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Influence of mineral sorbent on the accumulation of 137Cs, Pb, and Cd in the muscle tissue and liver of pigs

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The research is devoted to establishing the most optimal dose of natural saponite mineral in the diets of young pigs of large white breed and determining its impact on the quality and safety of pig products during its production in the III zone of radioactive contamination due to the Chernobyl accident. We registered the positive effect of the mineral sorbent on the ecological quality of pork in reducing the specific activity of 137Cs and the concentration of heavy metals, particularly Cd and Pb, in the longest back muscle. We found that the inclusion in pigs' fattening of the natural mineral saponite in the amount of 3, 5, and 7% by weight of concentrated fodders in the diet reduced the specific activity of 137Cs in muscle tissue of animals of experimental groups relative to control by 10.1-35.7%. At the same time, the sorbent dose of 7% was the best in terms of sorption efficiency. The multiplicity of 137Cs accumulation in the longest back muscle was 0.153–0.257 and was 15.2–68.0% higher in young pigs receiving saponite-free cereals. The concentration of Pb in the muscle tissue and liver of experimental animals was slightly lower than MAC (maximum allowable concentration). In contrast, the contamination of the longest back muscle of young pigs of all Cd groups exceeded the regulatory requirements by 1.54-2.48 times. Giving saponite to fattening pigs reduced the content of Pb and Cd in the muscle tissue of animals of the II-IV (experimental) groups by 5.9-52.7% and 21.8-37.9%, respectively. The most optimal amount of natural mineral to reduce the accumulation of Pb in the muscle tissue of animals was the dose of sorbent 3% (by weight) of concentrated fodders in the diet, and for Cd – a dose of 7%.

Keywords: young pigs, saponite, the longest back muscle, liver, 137Cs, Pb, Cd.

Introduction

Pollution of the environment with highly toxic cesium radionuclides released into the atmosphere due to the Chernobyl accident and their subsequent entry into the body of animals requires the use of livestock production technologies that ensure the required level of animals' health and environmental safety of food. (Zubets et al., 2011; Savchuk et al., 2014). Despite the general trend of stabilization of the radiation situation, it should be noted that the levels of radioactive contamination of agricultural products in some areas of Polissya in Ukraine are ten times higher than the pre-accident level and in some cases, especially in farms, remain much higher than existing standards (Romanchuk et al., 2019).

In addition, the intensification of agro-industrial production has negatively affected the condition of soils, annually polluting them with harmful substances, including heavy metals such as Pb, Cd, Cu, and Zn (Awad et al., 2006; Toth et al., 2016). It is known that the primary source of soil pollution is mineral fertilizers, the use of which is growing from year to year (Reis et al., 2010). Heavy metals and their compounds are the most toxic because they do not decompose in soil and water but migrate in the trophic chain and ultimately cause latent negative changes in overall metabolism in humans, animals (Honskyy et al., 2001; Pavan Kumar & Prasad, 2004; Peng et al., 2015). The combined action of radio-cesium and heavy metals leads to the activation of pathogenic mechanisms and acute and chronic intoxications of animal and human organisms.

With this in mind, considerable attention is currently being paid to natural adsorbents. Such substances include zeolites, bentonites, humolites, saponites, glauconites, and kizelgurs, which have adsorbent, ion exchange, catalytic and other properties (Hutjens, 1991; Drought, 1997; Corzo et al., 2005; Spivak et al., 2012; Polyakov & Tarasevich, 2012). At the same time, adequate use of these sorbents in animal husbandry requires a detailed study of their adsorption selectivity concerning specific conditions and toxicants.

Numerous studies conducted by domestic and foreign scientists and practitioners have shown that animal husbandry's use of natural sorbents can increase productivity, i.e., realize the genetic potential of animals, increase production and profitability without additional feed costs. The physicochemical ability of alumina to bind toxic substances due to their high sorption capacity is an essential factor in improving the biological value of fodders by feeding them to animals (Smith, 1980; Casal et al., 1997; Burlaka & Suknenko, 2005; Pshinko et al., 2010; Baturevich, 2019).

Saponite is an alkaline aluminosilicate belonging to the group of bentonite clays. It has high binding, adsorption, and cation exchange properties; the total capacity of exchangeable cations and chemical composition is the source of most macro-and micronutrients for animals (Ganzyuk & Yafinovich, 2010; Ryazanov & Voitko, 2017; Sokol et al., 2019). According to Garvie &

Metcalfe (1997), Brigatti et al. (1999), and Treiman et al. (2014), the mineralogical composition of raw clay samples, which were identified as saponites, significantly depends on their location. The largest saponite deposits in Ukraine are Varvarivske and Tashkivske in the Khmelnytsky region, whose reserves are over 100 million tons (Spivak et al., 2012). However, the effect of this sorbent on the intensity of complex excretion of radio-cesium and heavy metals from young pigs has not been studied enough.
The study aimed to establish the accumulation of ^{137}Cs, Pb, Cd in the muscle tissue and liver of young pigs to use different doses of saponite in their diets.

Materials and Methods

Experimental studies were conducted in the Institute for Agriculture of Polissia of National AcadeAAS (III zone of radioactive contamination due to the Chernobyl accident). For the research and production experiment, young pigs of large white breed (28 heads) were selected, formed into four groups of 7 heads in each by the method of balanced groups. The duration of the comparative and experimental periods was 18 and 185 days, respectively.
Young animals of the I (control) group during the experimental period received a feed from the main diet, which consisted of groats of barley, wheat, and pea, fodder beet, chalk, and table salt. Pigs of II, III, and IV (experimental) groups to the main diet were given the natural mineral saponite in the amount of 3%, 5, and 7% by weight of the concentrated feed. The nutritional value of the average daily diet for feeding experimental animals was 2,40 EFU (energetic feed units), 24.05 MJ of metabolic energy with a content of 218 g of digestible protein, or 91 g. per energy feed unit. The diets of young pigs are balanced in terms of nutrients and minerals, which provided their need for essential nutrients.
Determination of the specific activity of 137Cs in fodders and livestock products was performed on a spectrometer SEG-0,5. Preparation of plant and animal origin samples to establish heavy metals in their composition was carried out using dry mineralization analysis – on the atomic absorption spectrometer "Quantum-2A" (National Standard, 2015).
The transition rate (TR) of heavy metals (Pb and Cd) in the chain "diet – products (muscle tissue and liver)" were determined by the formula:

$$TR = Hmciap./ Hmcodd. \times 100,$$

where TR is the transition rate; Hmciap. – heavy metals content in animal products, mg/kg; Hmcodd. – heavy metals content of the daily diet, mg (Mamenko & Portyanyk, 2019).

This coefficient is a relative integrated indicator, which in % reflects the migration of heavy metals from the diet to the product, which allows a comparative assessment of the transition of pollutants using different doses of saponite for feeding pigs.
All animal manipulations were performed following the European Convention for the Protection of Vertebrate Animals Used for Experimental and Scientific Purposes (Strasbourg, 1986).

Results

Some substances can reduce the transfer of toxic substances from fodders into animal tissues. First of all, they include chemically different compounds that bind radionuclides in the digestive tract when added to the diet, reducing their absorption. They are called enterosorbents or simply sorbents. The use of radionuclide sorbents in the feeding of farm animals is an effective way to reduce the transition of 137Cs i 90Sr in livestock products (Bogdanov et al., 1996; Romanov et al., 1996).
The body of young pigs with fodders per day in terms of experimental groups received almost the same amount of radio-cesium – 77.3-83.8 Bq. At the same time, in the diets of animals of the II, III, and IV (experimental) groups, the concentration of 137Cs was higher by 3.6%, 5.9, and 8.4%, respectively, than in control. This is due to the natural mineral saponite, which determined the specific activity of 137Cs as 43.1 Bq/kg (Fig. 1).

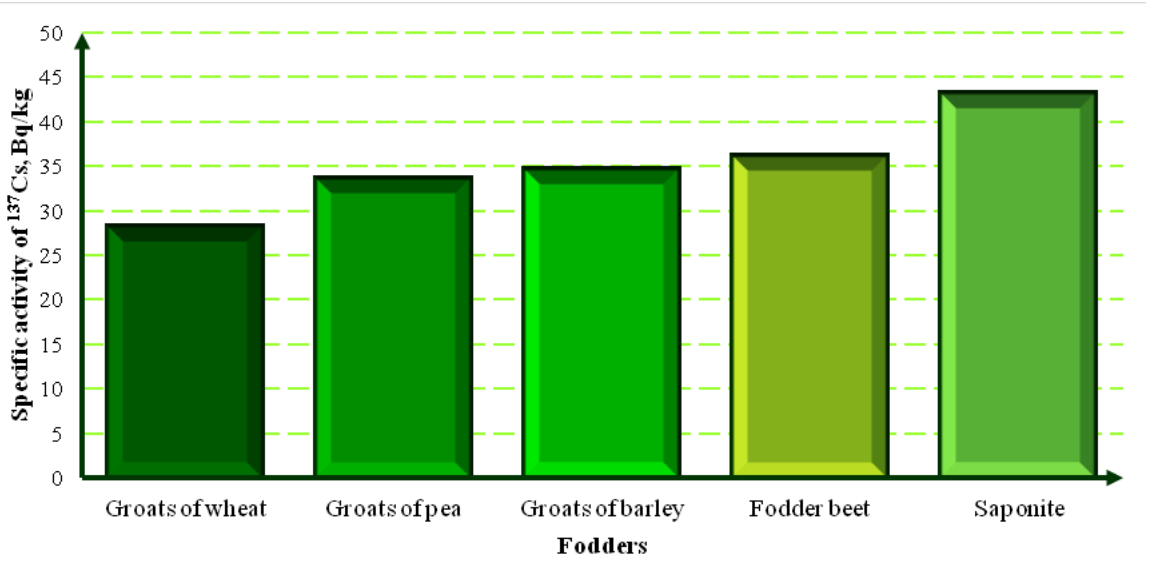

Fig. 1. The specific activity of 137Cs in fodders for experimental pigs.

The results showed insignificant intergroup differences in the concentration of 137Cs in the longest muscle of the back and liver of experimental pigs (Table 1). The specific activity of 137Cs in the longest muscle of the back of the animals ranged from 12.8 to 19.9 Bq/kg and did not exceed acceptable levels (DR-2006 = 200 Bq/kg). At the same time, when feeding young pigs as part of a grain mixture of different doses of the natural mineral saponite, the concentration of radiocaesium in muscle tissue relative to control is

reduced by 2.0-7.1 Bq/kg, or 10.1-35.7% for an incredible intergroup difference.A slightly different pattern was observed for the accumulation of 137Cs in the liver of experimental pigs – this figure was the lowest in animals of group II (10.2 Bq/kg) and the highest – in analogs of group III (17.8 Bq/kg). According to the specific activity of radio-cesium in the piglings' liver groups, I and IV occupy an intermediate position – 13.7-15.7 Bq/kg. Compared with the longest back muscle, the concentration of 137Cs in the liver of animals of groups I and II were lower by 31.2-43.0%, while when used for feeding pigs high doses of saponite (5 and 7% by weight of concentrated fodder), this figure was higher by 22.7-22.8%.

The multiplicity of 137Cs accumulation in the longest back muscle was 0.153-0.257 and was higher by 15.2-68.0% in young pigs that received a mixture without saponite, compared with the use of mixtures №2, №3, and №4 (3, 5 and 7% by weight of natural mineral) (Fig. 2). The multiplicity of 137Cs accumulation in the liver of experimental animals varied in the range of 0.127-0.217 and was 5.6-22.6% higher in piglings of III and IV (experimental) groups compared with I (control) group.

Table 1. The specific activity of 137Cs in the fodder diet and slaughter products of pigs (n = 3; M ± m).

Groups of animals	Concentration of 137Cs			
	an average daily diet, Bq	products, Bq/kg	towards the control group Bq/kg	%
	Musculus longissimus dorsi			
I – Control	77.3	19.9 ± 3.1	-	-
II – Experimental	80.13	17.9 ± 3.7	-2.0	-10.1
III – Experimental	81.9	14.5 ± 2.7	-5.4	-27.1
IV - Experimental	83.8	12.8 ± 5.2	-7.1	-35.7
	Liver			
I – Control	77.3	13.7 ± 3.9	-	-
II – Experimental	80.1	10.2 ± 2.2	-3.5	-25.6
III – Experimental	81.9	17.8 ± 2.1	+4.1	+29.9
IV - Experimental	83.8	15.7 ± 2.8	+2.0	+14.6

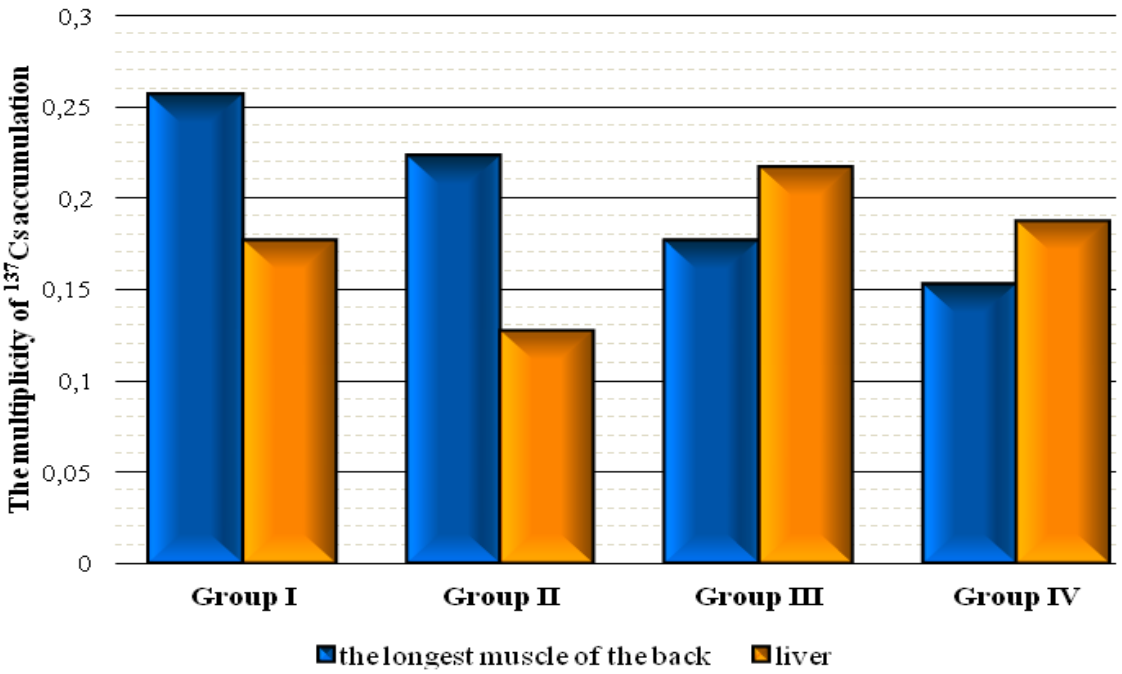

Fig. 2. The multiplicity of 137Cs accumulation in muscle tissue and liver of pigs.

Given the above, it can be argued that the use of a mixture of 3, 5, and 7% (by weight) of the natural mineral saponite for fattening young pigs in zone III of radioactive contamination leads to a slight decrease in the specific activity of 137Cs in the longest back muscle and decrease the multiplicity of accumulation.

Toxic chemical elements that enter the human and animal body (with food, feed) are excreted slowly. Heavy metals accumulate in the body by individual organs and tissues. Therefore, plant products grown on relatively clean or slightly contaminated soils can be sources of heavy metals in the body in excessive amounts and adversely affect metabolism (Lorez et al., 2003; Gutiy, 2013). Studies have shown that the concentration of Pb in the natural mineral saponite exceeded MAC (maximum allowable concentration) by 1.43 times, and Cd was 93.3% of the regulatory requirements (Table 2). In other studied fodders, the content of Pb and Cd did not exceed the permissible concentration, but most of them were contained in barley (0.450 and 0.110 mg/kg) and wheat (0.366 and 0.139 mg/kg).

Fodders contaminated with even a small amount of heavy metals can cause subclinical poisoning of animals. The studies showed that in the longest muscle of the back of pigs of all experimental groups, the accumulation of Pb was slightly lower than MAC (0.50 mg/kg) and varied in the range of 0.201-0.425 mg/kg (Table 3). The introduction of saponite to fattening pigs kept in zone III of radioactive contamination as a result of the Chernobyl accident, in the amount of 3, 5, and 7% by weight of concentrated feed in the diet, reduced the Pb content in the longest back muscle of animals by 52.7% ($p \leq 0.05$), 26.8 and 5.9%, respectively.

The lowest indicator of Pb content in the liver was characterized by young pigs of the II (experimental) group (0.288 mg/kg) and the highest – analogs of the III (experimental) group (0.481 mg/kg).

The transition rates of Pb from fodders ration to the longest back muscle ranged from 15.2 to 49.1%, and the liver from 17.7 to 39.6% (Fig. 3). The accumulation of Pb in muscle tissue and liver in young pigs of experimental groups was reduced by 28.5-33.9 and 10.2-21.9% abs., respectively, compared to control.

Table 2. The concentration of heavy metals in fodders, mg/kg of natural fodder.

Heavy metals	MAC	Fodders				
		Groats of barley	Groats of wheat	Groats of pea	Fodder beet	Saponite
Pb	5.0	0.450	0.366	0.248	0.077	7.170
Cd	0.3	0.110	0.139	0.100	0.028	0.280

Table 3. The concentration of Pb in fodders rations and pig slaughter products.

Groups of pigs	Concentration of Pb an average daily diet, mg	products, mg/kg	changes to the control group mg/kg	%
		Musculus longissimus dorsi		
I – Control	0.866	0.425 ± 0.050	-	-
II – Experimental	1.325	0.201± 0.031*	-0.224	-52.7
III – Experimental	1.633	0.311± 0.074	-0.114	-26.8
IV - Experimental	1.941	0.400 ± 0.075	-0.025	-5.9
Mac	-	0.50	-	-
		Liver		
I – Control	0.866	0.343 ± 0.033	-	-
II – Experimental	1.325	0.288 ± 0.056	-0.055	-16.0
III – Experimental	1.633	0.481± 0.022*	+0.138	+40.2
IV - Experimental	1.941	0.343 ± 0.048	-	-
MAC	-	0.60	-	-

* significant at p≤0.05

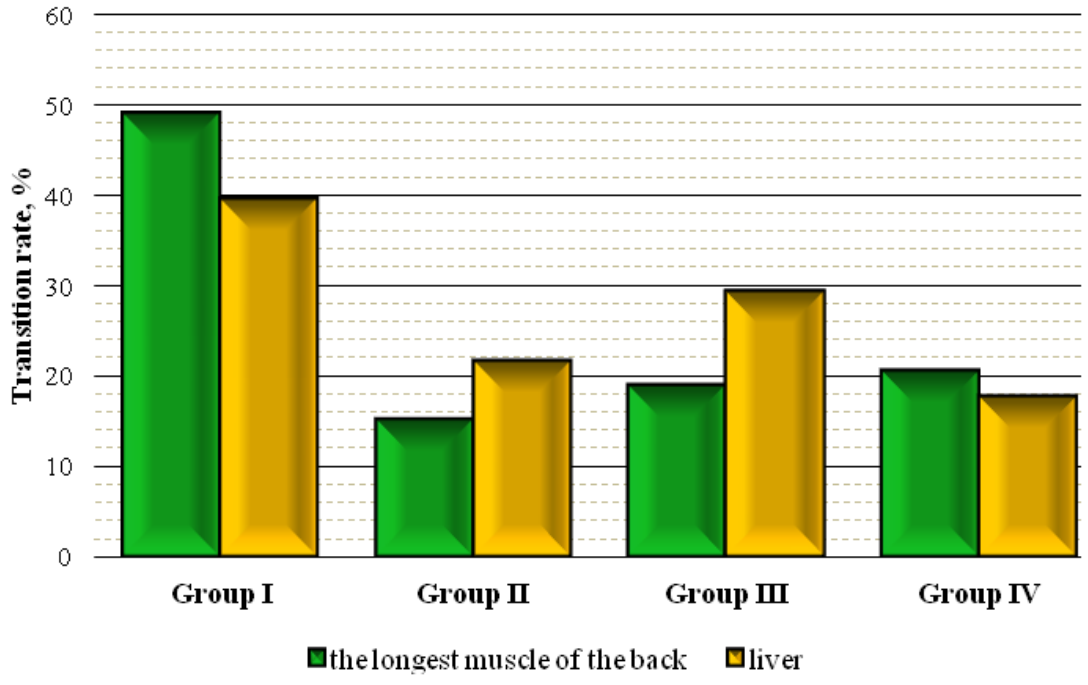

Fig. 3. Transfer coefficient of Pb in pig slaughter products.

The amount of Cd entering the body of young pigs for fattening with dietary fodders was significantly less than Pb and was 0.264-0.306 mg per day (Table 4). Studies have shown that the concentration of Cd in the muscle tissue of experimental pigs varied in a wide range of values – 0.077-0.124 mg/kg. This value in all experimental groups was higher than the maximum allowable concentration of 1.54-2.48 times. There is a tendency to reduce the content of Cd in muscle tissue depending on the dose of natural mineral sorbent in the diets of fattening pigs – in the longest back muscle of animals II, III, and IV (experimental) groups relative to I (control) group; the element concentration was lower by 0.037 mg/kg (29.8%), 0.027 (21.8) and by 0.047 mg/kg (37.9%), respectively.

The highest Cd content was accumulated in the liver of experimental animals – 0.121-0.178 mg/kg without exceeding MAC. Feeding pigs for fattening the natural mineral saponite in various quantities hurt the ecological quality of the liver – the concentration of Cd increased by 17.3-47.1%.

Cd rates in pork (the longest muscle) and liver were relatively high at 25.2-47.0 and 45.8-58.2%, respectively (Fig. 4). With the introduction of different doses of saponite in the diet, the transition of Cd to the longest back muscle of the experimental group animals decreased by 14.0-21.8% abs., compared to control. Young animals of the I (control) group have the lowest coefficient of Cd transition to the liver and the highest – the IV (experimental) group.

Table 4. The concentration of Cd in fodder rations and pig slaughter products.

Groups of pigs	an average daily diet, mg	Concentration of Cd products. mg/kg	towards the control group mg/kg	%
		Musculus longissimus dorsi		
I – Control	0.264	0.124 ± 0.037	-	-
II – Experimental	0.282	0.087 ± 0.020	-0.037	-29.8
III – Experimental	0.294	0.097 ± 0.024	-0.027	-21.8
IV - Experimental	0.306	0.077 ± 0.013	-0.047	-37.9
Mac	-	0.05	-	-
		Liver		
I – Control	0.264	0.121 ± 0.050	-	-
II – Experimental	0.282	0.142 ± 0.037	+0.021	+17.3
III – Experimental	0.294	0.147 ± 0.026	+0.026	+21.5
IV - Experimental	0.306	0.178 ± 0.027	+0.057	+47.1
MAC	-	0.30	-	-

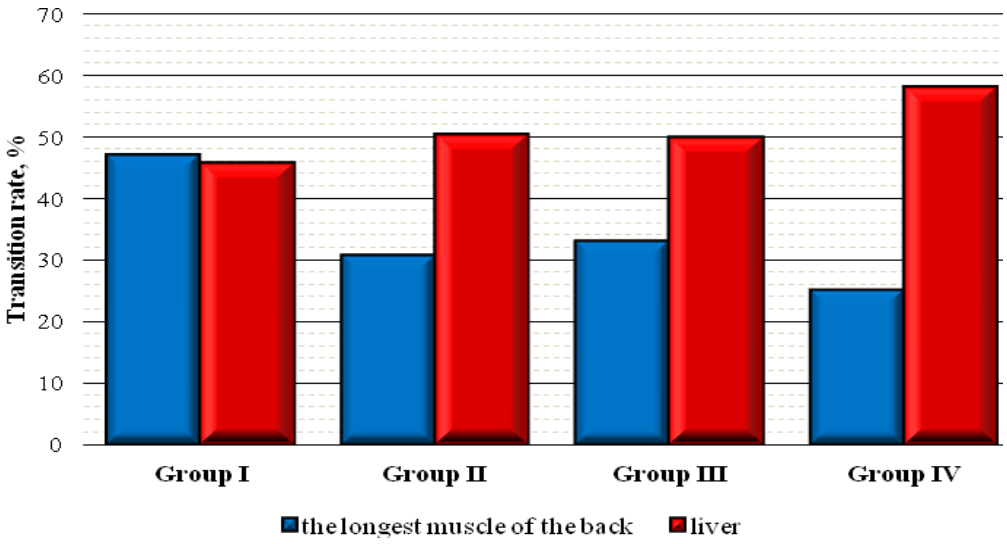

Fig. 4. Transfer coefficients of Cd in muscle tissue and liver of pigs.

Summarizing the above, we can conclude that feeding young pigs in the III zone of radioactive contamination and concentrated feed of the natural mineral saponite helps reduce the concentration of 137Cs, Pb, and Cd in the longest back muscle. According to the sorption efficiency for 137Cs i Cd, the best sorbent dose was 7% (by weight) of concentrated feed in the diet, and for Pb – a dose of 3%.

Discussion

Introduction of 3-7% (by weight) of complete fodder for fattening young pigs in the III zone of radioactive contamination into the feed rations of the natural mineral sorbent saponite had a positive effect on the ecological quality of pork, reducing the specific activity of 137Cs in the longest back muscle heavy metals, in particular, Cd and Pb. The transition of radionuclides and heavy metals from fodders to products depends on the environmental and technological conditions of production, type and degree of feed digestibility, age, the physiological condition of animals, and the level and completeness of feeding, balanced diets for substances with radioprotective (protective) properties. Due to their properties, natural minerals reduce the transformation of radionuclides and heavy metals from fodder into the body of animals due to the action of two mechanisms. The first mechanism is the transit of toxic substances through the body without inclusion in the metabolic process due to the high ion exchange and sorption properties of minerals. The second mechanism acts at the level of the animal organism, on the ability of minerals to normalize mineral metabolism (Kebko & Mamenko, 1994; Ogorodova et al., 2015). According to the authors (Bogdanov et al., 2002), when orally administered, sorbents in the fodder in the near-surface layers of their crystal structure bind to toxic components of chyme of exogenous and endogenous nature. In the gastrointestinal tract, sorbents act as a reliable barrier to the exclusion of xenobiotics from the metabolic processes that enter the fodder and are excreted from the intercellular environment and cell contents into the intestinal lumen. This reduces the content of radionuclides and heavy metals in the muscles and internal organs of animals.

Similar results have been obtained in other studies (Butsyak, 2002), which found that the use of zeolite as an adsorbent increased the binding of heavy metals in the gastrointestinal tract and their excretion from animals. Under the influence of the mineral, the accumulation coefficient of Pb, Cd, and Hg ions decreased by 40.9, 33.2 and 44.5%, respectively. Natural zeolites increased the content of heavy metals in the fecal masses of experimental cows by 2.4-23.6%, with a simultaneous decrease of their concentration in the urine by 1.6–13.2%.

Conclusion

The specific activity of 137Cs in the longest back muscle of young pigs ranged in groups within 12.8-19.9 Bq/kg and did not exceed acceptable levels (DR-2006 = 200 Bq/kg). Due to the introduction into the diets of young pigs of the natural mineral saponite in the amount of 3-7% (by weight of concentrated fodder), the concentration of radio-cesium in the muscle tissue of pigs II-IV (experimental) groups relative to control decreased by 2.0-7.1 Bq/kg, or 10.1-35.7% with an unreliable difference. At the same time, the dose of sorbent 7% (by weight) of concentrated fodder in the diet was the best in terms of sorption efficiency.

The concentration of Pb in the muscle tissue and liver of experimental animals was slightly lower than the MAC, while the level of contamination of the longest back muscle of young pigs of all Cd groups exceeded the regulatory requirements by 1.54-2.48 times. The use of saponite as an adsorbent for fattening animals in the III zone of radioactive contamination had a positive effect on the environmental quality of products – the accumulation of Pb and Cd in the muscle tissue of pigs of the experimental groups relative to control was lower by 5.9-52.7% and 21.8-37.9% respectively. According to the Pb sorption efficiency, the best dose of sorbent (as concentrated fodders) in the diet was 3%, and for Cd, this dose was 7%.

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