

Triticale diets and pork quality in the zone of radioactive contamination

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The study is devoted to the substantiation of the use of grain mixtures with different amounts of triticale in the diets of store pigs of large white breeds and to determine their impact on the quality and safety of pig products during its production in III zone of radioactive contamination caused by the Chernobyl accident. Based on the study, fodder grain mixtures for fattening of store pigs in Ukrainian Polissia have been developed. These mixtures make it possible to replace partially or entirely wheat with triticale in the diets of animals. It has been found that when 20-40% (by weight) of wheat groats in the grain mixture is replaced with a similar amount of triticale groats, the concentration of radiocaesium in muscle tissue of pigs in the experimental groups reduces by 9.6-9.8 Bq/kg or 30.7-31.3% compared to the control group. At the same time, the multiplicity of accumulation of ¹³⁷Cs in the musculus longissimus dorsi of piglets was 0.233-0.325 and was higher by 4.2-39.5% in animals which received grain mixture No. 1 without triticale, compared with the use of grain mixtures No. 2 and No. 3 (20-40 % of triticale by weight). The concentration of Pb, Cu, and Zn in the products of experimental store pigs was significantly lower than MAC, while the level of contamination of muscle tissue (groups I and II) and liver (groups I and III) with Cd exceeded the regulatory requirements by 2.0-2.4 times and by 24.7-28.7%, respectively. Replacement of 20-40% (by weight) of wheat groats in the grain mixture with a similar amount of triticale groats for fattening store pigs in III zone of radioactive contamination contributed to a much smaller transition of Pb, Cd, Cu, and Zn into musculus longissimus dorsi – by 3.27 (group III), 0.55-8.96, 1.15-1.27 and 0.52-7.86% absolute), respectively.

Keywords: store pigs, triticale, musculus longissimus dorsi, liver, ¹³⁷Cs, Pb, Cd, Cu, Zn.

Introduction

The current pace of agricultural development is accompanied by an adverse impact of pollutants of human-made origin on the environment. The Chernobyl accident led to the contamination of large areas of the Polissia zone of Ukraine with radioactive decay products. As a result of the termination of relevant measures due to the economic downturn in the country, the most important task of modern radioecology is the systematic control over contamination of livestock and crop products with radionuclides, as well as studying the specific aspects of their migration in agricultural ecosystems (Prister et al., 2007; Romanchuk et al., 2019; Bidenko & Slavov, 2016).

Another fundamental problem is the contamination of the area with heavy metals such as Pb, Cd, Cu, and Zn. These chemical elements 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 and animals (Honsky et al., 2001; Pavan Kumar & Prasad, 2004; Peng et al., 2015). The collective effect of radiocaesium and heavy metals leads to the activation of pathogenic mechanisms and acute and chronic intoxications of animal and human organisms.

Because Polissia is characterized by heterogeneous soil and climatic conditions, there is a different degree of contamination of landscapes on its territory, and hence the different degree of contamination of fodder with radionuclides and heavy metals. Given this, the accumulation of harmful substances in fodder crops in the area of radioactive contamination and their transition to livestock products largely depends on environmental and technological conditions of production.

Equally important is finding types of animal feed and diets that will help reduce the accumulation of ¹³⁷Cs and heavy metals in livestock products when produced in human-made pollution regions (Butsiak, 2002; Hea et al., 2005; Savchenko et al., 2017). According to the literature data (Bratyshko et al., 2014; Meale & McAllister, 2015), triticale merits serious attention in this regard. It is a hybrid of rye and wheat explicitly created to increase grain production and improve its quality. Triticale has high yield

potential, increased protein content, which determines its biological and nutritional value and feeding qualities. It is both a food crop and a fodder crop, and it is winter-hardy and drought-resistant. Groats contain B vitamins and more digestible protein than rye and wheat (Moharrery et al., 2015). At the same time, due to its high sulfur content, triticale grain is one of the most optimal fodder crops for feeding animals in the area of radioactive contamination (Stoliarchuk et al., 2008; Tarkowski et al., 1974), since sulfur-containing amino acids increase the resistance of a body to radiation, facilitate the excretion of toxic substances from the body and have radioprotective properties.

Studies by foreign authors (Al-Athart & Guenter, 1989; Swierezewska et al., 1989) provide various data on the inclusion of triticale in animal and poultry fodders 15 to 60%. Researcher Burgstallor, G. (1986) proposes to include up to 40% of triticale in the feed mixtures for pigs at the initial and final fattening stages. Positive signs were also observed when 50–60% of triticale was introduced. However, according to Gorkovenko L. et al. (2010), it is most optimal to include up to 10% triticale at the initial stage of fattening and 20% at the second stage of fattening of pigs; an increase of the level was accompanied by a decrease in average daily gain and deterioration of feed conversion.

The study aims to determine the content of ^{137}Cs , Pb, Cd, Cu, and Zn in fodders, muscle tissue, and liver in the store pigs with different composition of grain mixtures and to determine diets impact on the environmental quality and safety of the pig products.

Materials and methods

Experimental studies were conducted in the Institute for Agriculture of Polissia NAAS (village Grozyne, Korosten raion, Zhytomyr region). Store pigs of the large white breed (21 heads) were selected for the scientific and production experiment; they were divided into three groups. The duration of the comparative and experimental periods was 21 and 153 days, respectively.

According to the experimental scheme, all experimental groups' animals received grain mixture No. 1 during the comparative period. The mixture included concentrated feedstuff of local produce grown in zone III of radioactive contamination, with mixed feed concentrate K 55-13 (Table 1).

Table 1. Composition of grain mixtures for feeding experimental animals, % by weight

Ingredients	Groups		
	I (control) (grain mixture No. 1)	II (experimental) (grain mixture No. 2)	III (experimental) (grain mixture No. 3)
Wheat	75	55	35
Triticale	-	20	40
Lupine	10	10	10
Mixed feed K 55-13	15	15	15
Total	100	100	100

The difference in feeding pigs in the main period of the experiment was reduced because the I (control) group received the same feed diet as in the comparative period of the experiment. In particular, for piglets of the II (experimental) group, 20% of wheat groats in the diet was replaced with the same amount (by weight) of triticale, whereas for analogs of the III (experimental) group, by 40%, respectively.

The specific activity of ^{137}Cs in fodders and livestock products was determined on a spectrometer SEG-0.5. Preparation of plant and animal origin samples for the identification of heavy metals in their composition was carried out by the method of dry mineralization, and their analysis was conducted on the atomic absorption spectrometer "Kvant-2A" (National Standard, 2015). The experiment was carried out according to the requirements for zootechnical experiments on selecting and keeping animals-analogs in groups, storing technology, and using and accounting for fodders consumed. The diets of store pigs were balanced in terms of nutrients and minerals, which met their need for essential nutrients.

Results

In the area affected by the Chernobyl accident, more than 95% of radioactive substances enter the bodies of farm animals with fodders, mainly consisting of plants; a small amount of these substances enters the bodies of farm animals with water. Thus, animal husbandry's main task in areas contaminated with radionuclides is to provide animals with "clean" fodders. Unfortunately, this is not always possible. Therefore, the system of measures aimed at reducing the transfer of ^{137}Cs in livestock products involves the introduction of countermeasures that reduce the content of radionuclides in fodders; changes in animal feeding diets; addition of supplements and preparations that prevent the transfer of radiocaesium in milk and meat.

Scientific and experimental work was carried out in the third zone of the Chernobyl accident; the density of radioactive contamination of the territory is 5-6 Ci/km² (185–222 kBq/m²). The specific activity of diets in terms of ^{137}Cs in the experimental groups ranged within 69.5-96.4 Bq/day and was by 4.1-26.9 Bq/day (or 4.4-38.7%) higher in I (control) group than in II and III (experimental) groups, which is associated with the fact that experimental pigs consumed mixtures of different composition. The accumulation of radionuclide in winter wheat compared to triticale was likely much greater (Figure 1).

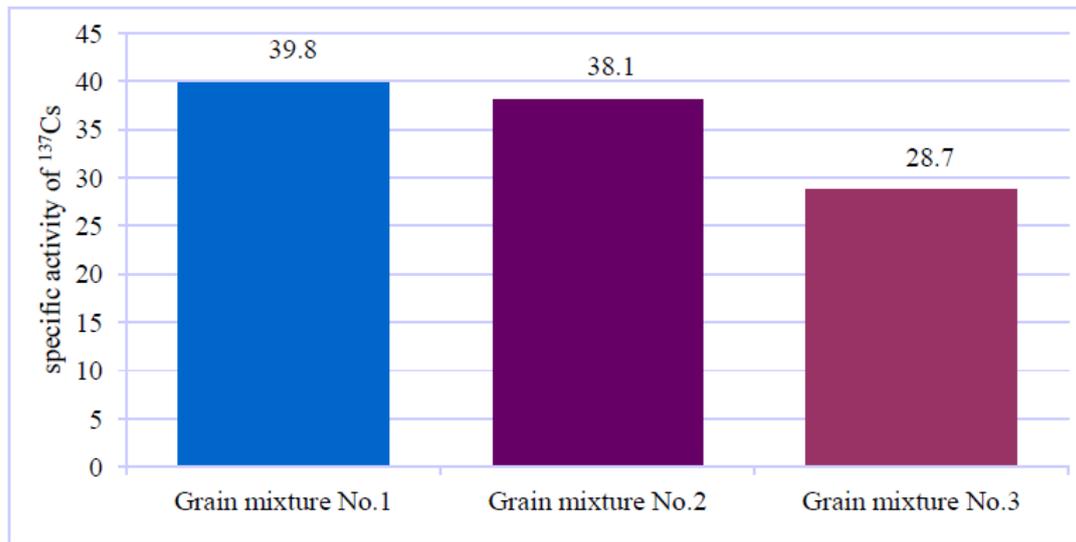


Figure 1. The specific activity of ¹³⁷Cs in grain mixtures for feeding pigs, Bq/kg

The studies showed a significant intergroup difference in the concentration of ¹³⁷Cs in musculus longissimus dorsi and liver of experimental pigs (Table 2). The specific activity of ¹³⁷Cs in musculus longissimus dorsi of animals ranged in groups from 21.5 to 31.3 Bq/kg and did not exceed allowable levels (DR-2006 = 200 Bq/kg). At the same time, when 20-40% (by weight) of wheat groats in the grain mixture was replaced with a similar amount of triticale groats (II and III experimental groups), the concentration of radiocaesium in muscle tissue is reduced by 9.6-9.8 Bq/kg or 30.7-31.3% ($P \leq 0.05-0.01$) compared to the control group.

Table 2. The concentration of ¹³⁷Cs in diet fodders and pig slaughter products ($n=3$; $M \pm m$)

Groups of animals	Concentration of ¹³⁷ Cs			
	an average daily diet, Bq	products Bq/kg	± to the control group	
			Bq/kg	%
Musculus longissimus dorsi				
I – control	96.4	31.3 ± 1.3	-	-
II – experimental	92.3	21.5 ± 1.1**	-9.8	-31.3
III – experimental	69.5	21.7 ± 1.6*	-9.6	-30.7
Liver				
I – control	96.4	27.5 ± 2.5	-	-
II – experimental	92.3	29.4 ± 2.2	+1.9	+6.9
III – experimental	69.5	24.6 ± 3.1	-2.9	-10.6

* and ** statistically significant at $p \leq 0.05$ and $p \leq 0.01$.

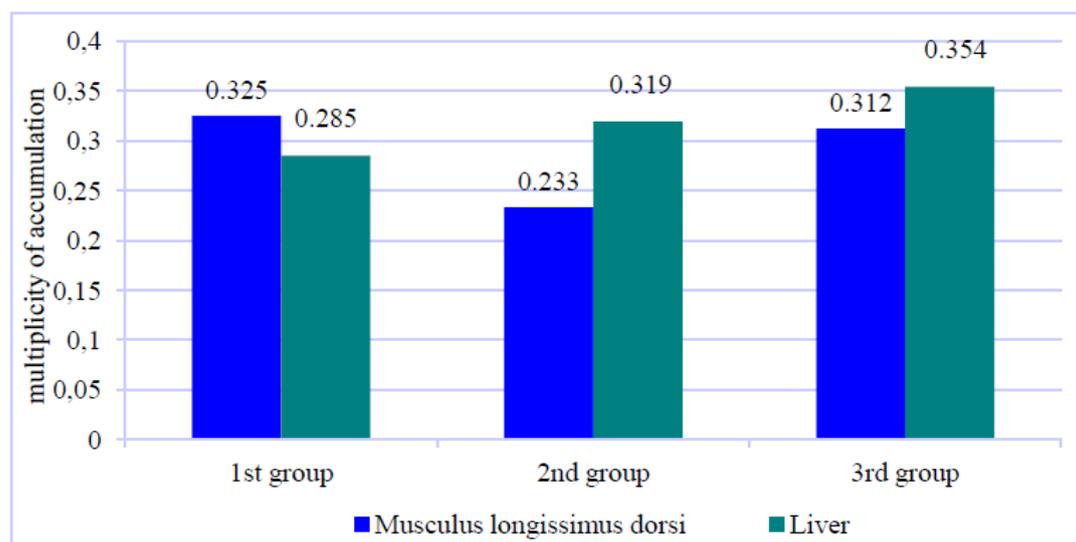


Figure 2. The multiplicity of accumulation of ¹³⁷Cs in musculus longissimus dorsi and liver of pigs

The multiplicity of accumulation of ^{137}Cs in musculus longissimus dorsi was 0.233-0.325 and was higher by 4.2-39.5% in-store pigs that received grain mixture No. 1 without triticale, compared with the use of grain mixtures No. 2 and No. 3 (20-40% of triticale by weight) (Figure 2).

A slightly different pattern was observed for the accumulation of ^{137}Cs in the liver of experimental pigs. This indicator was the highest in group II animals (29.4 Bq/kg) and the lowest in analogs of group III (24.6 Bq/kg). In terms of radiocaesium's specific liver activity, the I group's piglets occupy an intermediate position – 27.5 Bq/kg. Compared with the musculus longissimus dorsi, the concentration of ^{137}Cs in the liver of the experimental groups' animals was higher by 13.4-36.7%. However, this figure was lower by 12.1% when grain mixture No. 1 was used for feeding pigs.

The multiplicity of accumulation of ^{137}Cs in the liver of experimental animals varied in the range of 0.285-0.354 and was by 11.9-24.2% higher in piglets of experimental groups (II and III) compared with I (control) group. Given the above, it can be argued that the replacement of 20-40% (by weight) of wheat groats with triticale groats for fattening store pigs in the Polissia region of Ukraine leads to a significant decrease in the specific activity of ^{137}Cs in musculus longissimus dorsi and an increase in radionuclide accumulation in the liver.

Toxic chemical elements that enter the body of humans and animals (with food or fodder) are excreted slowly. Individual organs and tissues accumulate heavy metals in the body. Therefore, plant products and fodders that have been grown even on relatively clean or slightly contaminated soil can be a source of an excessive amount of heavy metals that enter the body and harm metabolism (Gutiy, 2013; Lorez et al., 2003). Studies have shown that the content of heavy metals in some grain mixtures exceeded the maximum allowable concentration (Figure 3). Thus, the concentration of Cd in grain mixture No. 2 (20% of triticale groats by weight) exceeded the MAC (0.3 mg/kg) by 10.0%, and the Zn content in this fodder was the highest (25.4 mg/kg). Grain mixture No. 1 contained a significant amount of Pb (0.96 mg/kg), grain mixture No. 3 contained a considerable amount of Cu (5.17 mg/kg). These values were lower than the regulatory requirements (5.0 and 30.0 mg/kg, respectively).

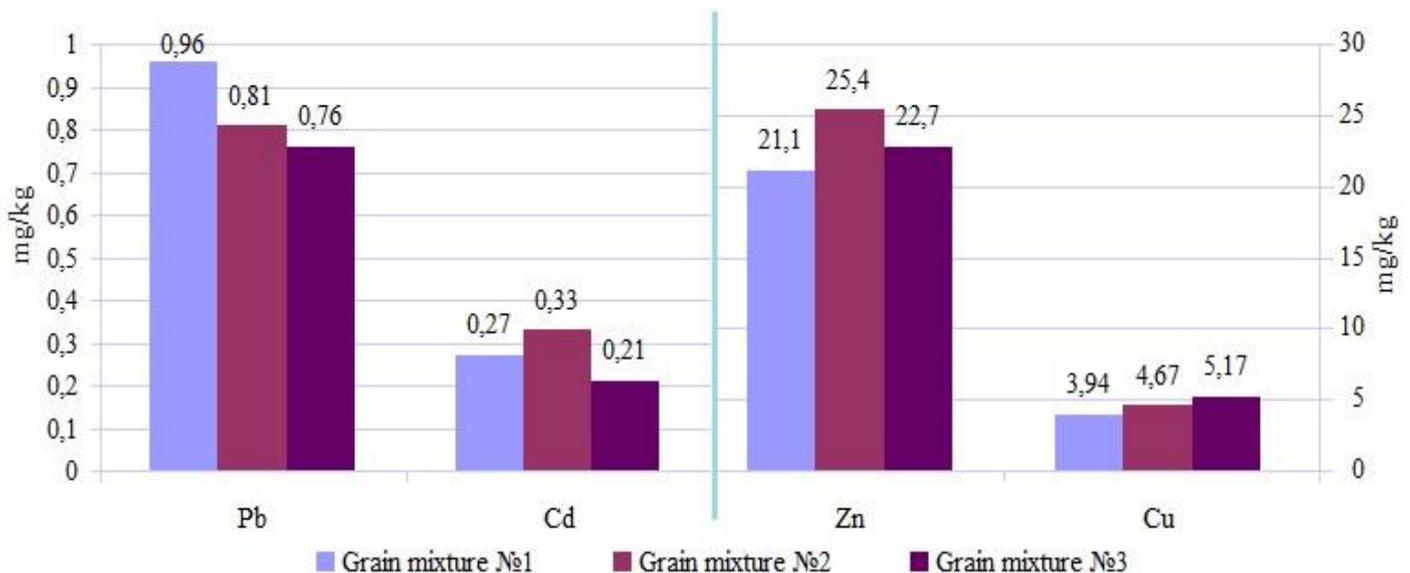


Figure 3. The concentration of heavy metals in fodders, mg/kg of natural fodder

Experimental studies have shown that a significant amount of heavy metals entered experimental pigs' bodies with feed diets. The Pb daily consumption in the store pigs ranged from 1.84 to 2.32 mg and was higher by 18.4-26.1% in the control group than in the experimental groups (Table 3).

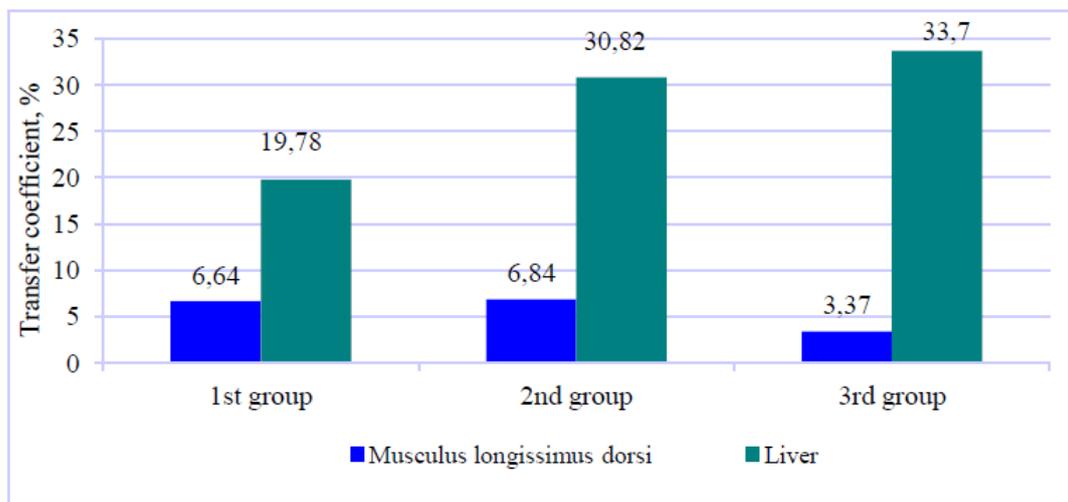
Studies have shown that in musculus longissimus dorsi of pigs of all experimental groups, the accumulation of Pb was significantly lower than the MAC (0.50 mg/kg); it varied within 0.062-0.154 mg/kg. However, as a result of the replacement of 20% (by weight) of wheat groats in the grain mixture with the relevant amount (by weight) of triticale groats, the concentration of Pb in the muscle tissue of animals of group II decreased by 0.020 mg/kg, or 13.0% compared with indicators for feeding store pigs with grain mixture No. 1. When 40% (by weight) of triticale groats was used in the grain mixture (III experimental group), in comparison to the control group, the Pb content in meat decreased by 0.092 mg/kg or 59.8% with a potential difference ($P < 0.01$). The opposite pattern was observed for the accumulation of Pb in the liver of experimental store pigs. Thus, when the amount of triticale was increased in the grain mixture, the concentration of the liver element of animals of II and III (experimental) groups compared with the I (control) group increased by 0.145-0.161 mg/kg, or 31.6-35.1%. It should be noted that the concentration of Pb in the liver of piglets of the experimental groups was higher than the MAC by 0.7-3.3%, while in the control group, it was 23.5% lower than the regulatory requirements.

As for the transition of Pb from diet fodders to musculus longissimus dorsi of store pigs, it should be noted that this indicator in animals of III (experimental) group was much lower than in I (control) and II (experimental) groups (Figure 4). Thus, the transfer coefficient of Pb in the meat of piglets of group III was 3.37%, while in other groups, it was higher by 3.27-3.47% abs. The use of triticale groats in grain mixtures No. 2 and No. 3 caused more intensive accumulation of Pb in the liver of animals of groups II and III – 30.82-33.70% compared to 19.78% in the control group, respectively.

Table 3. The concentration of Pb in feed diets and pig slaughter products

Groups of animals	Concentration of Pb			
	an average daily diet, mg	products mg/kg	± to the control group mg/kg %	
Musculus longissimus dorsi				
I – control	2.32	0.15±0.01	-	-
II – experimental	1.96	0.13±0.02	-0.02	-13.0
III – experimental	1.84	0.06±0.01**	-0.09	-59.8
MAC	-	0.50	-	-
Liver				
I – control	2.32	0.50±0.12	-	-
II – experimental	1.96	0.60±0.33	+0.15	+31.6
III – experimental	1.84	0.62±0.31	+0.16	+35.1
MAC	-	0.60	-	-

** statistically significant at $p \leq 0.01$.

**Figure 4.** Transfer coefficient of Pb in pig slaughter products

It has been suggested that the increase in Pb and Cd content in the soil, in fodders and pig products, was associated with the increased fallout from the Chernobyl accident and its elimination (experimental fields of the Institute are 80 km from Chernobyl).

Compounds of Cd affect the respiratory system and the gastrointestinal tract primarily. After absorption of the element into blood, its soluble compounds affect the central and peripheral nervous systems, internal organs, mainly the heart, kidneys, liver, skeletal muscles, and bone tissue. Animal experiments have shown gonadotoxic teratogenic effects; the Cd mutagen adversely affects heredity, destroys red blood cells, promotes testicular disease, and causes anemia (Kai-Fai et al., 1999). Cadmium raises blood pressure, which in some cases can cause a stroke. This element is a potent carcinogen; it can cause all forms of tumors (Kravtsiv & Vaseruk, 2001).

Cd's content, which entered the bodies of the experimental store pigs of the large white breed during its fattening with different grain mixtures, was significantly lower than Pb content, which was 0.509-0.799 mg/day (Table 4).

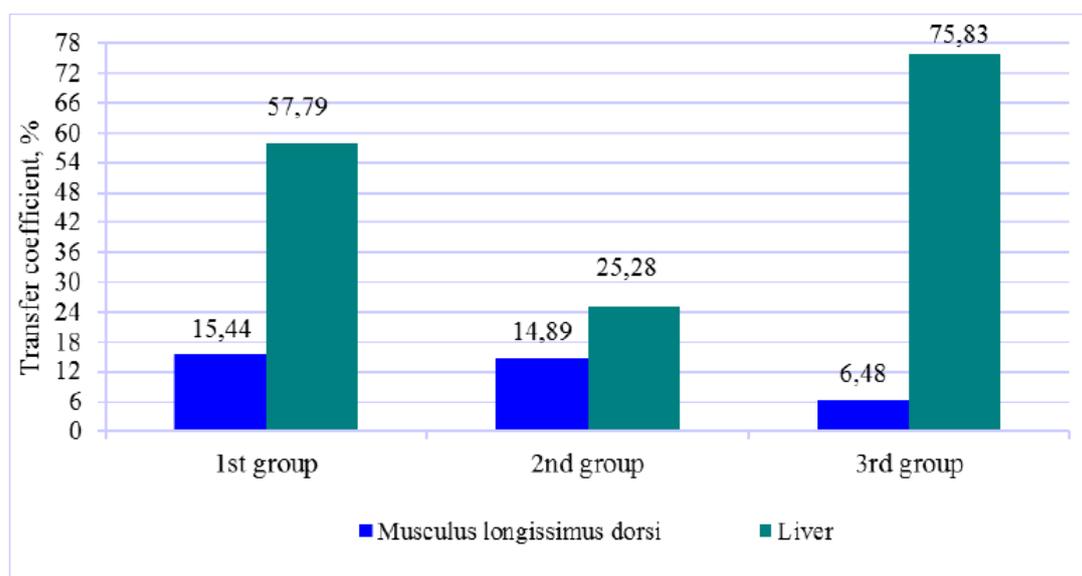
Studies have shown that Cd's concentration in the muscle tissue of experimental pigs varied in a wide range from 0.033 to 0.119 mg/kg. This indicator in groups I and II was higher than the maximum allowable concentration by 2.02 and 2.38 times, respectively, while in group III, it was significantly lower than the regulatory requirements - 0.033 mg/kg. There was a significant intergroup difference in the content of Cd in musculus longissimus dorsi depending on the type of mixture they were fed with: this figure was lower by 67.3% ($P \leq 0.01$) in the meat of store pigs of III (experimental) group, if compared with I (control) group, and by 72.3% ($P \leq 0.05$) if compared to II (experimental) group.

The most considerable amount of Cd is accumulated in the liver of experimental animals - 0.202-0.386 mg/kg. The maximum allowable concentration for the content of the liver of store pigs was exceeded in groups I and III by 24.7 and 28.7%, respectively. Instead, the lowest amount of Cd was found in the liver of piglets of group II (0.202 mg/kg), which were fed with a grain mixture of No. 2 (20% (by weight) of triticale groats). Transfer coefficients of Cd into pork (musculus longissimus dorsi) and liver were relatively high – 6.48-15.44 and 25.28-75.83%, respectively (Figure 5).

Table 4. Content of Cd in feed diets and pig slaughter products

Groups of pigs	an average daily diet, mg	Concentration of Cd		
		products mg/kg	± to the control group mg/kg	%
Musculus longissimus dorsi				
I – control	0.65	0.10±0.01	-	-
II – experimental	0.80	0.12±0.02	+0.02	+17.8
III – experimental	0.51	0.03±0.01**	-0.07	-67.3
MAC	-	0.05	-	-
Liver				
I – control	0.65	0.37±0.05	-	-
II – experimental	0.80	0.20±0.02	-0.17	-46.0
III – experimental	0.51	0.39±0.09	+0.01	+3.2
MAC	-	0.30	-	-

** statistically significant at $p \leq 0.01$.

**Figure 5.** Transfer coefficients of Cd in muscle tissue and liver of pigs

After triticale groats were introduced to grain mixtures in different amounts, Cd's transfer into musculus longissimus dorsi of the experimental groups' animals decreased by 0.55-8.96% abs compared to the control group. Store pigs of the II (experimental) group have the lowest Cd transfer coefficient into the liver, while III (experimental) group has the highest.

It is known that even a small amount of Cu, Zn, Fe, Co, Mo, Mn can act as trace elements necessary for the physiological processes of growth and development of plants, animals, and humans. As these elements are accumulated in an enormous amount than the body needs, they become harmful toxic metals and inhibit all the abovementioned processes. In this regard, we have conducted the study to determine the trace elements Cu and Zn in pig products (muscles and liver) under their cultivation in the III zone of radioactive contamination caused by the Chernobyl accident.

Cu's concentration in musculus longissimus dorsi of store pigs of all experimental groups was low (0.51-0.55 mg/kg) and did not exceed MAC (5.0 mg/kg). The use of grain mixtures of different compositions for fattening pigs did not significantly affect this element's content in meat.

The liver is the main Cu depot in animals; the Cu here is 10.9-13.7 times higher than in musculus longissimus dorsi. When the maximum proportion of triticale (40% by weight) was used in the proposed variants of grain mixtures, the concentration of Cu in the liver decreased by 0.76 mg/kg, or 11.2% concerning the control group with an incredible difference, whereas when moderate proportion (20% by weight) was used for feeding piglets, there was an increase of 3.4%. Simultaneously, in the store pigs of all experimental groups, the content of Cu in the liver was significantly lower than the regulatory requirements (20.0 mg/kg).

Transfer coefficients of Cu from dietary fodders to liver were high – 48.08-71.07% compared to 4.39-5.66% in musculus longissimus dorsi (Figure 6). A positive trend was noted – after triticale was introduced in the feed grain mixture, the accumulation of Cu in musculus longissimus dorsi and the liver of experimental animals decreased: group II - by 1.15 and 9.09%; group III - by 1.27 and 22.99% abs., compared to the control group, respectively.

Contamination with Zn of musculus longissimus dorsi and liver of store pigs of all experimental groups was low and 20.2-22.1 and 31.2-35.3 mg/kg, respectively significantly lower than MAC. Replacement of 20-40% (by weight) of wheat groats with the appropriate amount of triticale groats in the diets of animals did not have a significant effect on the concentration of Zn in the muscle tissue of pigs: in group II this figure was by 2.9% lower, and in group III by 6.2% higher than the control indicators. The trace element's content in the liver of store pigs of the experimental groups was slightly lower than in the control group (by 3.1-11.6%) with an incredible intergroup difference.

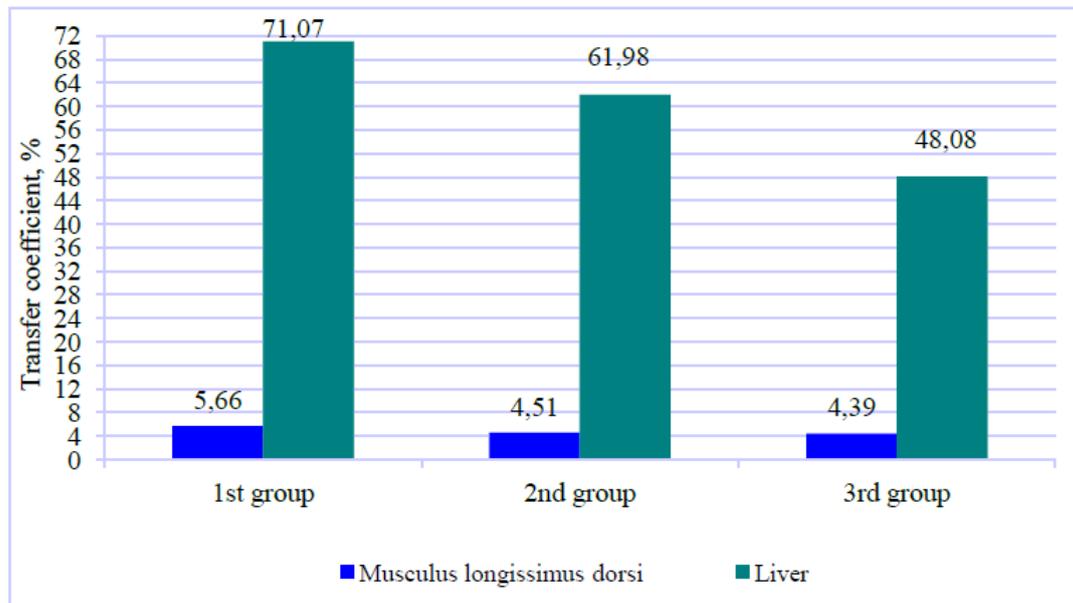


Figure 6. Transfer coefficients of Cu in products

Zn's transfer coefficients to slaughter store pigs' products were high and varied widely: from 32.84 to 40.70% in musculus longissimus dorsi, from 55.61 to 69.08% in the liver (Figure 7).

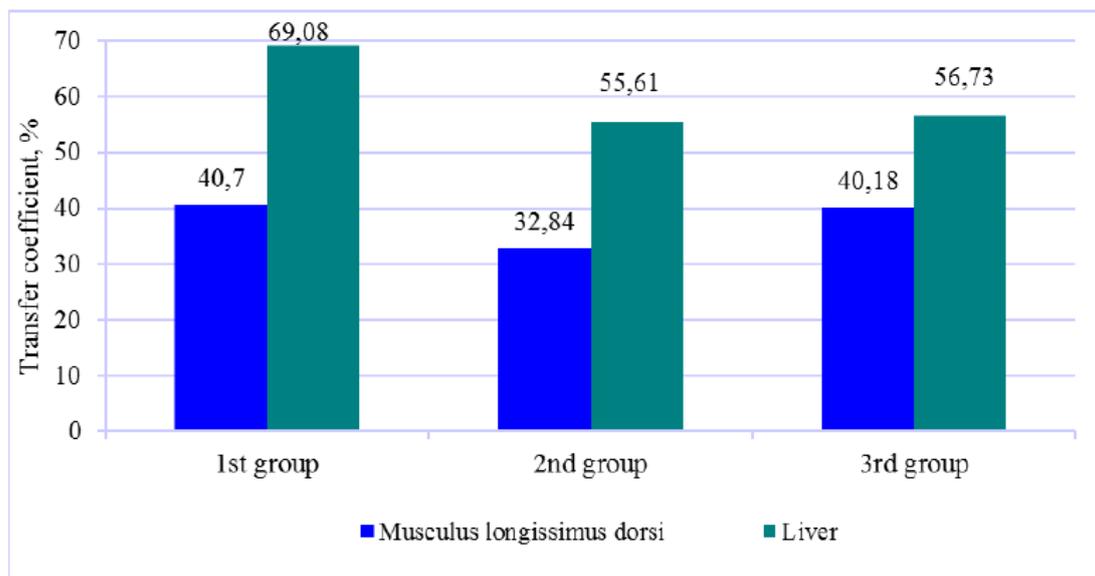


Figure 7. Transfer coefficients of Zn in products

When different proportions of triticale were used in grain mixtures, Zn's transfer coefficients into pig products were slightly lower than the control indicators: in muscle tissue by 0.52-7.86% abs., in the liver by 12.35-13.47% abs.

Based on the conducted study in the III zone of radioactive contamination, certain patterns of transforming heavy metals into products of the slaughter of store pigs have been found. Thus, according to our data, the transfer coefficients of individual metals were as follows (%):

- into musculus longissimus dorsi: Zn – 32.84-40.70 > Cd – 6.48-15.44 > Pb – 3.37-6.84 > Cu – 4.39-5.66;

- into liver: Cd – 25.28-75.83 > Cu – 48.08-71.07 > Zn – 55.61-69.08 > Pb – 19.78-33.70.

The abovementioned suggests that Zn has the highest migration and depositing activity in musculus longissimus dorsi, while Cu in the liver among the biotic metals. Regarding the migration capacity of the studied toxic metals, Cd is characterized by significant accumulation properties. Its transfer coefficients to pig products were 1.3-4.6 times higher than for Pb.

Discussion

Replacement of 20-40% (by weight) of wheat groats in the grain mixture with the appropriate amount of triticale groats for fattening store pigs in III zone of radioactive contamination had a positive effect on the environmental quality of pork, reduced the specific activity of ^{137}Cs and heavy metals in musculus longissimus dorsi, in particular Cd and Pb. This fact can be explained by a slightly higher supply of protein in the diets of store pigs of the experimental groups and its better amino-acid composition. Triticale grain and other grain crops contain the most important essential amino acid – lysine. Therefore, lysine content in triticale grain can be one of the indicators of the overall quality of protein. The content of lysine in triticale grain is increased (1.56 g/kg), i.e., almost 1.4 times higher than in wheat (Boros, 2002; Otchenashko, 2012). In the course of our study, the content of lysine in the diets of store pigs of II and III (experimental) groups was also higher by 11.7-23.4% compared with the I (control) group.

Besides, the transfer of radionuclides and heavy metals from fodder to products depends on environmental and technological conditions of production, type and degree of digestibility of fodder, age and physiological condition of animals, as well as it largely depends on the level and adequacy of feeding and on how well the diets are balanced in terms of substances that have radioprotective (protective) properties. These substances increase the body's resistance to radiation, accelerate radionuclides' excretion, and reduce their content in products. Such substances include many amino acids (especially sulfur-containing), fiber, minerals, vitamins (especially A, E, groups B, C) (Moharrery et al., 2015; Stolyarchuk et al., 2008).

Conclusions

The specific activity of ^{137}Cs in musculus longissimus dorsi of store pigs ranged in groups from 21.5 to 31.3 Bq/kg and did not exceed acceptable levels (DR-2006 = 200 Bq/kg). As a result of the replacement of 20-40% (by weight) of wheat groats in the composition of the grain mixture with the same amount of triticale groats, the concentration of radiocaesium in the muscle tissue of pigs of II and III (experimental) groups decreased concerning control by 9.6-9.8 Bq/kg or by 30.7-31.3% with a potential difference ($P \leq 0.05-0.01$). At the same time, the multiplicity of accumulation of ^{137}Cs in musculus longissimus dorsi of piglets was 0.233-0.325 and by 4.2-39.5% higher in animals that received grain mixture No. 1 without triticale, compared with the use of grain mixtures No. 2 and No. 3 (20-40% of triticale by weight).

The concentration of Pb, Cu, and Zn in experimental animals' slaughter products was significantly lower than MAC. Simultaneously, the level of contamination of musculus longissimus dorsi of store pigs (groups I and II) with Cd exceeded the regulatory requirements by 2.02-2.38 times. The introduction of 20-40% (by weight) of triticale groats in the grain mixture instead of the same amount of wheat groats for fattening animals in III zone of radioactive contamination contributes to a much smaller accumulation of heavy metals in the muscle tissue of pigs: Pb by 13.0-59.8 %, Cd by 67.3% (group III).

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