion, which positively affected metabolic processes. E.R. Grela *et al.* (2021) demonstrated the need to improve microbial digestion of feed to normalise fatty acid content in pigs during the fattening period. The study aimed to determine the effect of the prebiotic inulin on improving metabolic processes in animals, preventing the occurrence of antioxidant stress and improving the fatty acid profile. At the same time, the primary task was to avoid the significant use of antibiotics in the pig diet and replace them with prebiotics, with a subsequent positive effect on metabolism. However, using this feed additive had a negligible impact on the intensity of metabolism.

H. Zhou *et al.* (2021) investigated the effect of short-chain fatty acids on lipid metabolism in pigs and their impact on the intestinal microflora. The study was based on determining the effect of exogenous sources of fatty acids, rather than those synthesised during digestion by microorganisms. After 21 days of using the modified diet, an increase in protein synthesis ($P < 0.05$) and changes in metabolism associated with the biosynthesis of unsaturated fatty acids were observed.

Materials and Methods

The study was conducted throughout 2023 at the pig farm of Koshet LLC in the village of Chapivtsi, Mukachevo district, Zakarpattia region, on pigs of the Large White breed. The experimental groups of pigs were formed by studying the individual characteristics of autonomous regulation using the pulsometric method, followed by statistical evaluation of the obtained indicators, which allowed forming three groups of 10 animals each: normotonic (pigs with a predominance of normotonic processes in the nervous system), sympathicotonic (pigs with a predominance of sympathicotonic processes in the nervous system) and vagotonic (pigs with a predominance of vagotonic processes in the nervous system). The experimental studies involving pigs described in this paper, namely all manipulations with pigs, were carried out following the basic principles of bioethics, by Law of Ukraine No. 3447-IV (2006), the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (1986), Directive 2010/63/EU of the European Parliament and the Council (2010) and the "General Ethical Principles for Animal Experiments" adopted by the First National Congress on Bioethics (Law of Ukraine No. 249, 2012).

The pre-formed pigs were divided into two subgroups – control and experimental, five heads each. The experimental group of pigs was fed a feed supplement containing nano-compounds of iron (3 mg/day) and germanium (0.01 mg/day) per head for 40 days. Pig blood plasma was used to study the content of saturated fatty acids. Blood was collected from pigs through the cranial hollow vein at the jugular groove on the left or right side, 1-2 cm to the side of the trachea and 1-2 cm above the sternum, using a sterile syringe with a 1% heparin solution in a volume of three drops per 10 cm^3 blood. The collected blood was placed in a thermocontainer at a temperature of 4°C. Blood plasma was obtained by centrifugation for 10 minutes at 2,000 rpm.

To investigate the content of saturated fatty acids in pig blood plasma, lipids were extracted using the method of J. Folch *et al.* (1957), which was based on the use of blood plasma as a lipid-containing medium, from which lipids soluble in chloroform were extracted using a mixture of chloroform and methanol in a 1:2 ratio and subsequent addition of 0.74% potassium chloride, and the fat was concentrated using a reverse refrigerator. Chromatographic analysis was performed using a Trace GC Ultra chromatograph (USA) with a flame ionisation detector. A standard sample of Supelco 37 Component FAME Mix was used to identify the results of the chromatographic study and determine saturated fatty acids in pig blood lipids. The study was performed in three parallel groups. Statistical processing of the obtained indicators of saturated fatty acids in pig blood was performed using Microsoft Excel with an assessment of the probability of differences in indicators of the blood and evaluation using Student's t-test with significance levels: P < 0.05, P < 0.01, P < 0.001.

Results and Discussion

After analysing the blood lipid chromatography indicators of pigs in the control group of normotonic animals using descriptive statistics, a corresponding data table was formed based on the percentage content of the fatty acids studied (Table 1).

Table 1. Descriptive statistics of saturated fatty acid indicators in the blood plasma of pigs in the control group of normotonic animals (n = 5)

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Average, %	0.15	0.20	24.63	0.42	27.55	1.12
Standard error, %	0.01	0.02	0.34	0.04	0.26	0.05
Standard deviation, %	0.02	0.04	0.75	0.10	0.58	0.12
Asymmetry	-0.24	-0.60	1.09	0.31	1.08	-0.20
Minimum, %	0.12	0.14	23.92	0.31	27.01	0.97
Maximum, %	0.17	0.25	25.81	0.55	28.45	1.26

Note: *C14:0 – myristic acid; C15:0 – pentadecanoic acid; C16:0 – palmitic acid; C17:0 – heptadecanoic acid; C18:0 – stearic acid; C22:0 – behenic acid*
Source: *authors' development*

Descriptive statistics of saturated fatty acid levels in the blood lipids of normotonic pigs are statistically significant. In particular, it was found that the standard error and standard deviation for palmitic acid were higher, ranging from 6.25 to 8.5 times, and for stearic acid – in the range from 4.8 to 6.5 times, compared to other fatty acids. However, considering that the average values of these saturated fatty acids are significantly higher than those of others, these figures were within relatively favourable limits. When assessing asymmetry, it was found that myristic and behenic acids had low negative asymmetry, while pentadecanoic acid had medium asymmetry. Heptadecanoic acid showed positive low asymmetry, while palmitic and stearic acids had medium asymmetry. It should also be noted that the differences between the minimum and maximum values of the studied saturated fatty acids are insignificant, ranging from 0.08 to 1.89% depending on the type of fatty acid. The following statistical data were obtained after examining the fatty acid levels in the pigs' blood in the normotonic experimental group, which were given a mixture of iron and germanium microelements (Table 2).

Table 2. Descriptive statistics of chromatography indicators in blood lipids of pigs in the experimental group of normotonics (n = 5)

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Average, %	0.25	0.24	21.64	0.34	24.60	1.08
Standard error, %	0.02	0.03	0.63	0.02	0.44	0.02
Standard deviation, %	0.04	0.07	1.41	0.05	0.98	0.04
Asymmetry	0.01	0.01	0.60	-0.56	-1.38	0.78

Table 2. Continued

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Minimum, %	0.21	0.16	20.50	0.27	23.01	1.05
Maximum, %	0.29	0.32	23.25	0.4	25.51	1.14

Note: *C14:0 – myristic acid; C15:0 – pentadecanoic acid; C16:0 – palmitic acid; C17:0 – heptadecanoic acid; C18:0 – stearic acid; C22:0 – behenic acid*
Source: *authors' development*

According to descriptive statistics of blood lipids in pigs, it has been proven that the average values formed had insignificant differences. At the same time, the standard error and standard deviation values for palmitic acid were 15-20 times higher, and for stearic acid – 14.0 to 20.0 times higher than for other fatty acids. When analysing the asymmetry of fatty acid indicators, a slight positive symmetrical asymmetry was found in myristic and pentadecanoic acids. Palmitic and behenic acids were characterised by moderate positive asymmetry. Heptanoic acid was characterised by negative average asymmetry, and stearic acid by more pronounced negative asymmetry. The value of this indicator was not critical, which can be explained by the content of these fatty acids. When evaluating the minimum and maximum values, a slight discrepancy within the range of 0.16% to 2.75% of the initial data is worth noting. After analysing the data on saturated fatty acids in the blood plasma lipids of pigs in the control group of sympathicotonic animals using descriptive statistics, a corresponding data table was formed depending on the percentage content of the fatty acids studied (Table 3).

Table 3. Descriptive statistics of blood lipid parameters in pigs of the control group of sympathicotonic animals (n = 5)

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Average, %	0.32	0.25	23.96	0.53	24.44	0.80
Standard error, %	0.01	0.01	0.49	0.02	0.42	0.03
Standard deviation, %	0.02	0.03	1.09	0.05	0.94	0.07
Asymmetry	-0.21	-0.31	-0.57	0.94	1.10	-0.48
Minimum, %	0.29	0.21	22.53	0.48	23.50	0.70
Maximum, %	0.35	0.28	24.96	0.60	25.92	0.87

Note: *C14:0 – myristic acid; C15:0 – pentadecanoic acid; C16:0 – palmitic acid; C17:0 – heptadecanoic acid; C18:0 – stearic acid; C22:0 – behenic acid*
Source: *authors' development*

According to statistical analysis, the chromatographic analysis of lipids in the blood of pigs in the control group with sympathicotonia showed that the average values for fatty acid content were highly reliable and showed insignificant differences in the values of the corresponding indicators. This was confirmed by the standard error and standard deviation values obtained, which were relatively low, especially for myristic, pentadecanoic, heptadecanoic and behenic acids. At the same time, the standard error and standard deviation were significantly higher for palmitic acid, corresponding to a range of 15.5 to 16.0 times, and for stearic acid, within a range of 13.4 to 14 times, relative to the data for other saturated fatty acids. Considering the values of these acids, the standard error and standard deviation were relatively low.

Regarding asymmetry, myristic, pentadecanoic and behenic acids differed in their low negative asymmetry, while palmitic and heptadecanoic acids showed moderate asymmetry. Despite its high asymmetry, the content of stearic acid corresponded to the normal numerical distribution. The differences between the minimum and maximum values of the six saturated fatty acids were within the acceptable range of 0.07% to 2.43%. After examining the descriptive statistics of lipid content in pigs' blood in the experimental sympathotonics group, the corresponding statistical data were compiled (Table 4).

Table 4. Statistical analysis of lipid indicators in the blood of pigs in the experimental group of sympathotonics (n = 5)

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Average, %	0.21	0.20	20.77	0.42	20.74	0.54
Standard error, %	0.02	0.01	0.21	0.03	0.15	0.03
Standard deviation, %	0.06	0.03	0.47	0.06	0.33	0.06
Asymmetry	1.06	1.22	-0.21	0.08	0.24	-0.24
Minimum, %	0.15	0.18	20.13	0.36	20.33	0.47
Maximum, %	0.30	0.25	21.38	0.49	21.18	0.60

Note: *C14:0 – myristic acid; C15:0 – pentadecanoic acid; C16:0 – palmitic acid; C17:0 – heptadecanoic acid; C18:0 – stearic acid; C22:0 – behenic acid*
Source: *authors' development*

When evaluating the data from the chromatographic analysis of blood lipids in pigs of the experimental group with sympathicotonia, characteristic values of the spectrum of saturated fatty acids were determined. It should be noted that in pigs of this group, the standard error and standard deviation values were predominantly relatively low. However, the standard error and standard deviation values for palmitic acid were higher, ranging from 7 to 7.8 times, and for stearic acid, 5.0 and 5.5 times, unlike other fatty acids. Considering the numerical data on asymmetry, the highest values were found in myristic and pentadecanoic acids, indicating significant asymmetry in the sequence of numbers. Other saturated fatty acids, such as palmitic, heptadecanoic and behenic acids, were characterised by moderate asymmetry, while palmitic acid had low asymmetry. The distribution of data within the range of 0.07% to 1.25% between the maximum and minimum values of saturated fatty acids in the experimental group of sympathotonics indicated a slight discrepancy in the results of their chromatographic study in pig blood plasma. The results of descriptive statistics on the content of lipids in the blood of pigs in the control group of vagotonics are presented in Table 5.

Table 5. Statistical analysis of lipid indicators in the blood of pigs in the control group of vagotonics (n = 5)

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Average, %	0.32	0.25	23.96	0.53	24.44	0.80
Standard deviation, %	0.01	0.01	0.49	0.02	0.42	0.03
Standard deviation, %	0.02	0.03	1.09	0.05	0.94	0.07
Asymmetry	-0.21	-0.31	-0.57	0.94	1.10	-0.48

Table 5. Continued

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Minimum, %	0.29	0.21	22.53	0.48	23.50	0.70
Maximum, %	0.35	0.28	24.96	0.60	25.92	0.87

***Note**: C14:0 – myristic acid; C15:0 – pentadecanoic acid; C16:0 – palmitic acid; C17:0 – heptadecanoic acid; C18:0 – stearic acid; C22:0 – behenic acid*
***Source**: authors' development*

According to the statistical assessment of the lipid content in pigs' blood in the control group of vagotonic animals, it was established that the data obtained for six fatty acids were within the permissible limits. The average values had relatively small standard errors and standard deviations, characterising them as numerical data with insignificant discrepancies. This emphasises the reliability of the results obtained in the chromatographic study. The asymmetry index for myristic, pentadecanoic, palmitic and behenic acids was characterised by a negative average asymmetry, while heptadecanoic acid showed a positive average asymmetry. Stearic acid was characterised by high positive asymmetry, which is not critical for the calculated indicator. When evaluating the minimum and maximum values of all saturated fatty acids in the control group of vagotonic animals, it was determined that they ranged from 0.07% to 2.43%, which indicated a slight discrepancy in the initial data values. Descriptive statistics were used to analyse the blood lipid spectrum of pigs in the experimental group of vagotonics that were given a mixture of iron and germanium nanocomposites (Table 6).

Table 6. Statistical analysis of blood lipid levels in pigs from the experimental group of vagotonic animals (n = 5)

Indicator	C14:0	C15:0	C16:0	C17:0	C18:0	C22:0
Average, %	0.19	0.22	21.31	0.25	21.36	1.06
Standard error, %	0.01	0.02	0.32	0.02	0.20	0.04
Standard deviation, %	0.02	0.04	0.71	0.04	0.45	0.09
Asymmetry	0.59	0.59	1.60	-0.05	0.41	0.55
Minimum, %	0.17	0.17	20.71	0.19	20.82	0.95
Maximum, %	0.22	0.28	22.5	0.30	21.99	1.2

***Note**: C14:0 – myristic acid; C15:0 – pentadecanoic acid; C16:0 – palmitic acid; C17:0 – heptadecanoic acid; C18:0 – stearic acid; C22:0 – behenic acid*
***Source**: authors' development*

According to the descriptive statistics of the blood lipid chromatograms of pigs in the experimental group, it was determined that the average values are highly reliable and show insignificant differences. This is confirmed by the obtained standard error and standard deviation values, which were relatively low, especially for myristic, pentadecanoic, heptadecanoic and behenic acids. It should be noted that the standard error and standard deviation were significantly higher for palmitic acid, ranging from 7.8 to 18.0 times, and for stearic acid, ranging from 5 to 11.3 times. This indicated that these indicators were relatively low. Regarding the asymmetry index, myristic, pentadecanoic, stearic, and behenic acids showed moderate positive asymmetry, while heptadecanoic acid showed negative asymmetry. Despite its high asymmetry, palmitic acid corresponded to a statistically correct distribution of data.

The differences between the minimum and maximum values of the six fatty acids ranged from 0.05% to 1.79%, corresponding to the normal range. Comparing the indicators of saturated fatty acids, the blood lipids of pigs in the normotonic groups showed a higher content of myristic acid by 1.7 times ($P < 0.01$) in animals that did not receive a mixture of nanoaquachelates in their diet, unlike the pigs in the experimental group. The relative content of pentadecanoic acid did not differ between groups of pigs with a predominance of normotony (Fig. 1).

Figure 1. Content of myristic (C14:0) and pentadecanoic (C15:0) fatty acids in blood plasma lipids of normotonic pigs

Source*: authors' development*

The content of heptadecanoic acid increased by 22.81% ($P < 0.05$) in the blood plasma lipids of pigs with a standard diet compared to normotonic pigs that additionally received feed additives of nanoaquachelates. Conversely, behenic fatty acid increased by 2.95% ($P < 0.01$) in pigs with a standard diet of normotonic pigs, unlike normotonic pigs in the experimental group (Fig. 2). When studying the level of saturated fatty acids, the percentage of which was found to be the highest, it was found that the content of palmitic acid in pigs of the experimental group increased by 13.81% ($P < 0.01$) compared to normotonic pigs that had a regular diet. The content of stearic fatty acid in the blood of normotonic pigs increased by 11.97% ($P < 0.01$), compared to those that were not given nanoaquachelate feed additives, unlike the experimental group of animals (Fig. 3).

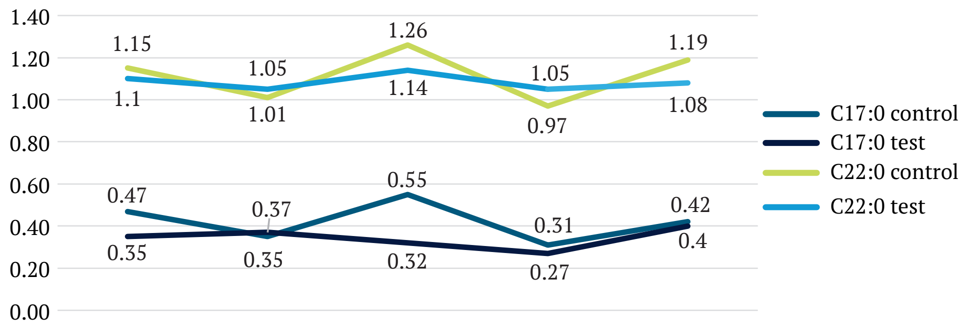

Figure 2. Indicators of heptadecanoic (C17:0) and behenic (C22:0) acids in the blood lipids of pigs in the experimental and control groups of normotonics

Source*: authors' development*

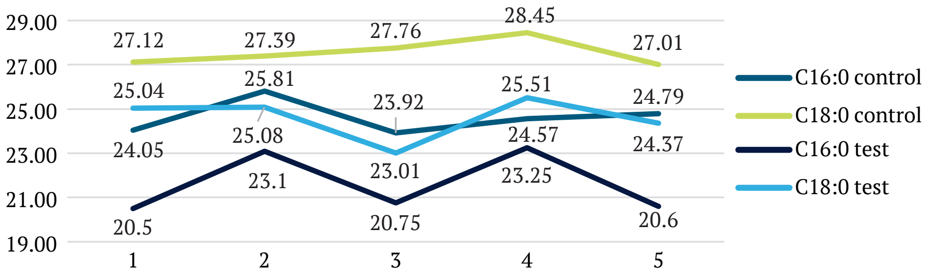

Figure 3. Indicators of palmitic (C16:0) and stearic (C18:0) acids in normotonic pigs
***Source**: authors' development*

Comparing the levels of saturated fatty acids in the blood plasma lipids of pigs in the control and experimental groups of sympathotonics, a decrease in myristic acid by 34.16% (P < 0.01) was observed in those that received an additional feed supplement compared to those that had a standard diet. Pentadecanoic acid decreased by 17.74% (P < 0.01) in sympathotonics pigs compared to the control (Fig. 4).

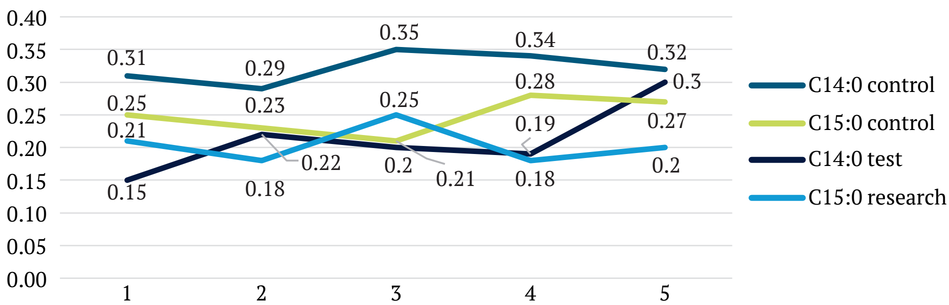

Figure 4. Levels of myristic (C14:0) and pentadecanoic (C15:0) acids in blood plasma lipids of pigs in the experimental and control groups of sympathotonics
***Source**: authors' development*

The content of heptadecanoic acid decreased by 19.39% (P < 0.01) in the blood lipids of pigs with sympathotonics that were given a feed supplement compared to animals in the control group that did not consume nanoaquachelate feed supplements. The content of behenic fatty acid decreased by 35.59% (P < 0.01) in pigs with sympathotonics that were given a feed supplement compared to control sympathotonics (Fig. 5). When studying the content of saturated fatty acids with the highest percentage, it was determined that palmitic acid in the blood lipids of pigs in the experimental group of sympathotonics decreased by 13.32% (P < 0.01), and stearic acid decreased by 15.17% (P < 0.001) compared to the control group of animals (Fig. 6). Comparing the levels of saturated fatty acids in the blood plasma lipids of pigs in the control and experimental groups of vagotonic animals, the content of myristic acid in the blood plasma lipids of pigs that did not receive a mixture of nanoaquachelates in their diet increased by 45.83% (P < 0.01). However, the content of pentadecanoic acid increased by 91% (P < 0.05) relative to the experimental group (Fig. 7).

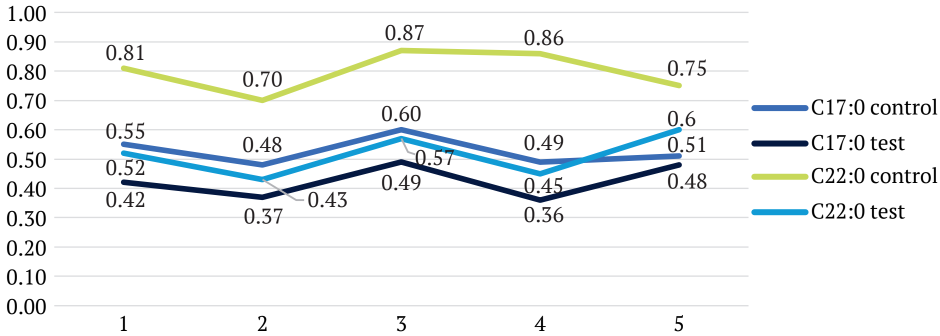

Figure 5. Levels of heptadecanoic (C17:0)
and behenic (C22:0) acids in blood plasma lipids of sympathotonics pigs
Source: *authors' development*

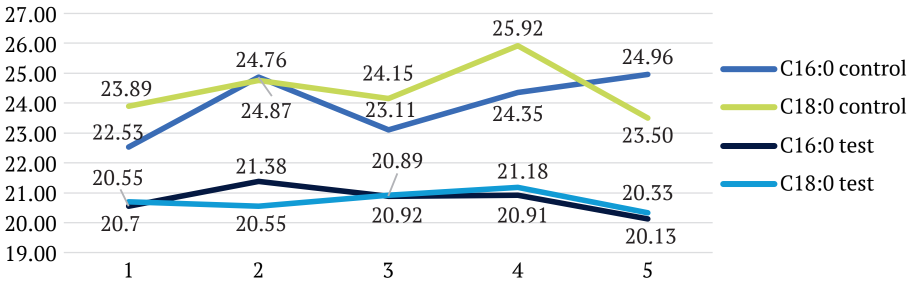

Figure 6. Indicators of palmitic (C16:0)
and stearic (C18:0) acids in the blood plasma lipids of sympathicotonic pigs
Source: *authors' development*

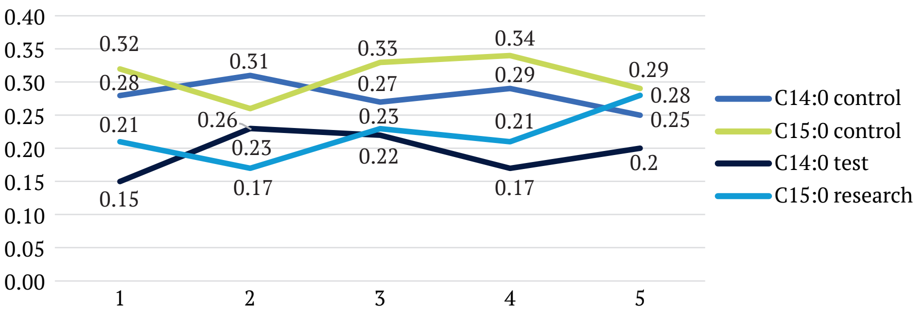

Figure 7. Indicators of myristic (C14:0)
and pentadecanoic (C15:0) acids in the blood plasma lipids of vagotonic pigs
Source: *authors' development*

The content of heptadecanoic acid increased by 27.64% ($P < 0.05$) in pigs of the control group with vagotonia compared to pigs that consumed feed additives of nanoaquachelates. The level of behenic fatty acid also increased by 21.24% ($P < 0.01$) in the blood lipids of pigs in the control group of vagotonic pigs, unlike vagotonic pigs in the experimental group (Fig. 8).

The content of palmitic acid in the blood lipids of pigs in the control group of vagotonic animals, which were not given nanoaquachelate feed additives, increased by 17.35% ($P < 0.01$), and stearic acid content increased by 13.45% ($P < 0.001$) compared to the experimental group (Fig. 9).

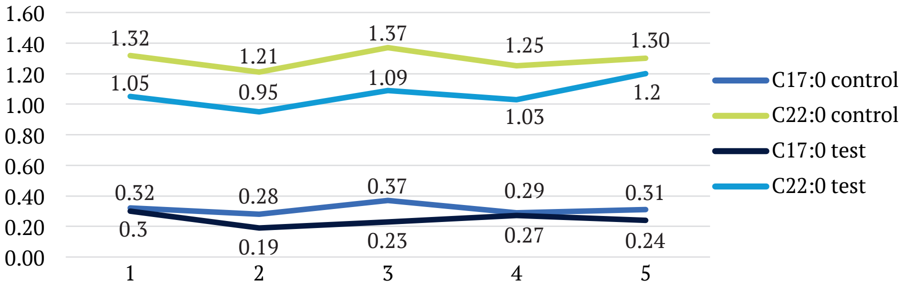

Figure 8. Content of heptadecanoic (C17:0) and behenic (C22:0) acids in blood lipids of vagotonic pigs
Source: *authors' development*

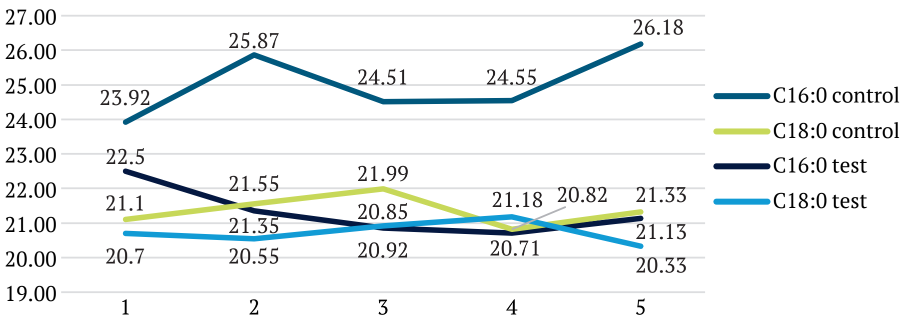

Figure 9. Levels of palmitic (C16:0) and stearic (C18:0) acids in the blood lipids of vagotonic pigs
Source: *authors' development*

D.O. Melnychuk & V.A. Hryshchenko (2014) established that lipid metabolism in mammals is influenced by both exogenous (ecopathogenic) and endogenous factors, and also found a corrective effect of adding milk phospholipids to the diet of animals at a dose of 13.5 mg/kg body weight. H. Zhang *et al.* (2022) investigated the fact that diet significantly affects lipid metabolism, especially regarding the composition of the diet and the feeding period. It has been proven that excessive feed intake inhibits lipid metabolism, accumulating saturated fatty acids in the animal's body without their further involvement in synthetic processes. According to the current study's results, additional feed additives improved lipid metabolism, as evidenced by a decrease in fatty acid levels in the blood lipids of pigs.

M. Scerra *et al.* (2024) investigated the effect of bergamot pulp and olive oil on lipid metabolism, especially fatty acids. The use of nanoaquachelates caused an increase in the content of myristic, pentadecanoic, palmitic, heptadecanoic and stearic acids in the range from 17.4% to 47.2% ($P < 0.05$). Compared with the results presented in this study, the nanopreparation led to a decrease in fatty acid levels in pig blood plasma from 13.45% to 45.83%

(P < 0.001), which may indicate an increase in lipid metabolism in the body. It is also important to note that more accurate results of chromatographic analysis were obtained due to the formation of pigs following the individual characteristics of their vegetative regulation.

M. Xu *et al.* (2022) investigated the effect of a proanthocyanidin feed supplement from grape seed extract on lipid metabolism in pigs. According to the results obtained, the scientists noted a decrease in the content of myristic, pentadecanoic, palmitic, heptadecanoic and stearic acids in the range from 10% to 6% (P < 0.05) at a maximum concentration of the dietary supplement at a dose of 200 mg/kg. Compared with the study's results, there was a decrease in the content of saturated fatty acids, which may indicate better efficiency of the nanopreparation. At the same time, the standard error and standard deviation decreased, possibly due to the distribution of animals into groups based on vegetative regulation.

L. Zhang *et al.* (2021) investigated the effect of a feed supplement in the form of branched-chain amino acids. According to the results obtained, the authors demonstrated a gradual decrease in the concentration of total lipids in the bloodstream and an increase in triacylglycerols (P < 0.05), the main transport compounds of fatty acids. These researchers noted the positive effect of the feed supplement on lipid metabolism. Compared to the results of this study, the concentration of saturated fatty acids decreased significantly, and the formation of pigs following vegetative regulation had a positive effect on the results obtained. Z. Guo *et al.* (2021) investigated the effectiveness of the feed supplement dihydromyricetin. According to the results obtained, the reduction in saturated fatty acid content ranged from 2.5% to 3.6%, and it is also worth noting the high P-value, which indicated a significant discrepancy in the data. According to the results obtained, the significance coefficient P was significantly lower due to the distribution of animals according to individual characteristics.

O. Kovalchuk *et al.* (2024) used a feed supplement with the same composition as in this study. According to the results of their research, there were changes in lipid metabolism in the triglyceride indicators between the control and experimental groups of pigs, which were 24.3% higher in the experimental group (P < 0.05) and non-esterified fatty acids, which increased in the control group by 8.0% (P < 0.05). Comparing our results regarding lipid metabolism and the use of nanoaquachelate feed additives, it should be noted that taking into account the individual characteristics of pigs' organisms gives more accurate results when using a modified diet. Therefore, the formation of animals according to the activity of autonomous regulation, based on our study, provides more detailed data.

After analysing the results of other researchers and comparing them with those described in this paper, it should be noted that the effectiveness of each feed additive varies considerably. It should also be noted that the region, country and breed of pigs are significant factors, as climatic conditions and access to the same feed additives vary from farm to farm within a country. Therefore, it is understandable why scientific works differ significantly in their approach to the issue of additional components to the feed ration that improve lipid metabolism in pigs. However, despite these differences, the processes of lipolysis and lipogenesis occurring in pigs are unchanged. Therefore, according to the results obtained, it is clear that the physiological differentiation of pigs according to the individual characteristics of their vegetative regulation makes a significant contribution to the study of the feed additives used and improves the accuracy of the results obtained. It should also be noted that the feed additive used in the experiment, a nanopreparation of a mixture of germanium and iron, has significant results in lipid metabolism in pigs.

Conclusions

Quantitative changes in lipid metabolism indicators, namely saturated fatty acids, were determined when pigs with different autonomic nervous system tone were fed a feed mixture of iron and germanium nanocomposites. It was found that the blood plasma lipids of pigs in the experimental group with different autonomic nervous system tone showed a decrease in the content of saturated fatty acids. Thus, the content of myristic fatty acid in the blood lipids of pigs with a modified diet decreased from 34.16% to 45.83% ($P < 0.01$), pentadecanoic fatty acid – from 17.74% to 27.64% ($P < 0.05$; $P < 0.01$), palmitic acid – from 13.32% to 17.35% ($P < 0.01$), heptadecanoic acid – from 19.39% to 27.64% ($P < 0.05$; $P < 0.01$), stearic fatty acid – from 11.97% to 15.17% ($P < 0.01$; $P < 0.001$), behenic acid – from 2.95% to 35.59% ($P < 0.01$). According to the studies, using a nano-mixture of iron and germanium positively affected saturated fatty acids, as evidenced by a decrease in their relative content in the plasma lipids of pigs. These results reflect the stability of homeostasis in the body of the experimental pigs, which was ensured by using nanoaquachelates in their diet. According to the statistical analysis of the results of the chromatographic study, there was a significantly lower discrepancy between the numerical values obtained from the five animals in the experimental and control groups with different vegetative regulation. The low values of the standard error and standard deviation confirm this. Using the pulsometric study indicator for more accurate formation of experimental groups of pigs contributed to a better analysis of the effect of nanoaquachelates on fatty acid indicators in the body of these animals. The prospect of further research lies in adjusting the doses of feed additives of iron and germanium microelements according to pigs with different vegetative regulation, since it is already known that animals in each of the normotonic, sympathicotonic, and vagotonic groups had specific characteristics regarding the content of saturated fatty acids when using iron and germanium nanocomplexes. Taking this into account, selecting an individual dose of feed additive for pigs according to the characteristics of the activity of the vegetative nervous system will help to effectively correct lipid metabolism and ensure the stable productivity of these animals.

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Conflict of Interest

None.

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Вплив наносполук германію і заліза на показники насичених жирних кислот у крові свиней залежно від вегетативної регуляції

Світлана Кравчук
Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0008-0767-9032
Олена Журенко
Доктор ветеринарних наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-4933-0372
Дмитро Криворучко
Кандидат ветеринарних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-1788-6090
Віталій Журенко
Кандидат ветеринарних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-2097-9212
Ігор Грищук
Доктор філософії, асистент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-2571-6876

Анотація. Актуальність виконаного досліду пов'язана із розробкою нових методів підвищення продуктивності свиней завдяки збалансуванню метаболічних процесів в організмі. Головною метою було визначити зміни показників насичених жирних кислот в організмі свиней при використанні кормової добавки наноаквахелатів з урахуванням індивідуальних особливостей організму. Формування дослідних груп тварин виконували за пульсометричним дослідженням, відповідно до якого було отримано три групи по 10 свиней, кожна з яких була поділена на дві підгрупи – контрольну і дослідну по 5 тварин. Дослідній групі за допомогою випоювання задавали суміш наносполуки мікроелементів заліза в дозі 3 мг/добу та германію – 0,01 мг/добу. Вміст насичених жирних кислот оцінювався за допомогою методу газової хроматографії. За результатами виконаного дослідження встановлено, що у крові свиней контрольної групи із нормотонією збільшувався вміст насичених жирних кислот: міристинової (P < 0,01), гептадеканової (P < 0,05), бегенової (P < 0,01). У крові свиней дослідної групи з симпатотонією зменшувався вміст насичених жирних кислот: міристинової (P < 0,01), пентадеканової (P < 0,01), гептадеканової (P < 0,01), бегенової (P < 0,01). У крові свиней контрольної групи із ваготонією вміст насичених жирних кислот збільшувався порівняно з дослідною групою. Встановлено, що у дослідних свиней нормотоніків жирні кислоти з найбільшою часткою, такі як пальмітинова – менша на 12,1 %, а стеаринова кислота – на 10,7 % (P < 0,01). У свиней симпатотоніків контрольної групи спостерігався більший вміст пальмітинової кислоти на 15,4 % (P < 0,01) та стеаринової – на 17,8 % (P < 0,001). У дослідних свиней ваготоніків – менший вміст пальмітинової на 14,8 % (P < 0,01) та стеаринової кислоти на 11,8 % (P < 0,001). За результатами дослідження відмічався позитивний вплив суміші наносполук заліза і германію на показники обміну насичених жирних кислот, а розподілення свиней відповідно до індивідуальних особливостей організму, покращило точність отриманих даних

Ключові слова: обмін речовин; нанопрепарат; продуктивні тварини; автономна нервова система; ліпіди