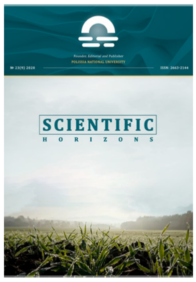
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 27(8), 35-46



UDC 636.084/085:637:546.4
Doi: 10.48077/scihor8.2024.35

Quality and safety of products using GM soybeans in the diet of bulls

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Article's History:
Received: 05.04.2024
Revised: 25.07.2024
Accepted: 28.08.2024

Abstract. The production of high-quality and safe food products in areas contaminated by radiation due to the Chornobyl Nuclear Power Plant accident remains a pressing issue. The aim of this study was to determine the concentration and transfer factors of 137Cs, Pb, Cd, Cu, and Zn in bull products when including various high-protein feeds, such as narrow-leaved lupin and genetically modified soybean, in their diets. The study employed zootechnical methods (design and conduct of a scientific-economic experiment on animals), radiological and spectrometric methods (determination of the concentration of 137Cs, Pb, Cd, Cu, and Zn in feeds, longissimus dorsi muscle, liver,

Suggested Citation:
Kovalova, S., Savchuk, I.,Tkachuk, V., Savchuk , O., & Pryimachuk, T. (2024). Quality and safety of products using GM soybeans in the diet of bulls. *Scientific Horizons*, 27(8), 35-46. doi: 10.48077/scihor8.2024.35.

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kidneys, and testes of bulls), and statistical methods. It was established that when using GM soybean in the grain mixture, the concentration of 137Cs in the muscle tissue of animals in Group II (experimental) decreased relative to the control by 2.57 Bq/kg, or by 40.5% with a statistically significant difference between groups ($P > 0.99$). Furthermore, the transfer factor of the radionuclide into the muscle tissue of animals in Group II compared to Group I also had 2.15% abs. lower. The content of Pb in the muscle tissue of bulls in both experimental groups exceeded the maximum permissible concentration by 2.52-2.78 times, while the concentration of Cd in the longissimus dorsi muscle and Cu in the liver of animals in Group II also exceeded sanitary-hygienic requirements by 10.0% and 2.0%, respectively. The introduction of 40% (by mass) of maize grain and 30% of GM soybean into the grain mixture instead of the same amount of wheat and lupin chop during the fattening of animals in the third zone of radioactive contamination contributed to significantly higher content and transfer of heavy metals into muscle tissue: Pb – by 10.3% and 0.10% abs., Cd – 10.0 and 0.03, Cu – 17.2 and 0.53, and Zn – by 17.2% and 2.40% abs. The results of the research can be used in agricultural enterprises and private households that produce livestock products in areas with a high anthropogenic load

Keywords: feeding; cesium-137; heavy metals; concentration; muscle tissue; kidneys; testes

INTRODUCTION

As a result of the accident at the Chornobyl Nuclear Power Plant, a large area of Ukrainian Polissya was contaminated with radioactive substances such as ^{137}Cs and ^{90}Sr. Their ingestion by animals through feed has necessitated the use of technologies in livestock production that enable the production of safe and high-quality food for the population living in these regions (Bartkowiak, 2021). Reducing the impact of the Chornobyl disaster on agriculture, specifically on crop production, forestry products, and livestock products produced on contaminated land, is a primary societal goal to ensure the supply of safe raw materials and products (Chobotko *et al*., 2023). Therefore, one of the primary objectives of modern radioecological science is the systematic monitoring of the contamination of plant and animal products with ^{137}Cs and ^{90}Sr, and the study of the migration patterns of these radionuclides in agricultural ecosystems (Romanchuk *et al*., 2019).

A significant challenge in the Polissya region is the contamination of soils with heavy metal salts such as Pb, Cd, Cu, and Zn (Savchuk *et al*., 2021). These heavy metals and their derivatives are toxic at high concentrations and can harm human health, animal productivity, and the quality of livestock products (Bakhrillaeva & Razamuradov, 2022). The primary sources of heavy metal pollution in the environment include industry, the thermal and chemical processing of minerals, the combustion of coal, gas, and liquid fuels, municipal waste (landfills, wastewater), and agriculture, particularly the excessive use of mineral fertilisers and pesticides (Nakagawa *et al*., 2022).

Heavy metals are dense metallic elements that accumulate progressively in the food chain, posing a threat to human health. However, some elements such as iron, iodine, cobalt, zinc, copper, manganese, molybdenum, and selenium are essential for various physiological functions and are often added as dietary supplements to animal feed (Chabanenko & Farionik, 2023). In contrast, other metals (Cd, Pb, Hg) do not have established biological functions and are considered pollutants. Heavy metals pose potential hazards due to their toxicity, bioaccumulation, and biomagnification, as they accumulate in living tissues more than they are excreted from the body (Abd Elnabi *et al*., 2023).

Lead is a chemical element belonging to the carbon group of the periodic table, with the symbol Pb and the Latin name *Plumbum*, meaning "liquid silver". It is considered one of the most dangerous heavy metal toxicants (Bernales *et al*., 2022). Lead can damage nearly every system in the body, including the haematopoietic, digestive, urinary, cardiovascular, and endocrine systems. It can also disrupt metabolic processes, the central and peripheral nervous systems, and damage cell membranes and cellular metabolism (Cuomo *et al*., 2020). According to studies by A. Ernyasih *et al*. (2023) and S. Satarug *et al*. (2023), Pb is a tissue toxin that accumulates over time and is found in the bodies of animals, particularly in bones, liver, kidneys, and brain. Research by A. Famurewa *et al*. (2022) has shown that lead exposure causes clinical pathological changes by increasing toxicity in the endocrine system and kidneys.

Cadmium (Cd) is a metal widely distributed in various ecosystems, not only in areas of radioactive contamination but also in soil and ore, where it is associated with zinc (Rahayuningsih *et al*., 2022). This metal is both a mutagen and a carcinogen, posing a significant genetic threat. It enters the environment through volcanic eruptions and is released by plants. However, the primary source of cadmium is anthropogenic (Yuan *et al*., 2019). Chronic cadmium poisoning disrupts calcium metabolism in bone marrow, causes anaemia, and adversely affects the central nervous, cardiovascular, reproductive, and musculoskeletal systems (Dasharathy *et al*., 2022). The high bioaccumulation factor of cadmium is a characteristic of this element's biological action, meaning that even low levels of long-term exposure can have negative health effects on animals.

Minerals such as copper (Cu) and zinc (Zn) are components of numerous enzymes that coordinate many biological processes, making them essential for maintaining animal health and productivity (Oconitrillo *et al.,* 2024). Essential micronutrients perform four critical functions: structural, physiological, catalytic, and regulatory. Zinc is necessary for maintaining and restoring barrier integrity, protecting against pathogens, and modulating the immune system by promoting the production of antibodies against intestinal pathogens (Duffy *et al*., 2023). Additionally, zinc can reduce diarrhoea and increase growth rates in weaned piglets. Copper is another important mineral with deep implications in animal husbandry. Adding to the diets of growing pigs results in faster growth and improved feed conversion ratio (Voloshchuk *et al*., 2020). In poultry, both copper and zinc help prevent certain diseases: copper prevents anaemia, while zinc acts as a catalyst for many enzymatic and hormonal reactions.

Given the broad spectrum of biological and toxic effects of ^{137}Cs and heavy metals and their negative impact on internal organs and animal systems, there is an urgent need to improve livestock management and feeding systems in regions with high levels of anthropogenic pollution in agricultural production. To reduce the accumulation of radionuclides (^{137}Cs) and heavy metal salts (Pb, Cd, Cu, Zn) in livestock products, research into different feeding types and rations for livestock production in the third zone of radioactive contamination following the Chornobyl NPP disaster is crucial. These studies aim to determine the accumulation of ^{137}Cs and heavy metals in the muscle tissue, liver, kidneys, and testes of bulls fed different protein-rich feeds.

MATERIALS AND METHODS

Experimental research was conducted at the physiological farm of the Polissya Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine, located in the Korosten territorial community, which falls within the third zone of radioactive contamination due to the Chornobyl disaster (Hrozyne village, Korosten district, Zhytomyr region), on young cattle (bulls) of Ukrainian Black-and-White dairy breed during 2022-2023. For the experiment, two groups of clinically healthy bulls (7 animal units in each) were formed using the balanced group method according to methodological guidelines (Ibatullin & Zhukorskyi, 2017). When forming the experimental groups, the origin, live weight, age, and growth rate of the animals during the comparative period were considered. The average live weight of the young cattle at the beginning of the experiment was 151.3-151.7 kg, and their age was 6.5-7.0 months. During the experiment, the animals were tethered and fed twice a day. The feeding and watering regimes, as well as the microclimate parameters, were identical in both groups. The duration of the comparative and experimental periods was 66 and 242 days, respectively.

The diets of the experimental animals did not differ significantly in terms of feed composition between the experimental groups, although the diets were balanced in terms of their content of major nutrients. The diets of the experimental animals were adjusted monthly according to the average daily gains and live weight of the animals, following modern detailed feeding standards and taking into account the actual chemical composition and nutritional value of the feed (Ibatullin *et al*., 2016). For feeding the bulls, cereal hay, mixed grass silage, wheat, triticale, and lupin chop were used, which were harvested from agricultural lands with a soil ^{137}Cs contamination level of up to 185 kBq/m^2. Maize grain and GM soy for the study were grown and supplied from a farm in Zhytomyr district (State Enterprise Research Farm "Nova Peremoha").

According to the experimental design, the young cattle in Group I (control) received a standard farm diet consisting of mixed grass silage, cereal hay, common salt, and grain mixture No. 1. Animals in Group II (experimental) received, in addition to the basic diet, grain mixture No. 2 (Table 1). The difference in feeding the experimental bulls during the main experimental period was that animals in Group I (control) received the same diet as in the comparative period of the experiment. Meanwhile, in Group II (experimental), 40% of wheat chop (by weight) in the diet was replaced with 40% corn chop, and 30% of lupin chop was replaced with an equal amount of genetically modified extruded soybeans. In the feed ration structure of the bulls, in terms of energy value, concentrates accounted for 39.4-41.3%, roughage for 23.8-24.6%, and succulent feed for 34.9-36.0%.

Table 1*. Composition of grain mixtures during the research, % by weight*

Concentrated feeds	Grain mixture No. 1	Grain mixture No. 2
Wheat chop	40	-
Corn chop	-	40
Lupine chop	30	-
GM extruded soybeans	-	30
Triticale chop	30	30
Total	**100**	**100**

Source: *compiled by the authors*

Feed samples were collected into polyethene bags, which were labelled with the feed name and the date of collection. The average sample weight for the analyses was 1.5 kg. Collected samples were delivered to the laboratory for further analysis on the day of collection. After the completion of the research, a control slaughter of three animals from each group was conducted at the Ovruch Meat Processing Plant, with live weights corresponding to the group averages, using the technology accepted in meat processing plants. The pre-slaughter live weight of the bulls in Groups I and II was 372.7 kg and 392.7 kg, respectively.

For laboratory analysis, samples of the longissimus dorsi muscle between the 9th and 12th ribs of the right half-carcasses were collected after 48 hours of cooling at 4°C. The weight of the collected samples of muscle tissue and liver was 1 kg, kidneys - 0.8-0.9 kg, and testes – 0.15-0.2 kg from each slaughtered animal. Samples were packaged in tight polyethene bags with zip closures. Labels were attached to the bags indicating the sample (product) code and animal number. The specific activity of ^{137}Cs in feed and products (longissimus dorsi muscle and liver) was determined using a SEG-0.5 gamma-ray spectrometer. Laboratory analyses of muscle tissue, liver, kidneys, and testes of animals, as well as feed for Pb, Cd, Cu, and Zn content, were conducted in the Agrochemical Research, Environmental Safety of Land, and Product Quality Laboratory at the Institute of Agriculture of Polissia NAAS. Plant and animal samples for heavy metal content were analysed using the atomic absorption method according to DSTU 7670:2014 (2015), with analysis performed on an atomic absorption spectrophotometer "Kvant – 2A".

The transfer factors (TF) of ^{137}Cs and heavy metals (Pb, Cd, Cu, Zn) from feed to animal products were calculated using the formula: $TF = C_{HMP}/C_{HMR} \times 100$, where TF is the transfer factor; C_{HMP} is the content of ^{137}Cs and heavy metals in animal products, Bq/kg, mg/kg; C_{HMR} is the content of ^{137}Cs and heavy metals in the daily ration, Bq, mg (Mamenko & Portyanyk, 2019). This factor is a relatively integrated indicator that reflects, in percentage terms, the migration of harmful substances from the diet into the product, allowing for a comparative assessment of the transfer of pollutants when using different feed mixtures for feeding bulls. The research data were processed using variation statistics based on the calculation of the arithmetic mean (M), mean squared error (m), and significance of the difference between comparable indicators (P) (Ruban *et al.*, 2020). All manipulations with animals were carried out by the European Convention for the Protection of Vertebrate Animals used for Experimental and Scientific Purposes, as well as the Law of Ukraine "On the Protection of Scientific Institutions Conducting Experiments and Experiments on Animals" (European Convention for the Protection..., 1986; Law of Ukraine No. 3447-IV..., 2006; Order of the Ministry of Agrarian Policy and Food of Ukraine No. 550 ..., 2017).

RESULTS AND DISCUSSION

Based on the average daily feed consumption by the animals and the ^{137}Cs content in the feed (Fig. 1), the average daily intake of this element into the bodies of growing and fattening bulls was calculated. In Group I, this figure was 123.2 Bq/day, which is 0.9 Bq/day higher than in Group II. In the course of the research, the main pathways of receiving ^{137}Cs entry into the animals' bodies: the lowest level of radioactive caesium was found in grain mixture No. 2 – 4.0 Bq/kg, and the highest – in mixed grass silage (7.5 Bq/kg).

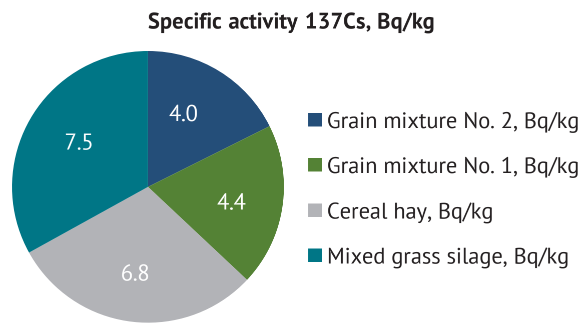

Figure 1*. The specific activity of ^{137}Cs in feed*
Source: *compiled by the authors*

Observations of the behaviour of bulls fed radioactively contaminated feed during the comparative and main observation periods did not reveal any abnormal symptoms in any of the animals. The study found a significant intergroup difference in the concentration of ^{137}Cs in the slaughter products of the experimental animals depending on the feed factor (Table 2).

Table 2*. Specific activity of 137Cs in bulls slaughter products, Bq/kg*

Indicators	Groups	
	I – Control	II – Experimental
^{137}Cs concentration in the feed, Bq/kg	123.2	122.3
^{137}Cs concentration in muscle tissue, Bq/kg	6.34 ± 0.24	3.77 ± 0.25**
137Cs concentration in the liver, Bq/kg	4.50 ± 0.15	4.88 ± 0.41

Note: *** $P > 0.99$*
Source: *compiled by the authors*

The examination results showed that the specific activity of ^{137}Cs in the longissimus dorsi muscle and liver of bulls in both experimental groups was within the range of 3.77-6.34 Bq/kg and 4.50-4.88 Bq/kg, respectively, which is significantly lower than the permissible levels (PL) for radionuclides in food products established by National Hygienic Regulations of Ukraine of permissible levels (MP) of radionuclides in food products (PL established in 2006 – 200 Bq/kg). At the same time, in animals that consumed diets with grain mixture No. 2, the concentration of ^{137}Cs in muscle tissue was 40.5% lower ($P > 0.99$), and in the liver 8.4% higher, compared to feeding the young animals with grain mixture No. 1. The transfer factors of ^{137}Cs into the longissimus dorsi muscle and liver of the experimental bulls were 3.08-5.15% and 3.6-3.99%, respectively. The highest transfer of ^{137}Cs into muscle tissue was observed in young cattle of Group I (control) – 5.15%, and into the liver – in animals of Group II (experimental) – 3.99% (Fig. 2).

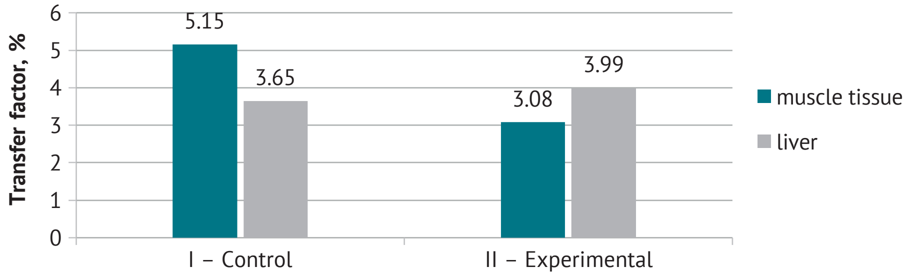

***Figure 2**. Transfer factors of ^{137}Cs to muscle tissue and liver of bulls*
***Source:** compiled by the authors*

The levels of heavy metals (Table 3) in some feeds exceeded the maximum permissible concentration (MPC) established by the Order of the Ministry of Agrarian Policy and Food of Ukraine in the "List of Maximum Permissible Levels of Undesirable Substances in Feed and Feed Raw Materials for Animals" (2017).

***Table 3**. Concentration of heavy metals in feeds, mg/kg of natural feed*

Heavy metals	MPC	Feeds			
		Cereal hay	Mixed grass silage	Grain mixture No. 1	Grain mixture No. 2
Pb	5.0	3.514	1.340	0.897	0.791
Cd	0.3	0.588	0.052	0.386	0.491
Cu	30.0	6.02	0.30	6.55	5.36
Zn	50.0	12.9	11.7	22.5	18.6

***Source:** compiled by the authors*

The research findings indicate that the levels of Pb, Cu, and Zn in roughage, succulent, and concentrated feeds grown on agricultural lands in the III zone of radioactive contamination did not exceed the maximum permissible limits. However, the highest amount of Pb was found in cereal hay, while Cu and Zn were most abundant in grain mixture No. 1. Currently, the amount of Cu and Zn in the analysed feed types is significantly lower than the maximum permissible concentration, which is confirmed by the data of Ukrainian authors on the deficiency of these microelements in feeds of the Polissia region of Ukraine (Ibatullin *et al.*, 2016). In terms of Cd content, most of the feeds exceeded the maximum permissible concentration. For example, this indicator was higher than the MPC for cereal hay by 96.0%, for grain mixture No. 1 by 28.7%, and for grain mixture No. 2 by 63.7%. The lowest amount of Cd was found in mixed grass silage – 0.052 mg/kg.

For feeding the experimental animals, diets with different types of grain mixtures were used with a Pb concentration ranging from 27.570 to 27.809 mg/day (Table 4). According to the Ukrainian State Sanitary Rules and Regulations "Maximum permissible levels of certain pollutants in food products" (Order of the Ministry of Health No. 1238, 2020), the maximum permissible level (MPL) of lead in meat is 0.10 mg/kg, in liver and kidneys – 0.5 mg/kg, and in testes – not regulated. The results of the examinations showed that the accumulation of Pb in the longissimus dorsi muscle exceeded the MPL in animals of both groups by 2.52-2.78 times. However, the concentration of this heavy metal in the muscle tissue of young cattle in Group II, relative to Group I, increased insignificantly by 10.3%. The content of lead in the liver and kidneys of animals in both groups was lower than the MPL by 20.8-26.6% and 35.4-40.4%, respectively. Nevertheless, feeding the bulls diets with GM soybeans compared to the control led to a decrease in Pb content in the liver by 7.3% and an increase in the concentration of the heavy metal in the kidneys and testes of animals by 8.4% and 19.7%, respectively.

***Table 4**. Pb concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Pb content in the diet, mg/kg	27.809	27.570
Pb content in muscle tissue, mg/kg	0.252 ± 0.004	0.278 ± 0.010
Pb content in the liver, mg/kg	0.396 ± 0.019	0.367 ± 0.004
Pb content in the kidneys, mg/kg	0.298 ± 0.008	0.323 ± 0.017
Pb content in the testes, mg/kg	0.193 ± 0.020	0.231 ± 0.041

***Source:** compiled by the authors*

The lowest transfer of this element to the longissimus dorsi muscle, kidneys, and testes was observed in the animals of Group I. However, in the liver of animals from this group, Pb levels were 0.09% higher than in Group II (Fig. 3). Based on the obtained data, it can be concluded that among the studied slaughter products of the bulls, Pb accumulates the most in the liver, followed by the kidneys and muscle tissue, with the least accumulation occurring in the testes. Consumption of hay, silage, and feed mixture No. 2 increased the intake of Cd in the animals of Group II by 0.238 mg/day compared to those in Group I (Table 5).

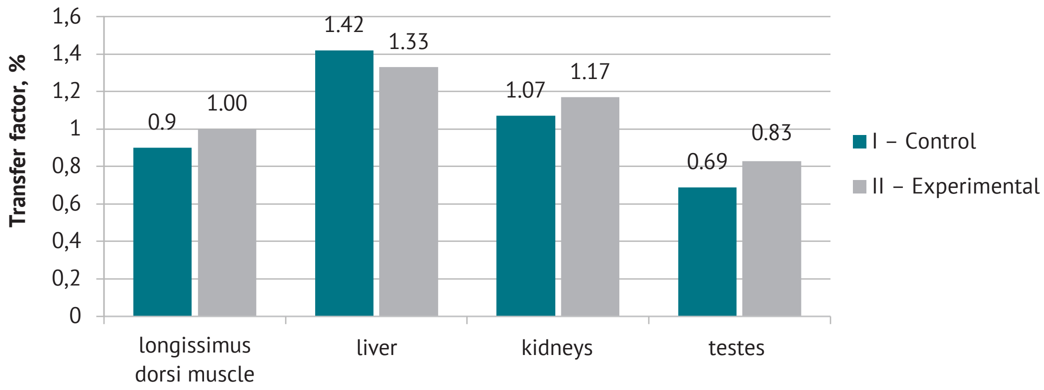

***Figure 3**. Pb transfer factors in slaughter products of bulls*
***Source:** compiled by the authors*

***Table 5**. Cd concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Cd content in the diet, mg/kg	2.961	3.199
Cd content in muscle tissue, mg/kg	0.050 ± 0.003	0.055 ± 0.003
Cd content in the liver, mg/kg	0.093 ± 0.011	0.088 ± 0.005
Cd content in the kidneys, mg/kg	0.169 ± 0.006	0.167 ± 0.004
Cd content in the testes, mg/kg	0.096 ± 0.009	0.110 ± 0.019

***Source:** compiled by the authors*

The conducted research indicated that the concentration of Cd in the longissimus dorsi muscle of young cattle in the fattening Group II (experimental) exceeded the MPC by 10.0%, while the content of this element in the muscle tissue of animals in Group I (control) was at the level of sanitary and hygienic requirements (0.050 mg/kg). At the same time, in bulls that consumed grain mixture No. 2 (Group II) as part of their diet, compared to grain mixture No. 1 (Group I), there was an increase in Cd accumulation in the longissimus dorsi muscle by 0.005 mg/kg, or by 10.0%, with no significant intergroup difference. The highest Cd content in the liver was found in the experimental young animals of the control group – 0.093 mg/kg, which did not exceed the normative values (0.50 mg/kg). In animals fed grain mixture No. 2, the concentration of Cd in the liver decreased by 0.005 mg/kg, or 5.4%, compared to Group I. The inclusion of different feed mixtures in the diet of the bulls during fattening did not significantly affect the Cd content in the kidneys and testes. Thus, when using grain mixture No. 2 compared to grain mixture No. 1, the element concentration decreased in the kidneys by 1.2% and increased in the testes by 14.6% at $P < 0.95$. The transfer factors of Cd into products were low and amounted to 1.68-1.71% in muscle tissue, 2.75-3.14% in the liver, 5.22-5.70% in the kidneys, and 3.24-3.43% in the testes (Fig. 4). It should be emphasised that the highest amount of this heavy metal accumulates in the kidneys of animals, followed by the testes, then the liver, and finally the longissimus dorsi muscle.

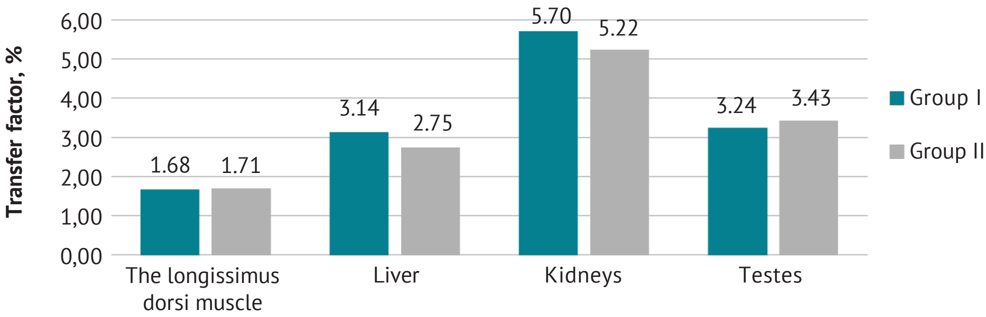

***Figure 4**. Cd transfer factors in slaughter products of bulls*

***Source:** compiled by the authors*

The concentration of Cu in the longissimus dorsi muscle, kidneys, and testes was low, ranging from 0.64-0.75 mg/kg, 2.92-3.37 mg/kg, and 0.63 mg/kg, respectively, and did not exceed the maximum permissible concentration (Table 6). The highest content of this element was found in the liver of the experimental animals – 16.0-20.4 mg/kg, which was slightly higher than the MPC in the latter case. In the muscle tissue, liver, and kidneys of bulls in the experimental group, whose diets included grain mixture No. 2 with genetically modified soybean, the copper content was higher compared to their counterparts in Group I (control) by 17.2% (P > 0.95), 27.5%, and 15.4% (P > 0.95), respectively.

***Table 6**. Cu concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	**II – Experimental**
Cu content in the diet, mg/kg	33.19	30.50
Cu content in muscle tissue, mg/kg	0.64 ± 0.02	0.75 ± 0.03*
Cu content in the liver, mg/kg	16.0 ± 3.56	20.4 ± 2.96
Cu content in the kidneys, mg/kg	2.92 ± 0.12	3.37 ± 0.06*
Cu content in the testes, mg/kg	0.63 ± 0.04	0.63 ± 0.09

***Note:** ** P > 0.99*

***Source:** compiled by the authors*

The transfer factors of Cu from feed rations to the liver of the animals were high – 48.20-66.88% compared to 1.90-2.06% in the testes, 1.93-2.46% in the longissimus dorsi muscle, and 8.80-11.05% in the kidneys (Fig. 5). A positive trend was observed: with the introduction of maize and GM soybeans into the feed grain mixture, the accumulation of Cu in the longissimus dorsi muscle, liver, kidneys, and testes of animals in Group II (experimental) relative to the control increased by 0.53% abs., 18.68%, 2.25%, and 0.16% abs., respectively.

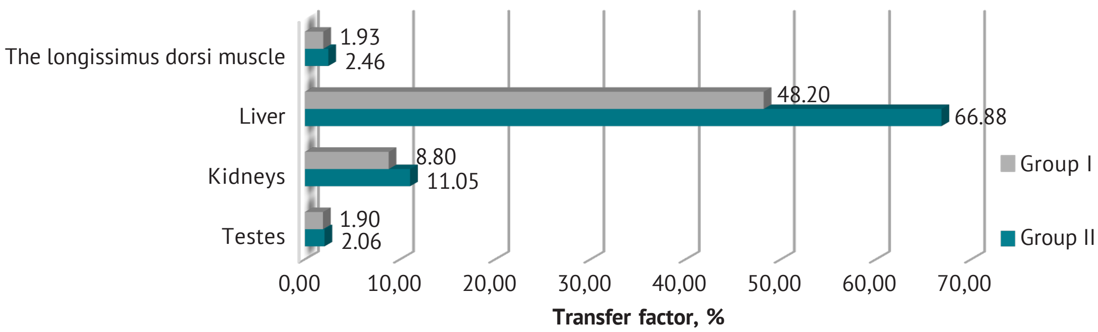

***Figure 5**. Cu transfer factors in slaughter products of bulls*

***Source:** compiled by the authors*

A significant amount of Zn was supplied to the experimental bulls with the feed rations (233.10-224.29 mg/day), therefore its accumulation in the products was the highest among the studied heavy metals: in the longissimus dorsi muscle – 25.5-29.9 mg/kg, liver – 30.9-31.0, kidneys – 13.98-15.10, and testes – 11.70-16.55 mg/kg without exceeding the MPC (Table 7). Moreover, when feeding young cattle in Group II with a grain mixture containing genetically modified soybean (30% by weight) compared to Group I (30% by weight of lupin), the concentration of Zn in slaughter products increased: in the longissimus dorsi muscle – by 17.2% ($P > 0.95$), liver – by 0.3%, kidneys – by 8.0%, and testes – by 41.4%.

***Table 7**. Zn concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Zn content in the diet, mg/kg	233.10	224.29
Zn content in muscle tissue, mg/kg	25.5 ± 0.49	29.9 ± 0.71*
Zn content in the liver, mg/kg	30.9 ± 5.17	31.0 ± 0.99
Zn content in the kidneys, mg/kg	13.98 ± 0.67	15.10 ± 0.49
Zn content in the testes, mg/kg	11.70 ± 1.32	16.55 ± 1.99

Note: *** P > 0.99*
Source: *compiled by the authors*

As a result, the transfer factors of Zn to the products of bulls in the experimental group (Group II) relative to the control group also increased: in the longissimus dorsi muscle – by 2.36% abs., in the liver – by 0.57%, in the kidneys – by 0.74%, and in the testes – by 2.36% abs. (Fig. 6).

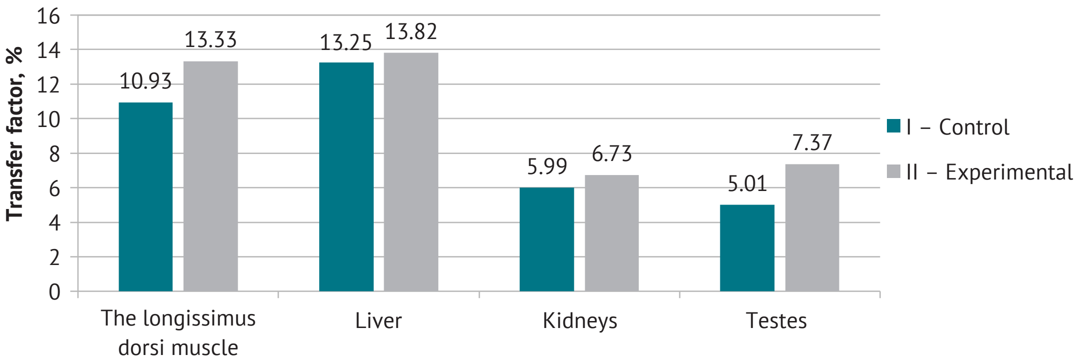

***Figure 6**. Zn transfer factors in slaughter products of bulls*
Source: *compiled by the authors*

Research conducted on young cattle grown in the third zone of radioactive contamination has revealed certain patterns in the transfer of heavy metals into animal products. According to the research results, the transfer factors of heavy metals were (%):

- in the longissimus dorsi muscle: Zn – 10.93-13.33 > Cu – 1.93-2.46 > Cd – 1.68-1.71 > Pb – 0.90-1.00;
- in the liver: Cu – 48.20-66.88 > Zn – 13.25-13.82 > Cd – 2.75-3.14 > Pb – 1.33-1.42;
- in the kidneys: Cu – 8.80-11.05 > Zn – 5.99-6.73 > Cd – 5.22-5.70 > Pb – 1.07-1.17;
- in the testes: Zn – 5.01-7.37 > Cd – 3.24-3.43 > Cu – 1.90-2.06 > Pb – 0.69-0.83.

These laboratory research results demonstrate and confirm that Zn exhibits the highest migratory and depositional activity in the longissimus dorsi muscle and testes, while Cu has the highest activity in the liver and kidneys. Cd also displays significant accumulation properties. The transfer factors of cadmium were 1.7-1.9 times higher than those of lead (Pb) in muscle tissue, 1.9-2.4 times higher in the liver, 4.5-5.3 times higher in the kidneys, and 3.9-5.0 times higher in the testes.

When growing cattle and producing beef in areas with varying levels of radionuclide contamination, the primary goal is to provide animals with "clean" feed and to reduce the transfer factors of ^{137}Cs and heavy metals into livestock products. However, this is not always achievable. Therefore, measures to significantly reduce the specific activity of radionuclides and the concentration of heavy metal salts in feed, as well as changes in the structure of animal diets and the addition of supplements to ensure adequate nutrition, can contribute to reducing the transfer of harmful substances into livestock products. Feeding animals clean and safe feed is not only crucial for their health but is also a significant factor in reducing the impact of toxic substances on human health. The accumulation of radionuclides and heavy metals in animal organs and tissues is a complex environmental issue that primarily depends on the concentration of toxicants in feed and the duration of feed consumption by animals. Other factors such as the age, weight, and sex of animals are less significant (Cygan-Szszegielniak & Stasiak, 2022).

According to R. Kulibaba *et al.* (2023), contaminated feed is the primary pathway for radionuclides to enter animal organisms after a nuclear disaster, while air and water intake were most significant for animals in the early stages of a nuclear accident. Furthermore, research by V. Kozak and V. Brygadyrenko (2018) revealed that chemical elements such as lead and cadmium and their compounds are highly toxic and do not decompose in soil or water. Instead, they migrate through the food chain, causing adverse effects on both humans and animals. The authors' studies indicate that the main contaminants of meat, liver, kidneys, and testes in animals in the Polissia region are coarse feed produced by natural drying and silage. Young animals have a biological capacity for intensive growth, development, and efficient utilisation of nutrients in muscle tissue when provided with a complete diet. Therefore, the production of high-quality beef should be based on a stable, environmentally friendly, and nutritionally complete diet for young animals from birth to slaughter, depending on age, breed, and live weight.

Following the conducted study, the authors compared the total amount of heavy metals ingested by bulls through feed and their content in muscle tissue, liver, kidneys, and testes. They observed the following accumulation patterns. Firstly, there is an uneven digestion of individual elements within the animal's body. Secondly, a significant portion of these elements is not deposited in the longissimus dorsi muscle or internal organs but is excreted from the body. Similar results were obtained in studies by I. Yashchuk and I. Savchuk (2021) when optimising the protein nutrition of bulls using various high-protein feeds. According to their data, the transfer factors to the young cattle's body were: copper – 3.62-3.97%, zinc – 3.33-3.41%, cadmium – 2.16-2.87%, and lead – 0.3-0.6%, which aligns with the results of the conducted experiment. Therefore, in conditions of high anthropogenic load to reduce the accumulation of harmful substances in animal organisms and obtain high-quality livestock products, scientifically sound feeding systems should be applied, balanced in terms of basic nutritional parameters.

According to both Ukrainian and international research, the transfer factors of radioactive substances and heavy metal salts from feed to livestock products are influenced by production and processing technologies, as well as environmental conditions (Mamenko & Portiannik, 2021; Chalabis-Mazurek *et al.*, 2021). The type and digestibility of feed, along with the age and physiological state of animals, significantly impact the transfer of these toxicants from feed to products. Additionally, the level and quality of animal feeding, a balanced diet in all nutrients with radioprotective properties, also influence transfer factors. Such substances can increase the body's resistance to radiation, accelerate the excretion of toxicants, and reduce their content in livestock products. These substances include sulphur-containing amino acids, minerals, vitamins A, E, B, and C, and fibre (Hashemi, 2018; Alengebawy *et al.*, 2021). Furthermore, selecting the optimal type of animal feeding can significantly reduce the transfer of radionuclides and heavy metals into livestock products, as confirmed by studies conducted on dairy cows, young cattle, and pigs.

It is anticipated that the findings of the authors' research will assist experts in understanding the biological mechanisms of the internal effects of ^{137}Cs, Pb, Cd, Cu, and Zn when feeding young cattle with diets containing various high-protein feeds in a radioactive contamination zone. This understanding is crucial for organising biologically complete feeding regimes and producing safe food products.

CONCLUSIONS

When using various high-protein feeds for optimising the protein nutrition of young cattle, it was found that the specific activity of ^{137}Cs in the longissimus dorsi muscle and liver of the experimental animals varied between groups within the range of 3.77-6.34 Bq/kg and 4.50-4.88 Bq/kg, respectively, and did not exceed the established standards (PL-2006 = 200 Bq/kg). At the same time, the introduction of GM soybean into the grain mixture led to a decrease in the concentration of radiocesium in the muscle tissue of bulls in Group II (experimental) compared to the control by 2.57 Bq/kg, or by 40.5% with a statistically significant difference ($P > 0.99$). Moreover, the transfer factor of the radionuclide into the muscle tissue of animals in the second group compared to the first group was also 2.07% lower (absolute). The concentration of Pb in the longissimus dorsi muscle of young animals in both groups was 2.52-2.78 times higher than the MPC, and the level of contamination of muscle tissue with Cd and liver with Cu in Group II of bulls also exceeded sanitary-hygienic requirements by 10.0% and 2.0%, respectively. The introduction of 40% (by mass) of maize grain and 30% of GM soybean into the grain mixture instead of the same amount of wheat and lupin chop during the fattening of animals in the third zone of radioactive contamination contributed to significantly higher content and transfer of heavy metals into muscle tissue: Pb – by 10.3% and 0.10% abs., Cd – 10.0 and 0.03, Cu – 17.2 and 0.53, and Zn – by 17.2% and 2.40% abs. Moreover, the use of grain mixture No. 2 in the diet of young cattle in Group II compared to Group I led to a higher concentration and transfer of heavy metals to all internal organs of the bulls, except for the content of Pb and Cd in the liver and Cd in the kidneys.

Further research will be aimed at studying various feedstuffs and feeding types for young mallard ducks to reduce the accumulation of radionuclides and heavy metals in duck products when growing poultry in the third zone of radioactive contamination as a result of the Chornobyl NPP accident.

ACKNOWLEDGEMENTS

The authors express their gratitude to the scientific and technical staff of the Animal Husbandry Department at the Polissia Institute of Agriculture of the NAAS for their assistance in conducting the laboratory and experimental research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Якість і безпечність продукції за використанням ГМ- сої в раціоні бугайців

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Анотація. Виробництво якісних і безпечних харчових продуктів в умовах радіоактивного забруднення території внаслідок аварії на Чорнобильській атомній електростанції було і залишається актуальною проблемою. Мета роботи – визначити показники концентрації та переходу 137Cs, Pb, Cd, Cu, Zn у продукцію бугайців за включення у їх раціони різних високобілкових кормів – люпину вузьколистого та генетично модифікованої сої. При проведенні досліджень використані наступні методи: зоотехнічні (постановка і проведення науково-господарського експерименту на тваринах), радіологічні і спектрометричні (визначення концентрації 137Cs, Pb, Cd, Cu, Zn в кормах, найдовшому м'язі спини, печінці, нирках і сім'яниках бугайців), статистичні. Було встановлено, що за використання у складі зерносуміші ГМ-сої, концентрація 137Cs в м'язовій тканині тварин II (дослідної) групи відносно контролю знижувалася на 2,57 Бк/кг, або на 40,5 % за статистично значущої міжгрупової різниці (P>0,99). До того ж коефіцієнт переходу радіонукліду в м'язову тканину тварин II групи порівняно з аналогами I групи також виявився меншим на 2,15 % абс. Уміст Pb у м'язовій тканині бугайців обох піддослідних груп перевищував гранично допустиму концентрацію в 2,52-2,78 раза, а концентрація Cd у найдовшого м'язі спини і Cu в печінці тварин II групи також виявилася більшою за санітарно-гігієнічні вимоги на 10,0 % і 2,0 % відповідно. Уведення до складу зерносуміші 40 % (за масою) дерті кукурудзи і 30 % ГМ-сої замість такої ж кількості дерті пшениці і люпину за відгодівлі тварин у III зоні радіоактивного забруднення сприяє значно більшому вмісту і переходу важких металів у м'язову тканину: Pb – на 10,3 % і 0,10 % абс., Cd – 10,0 і 0,03, Cu – 17 ,2 і 0,53 та Zn – на 17,2 % і 2,40 % абс. Результати досліджень можуть бути використані у сільськогосподарських підприємствах і особистих господарствах населення, які виробляють тваринницьку продукцію у зоні з підвищеним техногенним навантаженням

Ключові слова: годівля; цезій-137; важкі метали; концентрація; м'язова тканина; нирки; сім'яники
