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Method for Producing Environmentally Safe Meat in Radioactively Contaminated Area

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ABSTRACT

The purpose of this research was to study the possibility of cattle breeding in a radioactively contaminated area and to develop methods of purifying the animal body from cesium-137 before slaughter to obtain environmentally safe meat. Experiments were conducted on 4 groups of calves of Simmental breed grown with the cows and after weaning in a feedlot or in a fattening complex. The density of radioactive contamination by cesium-137 in the core sector was up to 925 kBq/m^2, out at grass 851-1110 kBq/m^2, in the "Clean" area, where the fattening complex was located to 185 kBq/m^2. For the period of cleaning the calves-body with clean feeds, the decrease multiplicity of the cesium-137 content in comparison with the control was 17.0-33.7 times, respectively. Similar results were obtained in the study of animal internal organs (heart, liver, lungs and kidneys). The meat production was safe for use in human food.

Key words: Radioactive contamination, radiocesium, beef, specific activity of the slaughter products, meat safety

INTRODUCTION

Due to the successful development of nuclear power engineering for peaceful purposes, there is emerged risk of technogenic accidents and disasters with the release of radioactive substances into the environment and the contamination of large areas (Ismail *et al*., 2003; Gaso *et al*., 2004; Sokouti *et al*., 2013). The most large-scale accidents of that kind have occurred at nuclear power stations "Chernobyl" (Ukraine) and Fugusima-1 (Japan). After the accident at the Chernobyl nuclear power station, about 0.5 million ha of land were withdrawn from agriculture in Belarus. In Russia, the area of contaminated land with a density of cesium-137 (15 Ci/km^2 and higher) was 2.4 thousand km^2, in Ukraine 1.5 thousand km^2 (Ilyazov *et al*., 2002; Draganov and Levakhin, 2014; Levakhin *et al*., 2014a).

Recent studies have shown that the production of "Clean" plant products and milk in the areas with contamination density of cesium-137 higher 15 Ci/km^2 is practically impossible without a set of measures, for example, the use of radionuclide sorbents (Green and Dodd, 1988; Zach and Mayoh, 1984; Alexakhin *et al*., 1991; Rahman *et al*., 2007; Melki and Sallami, 2008; Khotimchenko *et al*., 2014). Meanwhile, in the territories contaminated with cesium-137 of 40 Ci/km^2 or more, the beef production that meets the requirements of permissible limits is quite possible with technology of beef cattle "Cow-calf", followed by raising and fattening in a feedlot or in a complex. It is practicable under at least 1 of the following conditions, which are of vital importance: the livestock is provided with "Clean" rations in the final fattening period (Levakhin *et al*., 2014a) or the bodies of the animals are cleaned with sorbents having a selective action to radionuclides (Giese, 1988; Hofmann *et al*., 1990; Draganov and Levakhin, 2014).

The beef cattle breeding technology does not require large material expenses and most importantly, considerable human resources. Cattle, particularly of beef breeds, sustain a high level of background radiation of 25-40 Ci/km^2 and higher and adverse weather conditions without pathological changes in the physiological state (Levakhin *et al*., 2014b). In the area of "Relocation", the shift method of livestock management is quite acceptable: in summer, on enclosed pastures, in winter and in feedlots.

MATERIALS AND METHODS

The experimental part of the work was carried out in the Khoinikskij rayon in the Republic of Belarus. The 4 groups of newborn calves of Simmental breed, 10 heads in each were chosen for the experiment. Up to 8 months of age, the suckled calves were grown with the cows (the first 3 months-indoors and at the age of 3-8 months-out at grass). After weaning the calves of I and II experimental groups were transferred to the feedlot and of III group to the fattening complex, which was in the area clean of radioactive contamination. The difference was that the young stock in the control group was fed a diet contaminated with radionuclides (DCR) in all periods of the experiment, in I test group the DCR for 450 days and the rations of "Clean" feed (RCF) for 90 days, in II test group the DCR for the first 240 days and RCF later on (300 days), in III test group the young stock was fed a diet identical to the diet in II test group but after weaning (for 240 days) was kept in the fattening complex, which was located in a clean area.

The clinical indices are the body temperature, which was measured rectally using an electronic veterinary thermometer SC 12 (HauptnerandHerberholz, Germany), the pulse determined by palpation on the femoral artery pulsation, the breathing rate defined according to the movement of the chest and shocks of exhaled air. The hematologic parameters were measured using an automated hematology analyzer for veterinary Mindray BC-2900 Vet (Shenzhen Mindray Bio-Medical Electronics Co., Ltd, China) and a biochemical analyzer Stat Fax 1904+ (Awareness Technology, USA). The ethological indices were determined by visual observation and the use of video cameras (Sony, Malaysia) followed by systematization of the main manifestations of animal life.

The specific activity of feed and slaughter products of the animals were measured by gamma spectrometry (Adkam, USA; Nokia AU-10-24). The live-animal estimate was performed by a radiometers (SRP-68-01, Russia; "Silena", Italy).

The increase in weight of the experimental animals was determined by weighing at the age of birth, 8, 12, 15 and 18 months. The beef production of the animals was studied on the basis of the control slaughter of 3 calves from each group at the end of the experiment.

The data on different variables, obtained from the experiment were statistically analyzed by Statistica 10 package (StatSoft Inc.). The significance of differences between the indices was determined using the criteria of nonparametric statistics for the linked populations (differences with $p<0.05$ were considered significant: $^{c}p<0.001$, $^{b}p<0.01$, $^{a}p<0.05$, ns = not significant at $p>0.05$). Student's t-test was applied for the statistical analysis (Johnson and Bhattacharyya, 2010).

RESULTS AND DISCUSSION

In the course of the experiment, the density of radioactive contamination with cesium-137 was up to 925 kBq/m^2 in the base farms (“Sudkovo”, “Strelichevo”), up to 1110 kBq/m^2 out at grass, 185 kBq/m^2 in the clean area, where the fattening complex was located. Both of the base farms had hayfields and laylands with relatively low level of cesium-137 (up to 135 kBq/m^2) that allowed making the diets with different total activity of cesium-137 (Table 1). The exposure dose rate of air in the pasture was 180-240 mcR/h, in the feedlot, 80-120 mcR/h, in the fattening complex, 14-20 mcR/h.

Experimental diets of the young stock during the suckling period consisted of cow's milk and pasture grass, in the feedlots of hay mixed grass crop (in summer, herbage of cocksfoot) and fodder (0.5-1.0 kg in the nursery period and 3.0 kg in the fattening period), in the complex of hay mixed grass crop, silage (in summer, herbage) and fodder (1.3-1.8 kg in the nursery period and 3.0 kg in the fattening period). In general, the food consumption in the complex was nutritionally higher by 6.9% then in the feedlots that ensured the better growth for the youngsters (Table 2).

The level of the radioactive contamination of the diets the animals received did not influence their weight increase, which was about the same and as an aside not very high because of the limited range of feed as it was prepared in the area of high contamination density and limited time for animal care in heavy conditions (not more than 4 h). In this connection, the young stock in the fattening complex in the clean area with more comfortable conditions of feeding and housing

Table 1: Content of cesium-137 in the diets of animals for each periods of experiment (Bq kg^{-1})

Group	Nurse-cow (240 days)	Nursery (210 days)	Fattening (90 days)
DCR in all periods of the experiment	8.9-14.8	28.3-70.0	66.5-78.9
DCR for 450 days and RCF for 90 days	8.9-14.8	28.3-70.0	3.8-4.5
DCR for the first 240 days and RCF later on (300 days)	8.9-14.8	1.8-2.3	3.8-4.5
after weaning (for 240 days) was kept in the fattening complex, which was located in a clean area	8.9-14.8	2.3-3.2	2.8-3.4

DCR: A diet contaminated with radionuclides, RCF: Rations of "Clean" feed

Table 2: Dynamics of body weight and its average daily gain of the test animals

Indices	DCR in all periods of the experiment	DCR for 450 days and RCF for 90 days	DCR for the first 240 days and RCF later on (300 days)	After weaning (for 240 days) was kept in the fattening complex, which was located in a clean area
Live weight (kg)				
At birth	35.1±0.48	34.8±0.45	35.0±0.47	35.4±0.42
8	200.5±1.31	200.1±1.34	199.8±1.39	200.2±1.48
12	275.8±1.25	274.4±1.05	275.4±1.04	292.6±2.05^{c}
15	344.2±2.52	345.7±1.41	344.9±1.19	382.8±2.45^{c}
18	435.6±3.93	437.3±2.48	438.2±2.34	486.8±2.63^{c}
Average daily gain (g)				
0-8	689.0±18.42	690.0±26.34	687.0±15.16	686.0±28.14
8-12	627.0±16.44	617.0±18.43	630.0±10.32	770.0±18.32^{c}
12-15	760.0±20.72	792.0±14.12	772.0±20.41	1002.0±15.14^{c}
15-18	1015.0±14.45	1018.0±17.40	1037.0±11.20	1152.0±18.35^{c}
0-18	742.0±12.43	745.0±16.40	747.0±12.40	835.0±14.19^{c}

^{c}: $p<0.001$

Table 3: Hematological and biochemical parameters of calves at the age of one month

Indices	DCR in all periods of the experiment	DCR for 450 days and RCF for 90 days	DCR for the first 240 days and RCF later on (300 days)	After weaning (for 240 days) was kept in the fattening complex, which was located in a clean area
Erythrocytes (10^{12} L^{-1})	8.42±0.22	8.16±0.14	8.230±0.32	8.00±0.17
Leukocytes (10^9 L^{-1})	7.52±0.16	7.36±0.28	7.300±0.41	7.43±0.25
Hemoglobin (g L^{-1})	109.40±3.08	112.60±3.12	108.700±3.12	110.50±2.77
Glucose (mmol L^{-1})	3.86±0.23	3.77±0.21	3.910±0.14	3.80±0.16
Cholesterol (mmol L^{-1})	3.70±0.63	3.74±0.52	3.790±0.78	3.73±0.82
Total protein (g L^{-1})	57.50±1.52	56.80±1.44	58.300±1.66	57.80±1.54
Albumin (g L^{-1})	26.30±0.80	25.20±1.03	27.700±1.14	26.90±0.94
Globulin (g L^{-1})	31.20±1.33	31.60±1.24	30.600±1.17	30.99±1.11
α	11.70±1.21	11.40±0.82	12.000±0.90	11.20±0.76
β	9.30±1.07	9.60±0.54	9.400±0.62	9.70±0.56
γ	10.20±0.60	10.60±0.58	9.200±0.58	10.00±0.67
Triiodothyronine (nmol L^{-1})	2.34±0.17	2.52±0.22	2.410±0.19	2.46±0.16
Thyroxine (nmol L^{-1})	75.41±5.26	83.21±4.48	89.160±6.12	78.10±5.26
Insulin (mcU mL^{-1})	81.16±0.98	82.16±1.12	80.070±1.06	82.51±0.94
Cortisol (nmol L^{-1})	27.36±3.41	29.16±4.25	28.320±4.70	27.41±4.63

DCR: Diet contaminated with radio nuclides, RCF: Clean feed

Table 4: Hematological and biochemical parameters of calves at 18 months of age

Indices	DCR in all periods of the experiment	DCR for 450 days and RCF for 90 days	DCR for the first 240 days and RCF later on (300 days)	After weaning (for 240 days) was kept in the fattening complex, which was located in a clean area
Erythrocytes (10^{12} L^{-1})	6.92±0.21	6.32±0.16	6.23±0.14	6.16±0.12[a]
Leukocytes (10^9 L^{-1})	7.25±0.15	7.49±0.30	7.22±0.21	7.87±0.33
Hemoglobin (g L^{-1})	106.30±3.81	102.50±4.62	98.50±5.43	108.30±5.83
Glucose (mmol L^{-1})	4.05±0.43	4.36±0.50	3.86±0.33	4.51±0.45
Cholesterol (mmol L^{-1})	1.92±0.12	1.24±0.10[a]	1.26±0.14[a]	1.32±0.11[a]
Total protein (g L^{-1})	76.10±1.17	77.80±1.11	79.20±1.15	80.00±1.19
Albumin (g L^{-1})	37.40±1.40	38.00±1.73	38.60±1.36	40.50±1.55
Globulin (g L^{-1})	38.70±1.34	39.80±1.76	40.60±1.63	40.00±1.23
α	12.80±1.03	13.20±1.41	12.40±0.93	13.00±0.84
β	14.90±1.12	15.10±1.62	17.10±1.25	15.70±1.00
γ	11.00±0.50	11.50±1.08	11.10±0.74	11.30±0.92
Triiodothyronine (nmol L^{-1})	2.25±0.12	1.96±0.11	1.82±0.15	1.70±0.13[a]
Thyroxine (nmol L^{-1})	77.14±2.13	65.54±2.60[a]	63.71±2.42[b]	58.32±2.48[b]
Insulin (mcU mL^{-1})	8.77±1.48	9.32±1.11	8.52±2.00	9.05±1.78
Cortisol (nmol L^{-1})	29.11±1.12	23.07±1.03[a]	21.52±1.35[a]	20.34±1.46[b]

[a]: $p<0.005$, [b]: $p<0.001$, DCR: Diet contaminated with radio nuclides, RCF: Clean feed

showed more intensive growth. In their live weight at 18 months of age, the animals in III test group exceeded the ones in control, I and II experimental groups by 49.5-51.2 kg (11.0-11.7%, $p<0.001$), in their daily gain by 88-93 g (11.8-12.5%, $p<0.001$).

No significant difference was registered between the calves in the groups compared on clinical indicators, which were within the physiological norm: the body temperature of 38.8-39.1°C (depending on the season and the time of day: morning, noon), the respiratory rate per minute in a range from 17.9-19.0 (winter) 40.1-44.0 movements (summer), the pulse rate within the range from 68.8-70.9 (winter) 78.3-80.5 beats (summer). The hematologic indices were also within the limits of the physiological norm (Table 3 and 4). In general, the morphological and biochemical composition of blood of the animals in groups compared did not differ significantly. However, in blood of the 18-month calves fed with increased radioactive contamination throughout the experiment there was registered a higher content of red blood cells by 9.5-12.3%, cholesterol by 45.4-54.8%, triiodothyronine by 14.8-32.3%, thyroxine by 17.7-32.2% and cortisol by 26.2-43.1%.

According to the intravital dosimetry data of the calves at the end of the experiment, the dose of gamma radiation was 91.2 mcR/h in the control group, 3.3 mcR/h in I test group, 3.0 in II test group and 2.8 mcR/h in III test group with the permissible norm at slaughter to be no more than 4.0 mcR/h. Predicted patterns of the concentration decrease of radioactive cesium in animals should be illustrated by the example: in II test group the gamma dose radiation was 20.5 mcR/h 85 days prior to slaughter, 12.0-50 days before, 7.8-40 days before and 3.0 mcR/h just before the slaughter.

Cleaning the animal organism from radioactive substances under the equivalent housing conditions (control, I and II test groups) had no effect on the beef production (Table 5).

From the animals kept in feedlots after weaning there were obtained the carcasses weighing 235.1-237.9 kg, the visceral fat 9.6-10.1 kg with the slaughter yield 58.4-58.6%, without statistically significant difference. Significant difference in chemical composition of meat has not been registered.

After weaning, the calves of III experimental group were transferred into more comfortable housing conditions (an industrial livestock complex) in a clean area to the diets with a higher concentration of energy by increasing the proportion of complex feed that allowed increasing their beef production significantly. So, in comparison with the youngsters in II experimental group, there was received a heavier carcass (by 27.7 kg), greater amount of visceral fat (by 4.0 kg), the excess in the slaughter yield was 0.7% and the unit weight of dry matter in carcass flesh was higher by 2.92% ($p<0.01$), of fat by 3.28% ($p<0.01$).

The specific activity (Bq kg^{-1}) of muscle tissue and internal organs was quite strongly influenced by the cleaning of animals from cesium-137 (Table 6). Feeding the "Clean rations" for 90 days before slaughter reduced the cesium-137 content by a factor of 17.0 in muscle tissue, 13.3 in kidneys, 23.7 in heart, 16.1 in liver and 13.1 in lungs, for 300 days by a factor of 23.8, 19.1, 16.7, 19.6 and 15.1, respectively. Keeping the calves after weaning in the "Clean" zone provided a reduction of cesium-137 in muscle tissue of 33.7 times, internal organs from 40.5-64.2 times.

In accordance with the radiobiological and veterinary-sanitary evaluation, beef and slaughterhouse by-products from the animals in the control group were determined unsafe for human consumption and were disposed of or fed to animals (polar foxes). Beef from the test youngsters cleaned from the cesium-137 using "Clean" feed was sold by retail without any restriction.

In this regard, the observed hematological changes can be suggested to be caused by increased activity of the neuroendocrine system and should be identified as one of the manifestations of protective and adaptive responses of a healthy organism to the radiation stimulus. The effect of radioactively contaminated and clean feed on the animal ethology has not been found.

Table 5: Beef production of experimental animals

Indices	DCR in all periods of the experiment	DCR for 450 days and RCF for 90 days	DCR for the first 240 days and RCF later on (300 days)	After weaning (for 240 days) was kept in the fattening complex, which was located in a clean area
Preslaughter live weight (kg)	417.60±3.86	421.20±3.77	424.10±4.10	473.50±3.50^c
Hot carcass weight (kg)	235.10±1.82	237.50±1.30	237.90±2.30	265.30±2.26^c
Weight of visceral fat (kg)	9.80±0.20	9.60±0.12	10.10±0.24	14.10±0.21^c
Slaughter yield (%)	58.60±0.14	58.60±0.12	58.40±0.16	59.10±0.22
Fleshing index	3.82	3.90	3.95	4.24
Flesh weight in carcass (kg)	177.60±2.30	179.80±2.48	181.20±2.16	207.30±2.25^c
Chemical composition of flesh (%)				
Dry matter	33.72±0.47	34.41±0.52	33.67±0.52	36.59±0.32^b
Protein	20.18±0.17	20.47±0.25	20.21±0.18	19.82±0.20
Fat	12.54±0.45	12.92±0.36	12.48±0.22	15.76±0.45^b

^{b}: $p<0.01$, ^{c}: $p<0.001$

Table 6: Specific activity of the muscle tissue and the internal organs of the experimental animals (Bq kg^{-1})

Indices	DCR in all periods of the experiment	DCR for 450 days and RCF for 90 days	DCR for the first 240 days and RCF later on (300 days)	After weaning (for 240 days) was kept in the fattening complex, which was located in a clean area
Muscles	1840.0±42.6	108.4±8.4[c]	77.3±3.5[c]	54.6±5.3[c]
Kidney	1600.8±28.3	120.6±6.4[c]	63.7±14.6[c]	34.8±4.7[c]
Heart	1177.6±20.8	75.1±5.5[c]	70.5±2.7[c]	29.1±2.7[c]
Liver	1232.8±15.4	76.5±3.9[c]	62.8±2.2[c]	19.2±5.8[c]
Lung	883.2±22.5	67.3±4.1[c]	56.5±5.4[c]	14.7±3.6[c]

[c]: $p<0.001$

CONCLUSION

In the radioactively contaminated areas with a density of 40 Ci/km^2 and higher, the beef production and obtaining ecologically safe meat products are quite possible. This can be achieved by growing the animals according to the special beef cattle breeding technology that does not require considerable work force. The system "Cow-calf" supposes to keep the calves with the cows up to the age of 8 months, then to transfer them to the feedlot in the same area with the diets of "Clean" feed for at least 90 days prior to the slaughter. This period is sufficient for cleaning the animal organism to produce environmentally safe meat.

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