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Impact of the Breed-Specific Characteristics on the Metabolism and Heavy Metal Accumulation in the Organs and Tissues of Calves

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Abstract.

The major sources of forage pollution with heavy metals in the Republic of North Ossetia (RNO) – Alania are the non-ferrous industry facilities. These toxic agents are harmful for animal health; therefore, studies on better adaptation of animals to the accumulation of heavy metals in organs and tissues, regarding specific features of a breed, are important for beef production. The goal of our studies is the comparative assessment of the metabolic characteristics in calves of different dairy and dairy-beef breeds raised on a diet with elevated heavy metal concentrations in the RNO – Alania. Methods: The studies were conducted in calves of different breeds: group I – Black Pied, group II – Red Danish, group III – Schwyz, group IV – Simmental calves. The heavy metal concentrations in forage, organs and tissue samples were measured with atomic absorption spectrometry. The statistical analysis of the data was conducted with the SNEDECOR software package. Results: The highest growth intensity was observed in the animals of group IV, whose absolute body weight gain was 14.98% higher than in their matched controls. Moreover, the Simmental calves had the highest level of digestion and assimilation of the alimentary nutrients. The best adaptation to the impaired ecological characteristics of the nutrition was observed in the Simmental calves. The highest content of heavy metals was detected in fur, then, in decreasing order, in bones → liver → muscle tissue → lungs → kidneys. The animals of the examined breeds can be listed in the descending order of heavy metal accumulation in the assessed organs and tissues: Simmental → Schwyz → Red Danish → Black Pied. In Simmental calves, the content of the elements did not exceed the corresponding maximum permissible concentrations (MPC).

Keywords: calves, animal breed, heavy metals, digestibility and assimilation, organs and tissues, detoxication.

INTRODOCTION

The metabolism of fattening animals is highly affected by chemical and biological pollutants. Among them, heavy metals hold a special place. The biological impact of heavy metals is related to their high toxicity and their ability to accumulate in the organism, causing polytropic negative effects. Their toxicity is caused by the ability to form insoluble compounds with proteins, which leads to altered properties or even inactivation of a whole range of vital enzymes [1-3].

The RNO – Alania is one of the regions with the highest levels of heavy metal pollution in Russia due to a large number of the industrial facilities in Vladikavkaz. Among the major polluters of the environment are the non-ferrous industrial plants, AOOT "Magnit", OAO "Elektrotsink" and others. Lead, zinc, and cadmium are at the top of the list of heavy metal pollutants due to high rates of accumulation in the environment caused by industrial operations [4-5].

In view of this, the task of studying metabolic features and accumulation of heavy metals in organs and tissues of fattening calves of different dairy and dairy-beef breeds, raised on a diet with elevated heavy metal concentrations, in the industrial area of the RNO – Alania is highly relevant.

The aim of the study

was to perform comparative assessment of the metabolic characteristics in the calves of different dairy and dairy-beef breeds raised on a diet with elevated heavy metal concentrations in the RNO – Alania.

Table 1. Design of the scientific and production experiment

Group	Number of animals	Breed	Basic diet (BD) with increased concentrations of Zn, Pb and Cd
I – control	10	Black Pied	BD
II – experimental	10	Red Danish	BD
III – experimental	10	Schwyz	BD
IV – experimental	10	Simmental	BD

Table 2. Live weight gain in the experimental animals over the period of the study, kg

Parameters	Group			
	I	II	III	IV
Live weight, kg:				
at the beginning of the experiment	158.63 ± 0.35	158.92 ± 0.28	159.25 ± 0.24	160.44 ± 0.48
at the end of the experiment	407.32 ± 3.25	422.47 ± 3.01	431.44 ± 3.20	446.38 ± 3.55
Live weight gain:				
absolute, kg	248.69 ± 3.36	263.55 ± 3.35	272.19 ± 3.74	285.94 ± 4.11
mean daily, g	681.34 ± 16.1	722.05 ± 17.4	745.72 ± 18.3	783.40 ± 19.3
% of control	**100.0**	**105.9**	**109.4**	**114.9**

Note: n = 10

MATERIALS AND METHODS.

To achieve our goal, we conducted a scientific and production experiment on the premises of "Myasoprodukty" farming enterprise of the RNO – Alania. The study involved fattening calves of Black Pied, Red Danish, Schwyz, and Simmental breeds, i.e., young dairy and beef-dairy cattle. The experimental design is shown in Table 1.

According to the design, we have selected 40 calves at the age of 6 months and divided them into 4 groups of matched controls, each containing 10 animals, based on their breed, age, sex, and live weight.

Each month during our study, we collected the average samples of the whole range of forage used for feeding the experimental animals, which were then subject to the full zootechnical analysis. It was shown that all own-produced forages had excessive content of zinc, lead, and cadmium. Therefore, the diets of the experimental calves contained increased amounts of heavy metals (Cd, Pb, and Zn). The diets of the experimental animals were supplemented with the enzymatic preparation Celloviridin G20x at a dose of 0.01% of the dry matter of the ration.

We conducted a physiological experiment, using the calves of group I (control), and group IV (the most productive experimental group) at the age of 15 months, to examine the effects of the excessive heavy metal content on the digestion of the alimentary nutrients, and on the assimilation of nitrogen, calcium, phosphorus, zinc, lead, and cadmium, according to N.I. Ovsyannikov's methodical guidelines (1976). We selected 3 animals of each group that were kept separately, in individual stalls, to facilitate the collection of urine and feces.

The content of zinc, lead, and cadmium in the samples of forage, organs and tissues of the animals was measured with atomic absorption spectrometry, using the AAZ-115-M1 spectrophotometer.

The experimental data were analyzed with Student's t-tests.

RESULTS.

In the course of the scientific and production experiment, we studied the content of heavy metals in the daily rations of the calves of the examined breeds in relation to their age. The diets of the experimental calves contained excessive amounts of zinc: at the age of 6-9 months – 2.14-fold higher; 9-12 months – 2.48-fold higher; 12-15 months – 1.90-fold higher, and 15-18 months – 1.90-fold higher. The rations of the experimental calves of these age groups contained the following amounts of lead – 124.26; 192.46; 216.96; and 264.00 mg, and cadmium – 10.27; 13.27; 14.91; and 18.18 mg, respectively.

We calculated the absolute and mean daily live weight gain in the animals of the examined groups from the results of control weighing (Table 2).

According to the experimental data, the highest growth rates under the heavy metal intoxication were observed in the calves of the experimental group IV that had significantly ($P<0.05$) higher final body weight by the age of 18 months, exceeding the body weights of the animals of Black Pied, Red Danish, and Schwyz breeds by 3.71%, 5.91%, and 9.59%, respectively.

In the Black Pied calves, the absolute live weight gain was 248.69 kg. The highest growth rate was observed in the animals of group IV that had 14.98% higher ($P<0.05$) absolute body weight gain than their matched controls. The highest mean daily live weight gain occurred in the calves of group IV – 783.40 g, which is 14.98% higher ($P<0.05$) than in the control group. The values of this parameter in the animals of groups II and III fell between the values in their matched controls in the control group and group IV.

During the fattening of calves in the context of disturbed ecological characteristics of nutrition, particular attention should be paid to the efficiency of forage use, i.e., conversion of the nutrients to the final product.
We calculated the digestion coefficients for the dietary nutrients to assess the efficiency of forage use by the calves of the examined breeds during the physiological experiment (Table 3).
We observed the lowest digestion coefficients for the dietary dry matter (67.42%) and organic matter (69.68%) in the Black Pied calves, which was significantly ($P<0.05$) lower than in the Simmental calves – by 4.11 and 4.19%, respectively.
The highest rates of hydrolysis of the dietary raw protein, raw fibers, and nitrogen-free extractive substances (NFES) were found in the Simmental calves, whose digestion coefficients were significantly ($P<0.05$) higher than in the Black Pied animals – by 4.09%, 6.94%, and 4.50%, respectively.
The growth rates depend on the assimilation of the alimentary nutrients, most significantly, proteins. Therefore, in the course of the physiological experiment, we assessed the dietary nitrogen use by the calves of the examined breeds (Table 4).
The animals of the experimental group IV accumulated 4.40 g, or 14.91% more nitrogen ($P<0.05$) than their age-matched controls. The rates of dietary nitrogen assimilation were in agreement with the mean daily body weight gain in the experimental fattened calves. Moreover, the calves of the experimental group IV had significantly ($P<0.05$) higher proportion of assimilated nitrogen of the dietary input (by 2.77%) and of the digested amount (by 2.41%), as compared to the control group.
The rates of heavy metal assimilation in calves are very important for the assessment of the impact of breed-specific features on the parameters of digestion and ecological and nutritional value of the meat products, which is why we calculated the zinc, lead, and cadmium balance for the calves of the experimental groups (Table 5).

Table 3. Digestion coefficients for the dietary nutrients in the calves, %

Parameters	Group	
	I	IV
Dry matter	67.42 ± 0.21	71.53±0.42
Organic matter	69.68 ± 0.33	73.87±0.65
Raw protein	64.59 ± 0.34	68.68±0.57
Raw fiber	60.54 ± 0.56	67.48±0.37
Raw fat	58.92 ± 0.41	59.51±1.03
NFES	75.01 ± 0.34	79.51±0.34

Note: n = 3

Table 4. Nitrogen balance in the experimental calves, g

Parameters	Group	
	I	IV
Dietary nitrogen uptake	158.12 ± 0.53	158.20 ± 0.41
Nitrogen excreted with feces	55.85 ± 0.31	49.74 ± 0.29
Nitrogen excreted with urine	72.76 ± 0.34	74.55 ± 0.37
Nitrogen accumulated in the body	29.51 ± 0.22	33.91 ± 0.30
Nitrogen assimilation	18.66 ± 0.35	21.43 ± 0.42
%:of the uptake of the digested nitrogen	28.85 ± 0.30	31.26 ± 0.41

Table 5 – Zinc, lead, and cadmium balance in the experimental calves, mg

Group	Dietary uptake	Excreted		Accumulated	Assimilated, % of the uptake
		with feces	with urine		
Zinc balance, mg					
I	829.82 ± 0.041	191.96±0.004	223.50±0.003	414.36±0.006	49.93±0.46
IV	812.71 ± 0.029	204.20±0.006	243.17±0.004	365.34±0.017	44.95±0.61
Lead balance, mg					
I	256.09 ± 0.039	56.43 ± 0.004	74.27 ± 0.003	125.39 ± 0.006	48.96 ± 0.43
IV	250.78 ± 0.029	61.28 ± 0.002	78.21 ± 0.004	111.29 ± 0.008	44.38 ± 0.49
Cadmium balance, mg					
I	17.62 ± 0.019	3.51 ± 0.002	5.67 ± 0.003	8.44 ± 0.002	47.90 ± 0.27
IV	17.27 ± 0.014	3.62 ± 0.002	6.06 ± 0.004	7.59 ± 0.002	43.95 ± 0.41

Note: n = 3

Table 6. Heavy metal content in the organs and tissues of the calves

Organs and tissues	Group			
	I	II	III	IV
Zinc content, mg/kg				
Muscles	74.13 ± 0.15	64.56 ± 0.18	56.31 ± 0.22	39.07 ± 0.11
Bones	119.8 ± 0.29	131.8 ± 0.31	182.5 ± 0.27	221.8 ± 0.39
Liver	91.8 ± 0.16	88.8 ± 0.17	69.5 ± 0.21	46.8 ± 0.18
Kidneys	41.14 ± 0.17	48.55 ± 0.12	68.78 ± 0.11	78.11 ± 0.15
Lungs	71.44 ± 0.21	67.51 ± 0.14	52.35 ± 0.20	41.07 ± 0.16
Fur	138.9 ± 0.24	151.8 ± 0.31	262.5 ± 0.37	279.8 ± 041
Lead content, mg/kg				
Muscles	0.62 ± 0.002	0.55 ± 0.001	0.49 ± 0.002	0.37 ± 0.003
Bones	1.98 ± 0.004	2.19 ± 0.003	2.61 ± 0.002	3.42 ± 0.005
Liver	0.98 ± 0.003	0.93 ± 0.0030.	0.63 ± 0.003	0.53 ± 0.003
Kidneys	0.26 ± 0.003	0.29 ± 0.002	0.38 ± 0.003	0.48 ± 0.004
Lungs	0.60 ± 0.001	0.56 ± 0.001	0.32 ± 0.002	0.29 ± 0.002
Fur	2.18 ± 0.003	2.30 ± 0.0023	3.56 ± 0.004	3.68 ± 0.004
Cadmium content, mg/kg				
Muscles	0.071 ± 0.001	0.065 ± 0.001	0.059 ± 0.001	0.044 ± 0.001
Bones	0.289 ± 0.002	0.314 ± 0.002	0.378 ± 0.001	0.443 ± 0.002
Liver	0.097 ± 0.001	0.089 ± 0.001	0.062 ± 0.001	0.055 ± 0.001
Kidneys	0.027 ± 0.003	0.032 ± 0.003	0.039 ± 0.003	0.047 ± 0.003
Lungs	0.061 ± 0.001	0.057 ± 0.001	0.036 ± 0.002	0.030 ± 0.002
Fur	0.297 ± 0.002	0.318 ± 0.002	0.408 ± 0.004	0.459 ± 0.003

Note: n = 3

During the physiological experiment, the animals were consuming approximately equal amounts of zinc; however, the zinc balance in the calves of group IV was 49.02 mg lower than in their age-matched controls ($P<0.05$). The animals of group IV also showed 4.98% lower zinc assimilation rates than the calves of the control group.

The metabolic experiment has shown that the Black Pied calves accumulated 14.10 mg more lead ($P<0.05$) than the Simmental animals. They also had significantly ($P<0.05$) higher assimilation rates than the calves of group IV (by 4.58%).

The animals of the control group, on the average, accumulated 8.44 mg of cadmium per day, while the calves of group IV had 0.85 g lower accumulation rates ($P<0.05$). The cadmium assimilation rates were 3.95% lower in the animals of group IV than in their age-matched controls.

If the calves of different breeds are fed with the diets with increased content of heavy metal salts, the concentrations of toxins in organs and tissues, as well as the ratios between the accumulating organs, are changing (Table 6).

Zinc, lead, and cadmium content in the organs and tissues of the calves was highly variable. The highest content of heavy metals was detected in fur, then, in decreasing order, in bones → liver → muscle tissue → lungs → kidneys.

Certain consistent correlations were observed between the heavy metal content in the organs and tissues of the experimental animals and their meat productivity, ecological and nutritional quality of meat. It was shown that the rates of live weight gain in the calves of the compared groups and the content of heavy metals in the muscle tissue, liver, and lungs of the experimental animals were negatively related. We believe that the reason for this pattern is decreasing content of zinc, lead, and cadmium per unit volume of tissues and organs, caused by larger muscle mass and weight of the listed organs.

The highest heavy metal content was observed in the muscles, liver, and lungs of the calves of group I (Black Pied), being significantly ($P<0.05$) larger than in the animals of group IV (Simmental), with zinc levels 1.90, 1.96, and 1.74-fold higher, lead – 1.68, 1.85, and 2.07-fold higher, and cadmium – 1.61, 1.76, and 2.03-fold higher, respectively. In Simmental calves, the content of the elements did not exceed the corresponding maximum permissible concentrations (MPC).

We observed negative correlation between the heavy metal content in muscles, liver and lungs, and fur, bones and kidneys. Therefore, the highest levels of these toxic agents in fur, bones and kidneys were observed in the calves of group IV (Simmental), with zinc content being significantly ($P<0.05$) higher than in the animals of group I by a factor of 2.01, 1.85, and 1.90, lead content – 1.69, 1.73, and 1.85, cadmium content – 1.54, 1.53, and 1.74, respectively. We believe that the reasons for that are, on the one hand, that bones and fur are the main depots for the toxic agents, and, on the other hand, the Simmental animals excreted more zinc, lead and cadmium through their kidneys, with urine than the age-matched animals of other breeds. The latter argument is in agreement with the data on the heavy metal balance in the experimental animals from the physiological experiment.

DISCUSSION.

In the context of the industrial zone of the RNO – Alania, the breed-specific features had a substantial impact on the growth rates, digestion and assimilation of the nutrients, and the rates of heavy metal accumulation in the organs and tissues of the calves of the examined groups. The Simmental calves had the highest values of the absolute and mean daily live weight gain. These animals showed the highest rates of the nutrient digestion and dietary protein assimilation. Under the elevated content of heavy metals in the forage, the Simmental calves had the highest rates of zinc, lead, and cadmium excretion, which indicates the best adaptation to the disturbed ecological characteristics of the nutrition. In this view, the animals of the examined breeds can be listed in the descending order of heavy metal accumulation in the assessed organs and tissues: Simmental → Schwyz → Red Danish → Black Pied.

CONCLUSIONS.

Among the target dairy and beef-dairy breeds of the industrial zone of the RNO – Alania, breeding of the Simmental calves with remarkably well-developed protective mechanisms, providing a lower heavy metal accumulation in the muscle tissue and a higher ecological and nutritional value of beef, appears to be the most rational approach.

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