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Removal of heavy metals using sorbents and biochemical indexes in rats

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Abstract. A wide range of negative effects of heavy metals on the body of mammals predetermined the relevance of the search for ways to reduce the toxic effects of these chemical compounds. Solving this problem is possible by using sorbents. The research aims to determine the effect of sorbents on the content of heavy metals (cadmium, copper, lead, and zinc) in the rat tissues. Toxicological, physicochemical, and biochemical methods were used. Phillipsite sorbent reduced the content of copper and zinc in the blood of rats by 1.6 times, cadmium by 2 times and lead by 2.6 times. The content of copper and zinc in rat livers decreased by 1.4 times, and cadmium and lead – by 2 times. The content of the studied metals in kidney tissues decreased by half. A similar decrease in the level in the tissues was noted when using the chabazite sorbent for all heavy metals studied. Administration of the clinoptilolite sorbent into the body of rats contributed to a 2-fold decrease in the blood content of copper and zinc, cadmium, and lead by 2.6 and 3 times, respectively. A 1.6-fold decrease in copper and zinc levels and a 3-fold decrease in cadmium and lead levels were

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detected in the liver tissues. When mordenite sorbent was administered to animals, the content of copper and zinc in the blood decreased by 1.5 times, and cadmium and lead by 3 times compared to the control. The content of all studied metals in the liver of rats decreased by 2.4 times. The use of these sorbents in animal husbandry will contribute to the reduction of the content of heavy metals in animal tissues, which will ensure the production of high-quality and safe products, as well as contribute to the preservation of human health

Keywords: animal tissues; cadmium; copper; lead; zinc

Introduction

Man-made heavy metal environmental pollution requires studying the mechanisms of their action on humans and animals and developing new methods of protection against toxic effects. Sorbents are widely used to remove heavy metals and other foreign substances from the environment. The search for effective adsorbents that can reduce the concentration of heavy metals in human and animal organisms is currently relevant. Sorbents must be safe and effective so that they can be used regularly for preventive purposes (Ahmad *et al*., 2020; Alengebawy *et al*., 2021; Chen *et al*., 2022). The increase of harmful pollutants in the environment has become a serious global problem. Zeolite materials have been widely used in the last decade to prevent heavy metal pollution due to their excellent properties of high ion exchange capacity and absorption capacity (Haemmerle *et al*., 2021). Intensive pollution of the environment with heavy metals is quite significant and negatively affects the health of people and animals. The search for effective and safe means of detoxification of the human body from toxicants and the prevention of their adverse biological effects is one of the most urgent problems of modern biology, medicine, veterinary medicine, and toxicology (Kim *et al*., 2019).

The unique physical and chemical properties of zeolite materials make them extremely useful for a wide range of applications, in agronomy, ecology, veterinary medicine, production and industrial processes. Clinoptilolite, natural zeolite, has been widely studied in veterinary and human medicine. The use of clinoptilolite products in vivo has increased dramatically due to their many health benefits, including detoxification. However, concerns about the safety of clinoptilolite for in vivo use have been raised. The conducted studies showed the high efficiency of clinoptilolite in various medical and veterinary applications *in vitro* and *in vivo*. Clinoptilolite from the group of zeolites has the best physical and chemical properties, thanks to which it is widely used in various fields of industry, medicine, and veterinary medicine. Different zeolite minerals can be found together in a particular rock. Zeolite mineralization is associated with several secondary and accessory minerals (feldspar, micaceous minerals, chlorite minerals, opal, cristobalite, zircon, tourmaline, iron, sulphur compounds, and clay minerals). Natural zeolites are subjected to appropriate activation during which zeolites can acquire better properties (Pabi´s-Mazgaj *et al*., 2021).

Clinoptilolite is one of the most common and widely used zeolite minerals in the world. There are large deposits that are being developed and where zeolites are being mined, which have high selectivity and good temperature resistance. High ion exchange properties and molecular sieve properties make clinoptilolite one of the inexpensive adsorbents for the reduction of heavy metals. At the same time, the low cost of natural zeolites makes it possible to use them in sorption processes that do not involve the regeneration of ion exchange resins (Burakov *et al.*, 2018). Purified clinoptilolite tuff is used as a dietary supplement, which is made by applying a complex process to the substance to reduce the natural content of heavy metals and increase its effectiveness and ease of use. In addition, zeolites are natural ion exchangers and can combine the processes of adsorption and filtration (Tschegg *et al.*, 2020). Chemical precipitation, membrane flotation, ion exchange, and solvent extraction are used to remove soluble heavy metals. These traditional methods either require heavy capital and operating costs or cannot reduce the content of heavy metals to the maximum permissible standards. This determines the current emphasis on the development and use of sorbents as alternative and inexpensive materials (Irannajad & Haghighi, 2021).

Natural zeolites are a promising type of sorbents, as there are currently more than 100 and about 40 synthetic ones. Having high adsorption, antitoxic, radioprotective, ion exchange, catalytic and immunomodulatory properties, they are increasingly used in various fields of science, industry, biology, medicine, veterinary medicine, agriculture, and ecology. These features of zeolites attracted the attention of scientists and were used to establish the versatile effectiveness of their use, but the issues of complex rehabilitation of mineral homeostasis and the influence of sorbents on metabolic processes remain unknown, which requires further research (Belviso, 2020; Morante-Carballo *et al.*, 2021; Eberle *et al.*, 2022).

The research aims to determine the effect of sorbents on the content of heavy metals (copper, zinc, cadmium, and lead) and biochemical indicators in animals.

Materials and Methods

The research was performed on nonlinear male rats of the same age, weighing 200-220 g, which were kept in separate cages under normal conditions of vivarium. A total of 40 animals were used, which were divided into five groups: I – control, II – animals with orally administered solution of copper sulfate at a dose of 3 mg/kg, which is 1/10 of LD_{50}, III – zinc sulfate at a dose 2 mg/kg, which is 1/20 of the LD_{50}, IV – cadmium sulfate at a dose of 1.7 mg/kg, which is 1/30 of the LD_{50}, V – lead nitrate at a dose of 2.0 mg/kg, which is 1/50 from LD_{50}. Intoxication was performed for 14 days, and then for 2 weeks zeolites (filipsit, chabazite, clinoptilolite and mordent) were administered at a rate of 0.25 g/kg of animal weight once a day. At the end of the experiment, rats were decapitated. Blood, liver and kidney tissues were taken for further studies. The experiments were performed following the Council of European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes (European convention…, 1986).

The content of heavy metals in the blood, liver, and kidney samples was determined using a spectrochemical method using the absorption mode in an air-acetylene flame in atomic absorption spectrophotometer SpectrAA-55B (“VARIAN”, USA). The standard samples of heavy metals solution served as control. They were produced at the Institute of Physical Chemistry, Academy of Sciences of Ukraine (Odesa). Biochemical parameters were determined in serum photometrically were performed using a semi-automatic biochemical analyzer Microlab 300 (Netherlands). Concentrations of urea, bilirubin (total and direct), creatinine, glucose, albumin, total protein, cholesterol, triglycerides, magnesium (Mg), inorganic phosphorus (Pi), calcium (Ca), chloride (Cl), Sodium (Na), Potassium (K) and the activity of alkaline phosphatase (ALP, EC 3.1.3.1), alanine aminotransferase (ALT, EC 2.6.1.2), aspartate aminotransferase (AST, EC 2.6.1.1,), γ-glutamyltranspeptidase (γ-GTP, EC 2.3.2.2), lactate dehydrogenase (LDG, EC 1.1.1.27), cholinesterase (ChE, EC 3.1.1.8), α-amylase total (EC 3.2.1.1) were determined using Pliva Lachema test kits (Czech Republic).

Statistical analyses were carried out using "Microsoft Excel 2007". Data were shown as average ± standard deviation (SD). Comparisons between groups were performed with analysis of non-parametric tests. A value of $P<0.05$ was considered statistically significant (Kucherenko *et al.*, 2001).

Results and Discussion

In the liver, the concentration of copper and zinc decreased by a factor of 1.3, cadmium and lead by a factor of 2, and in the kidney tissues, the concentration of all of them at all studied decreased 2-fold. Similar changes were established when using chabazite for all the studied metals. When clinoptilolite was used, blood levels of copper and zinc decreased 2-fold, cadmium and lead 2.5 and 3-fold, respectively, while the liver showed a 1.5-fold decrease in copper and zinc and a 3-fold decrease in cadmium and lead. When using mordenite, the levels of copper and zinc in the blood decreased by 1.5 times, cadmium, and lead by 3 times, and in the tissues of the liver and kidneys, the content of all the metals studied decreased by 2.5 times (Figs. 1-3).

Figure 3 shows the results of the study. It shows the concentration of heavy metals in the tissues of the kidneys of rats.

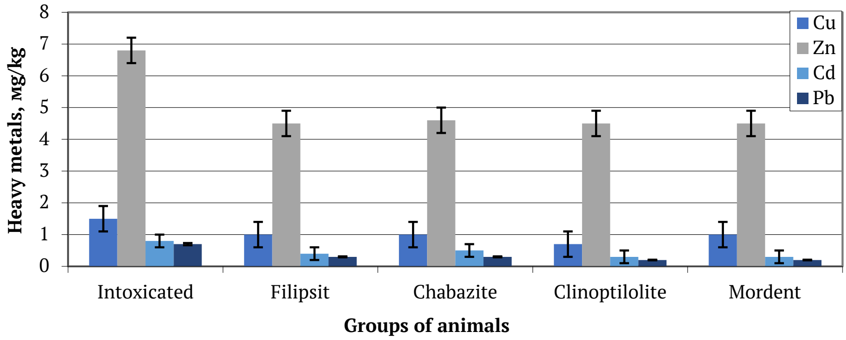

Figure 1. The concentration of heavy metals in the blood of rats with sorbents (M±m, n=8)
Source: *author's development*

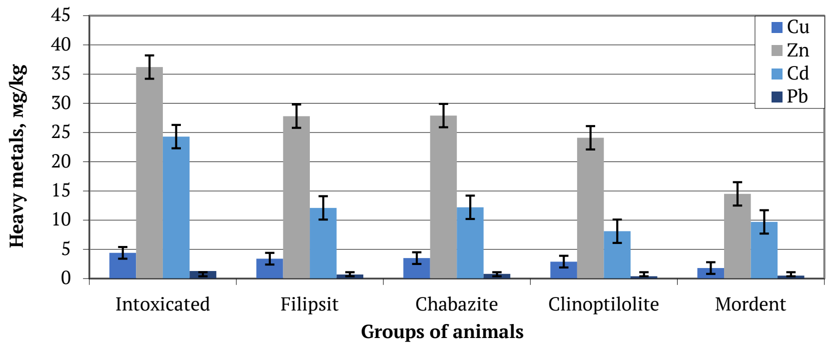

Figure 2. The concentration of heavy metals in the liver tissues of rats with sorbents (M±m, n=8)
Source: *author's development*

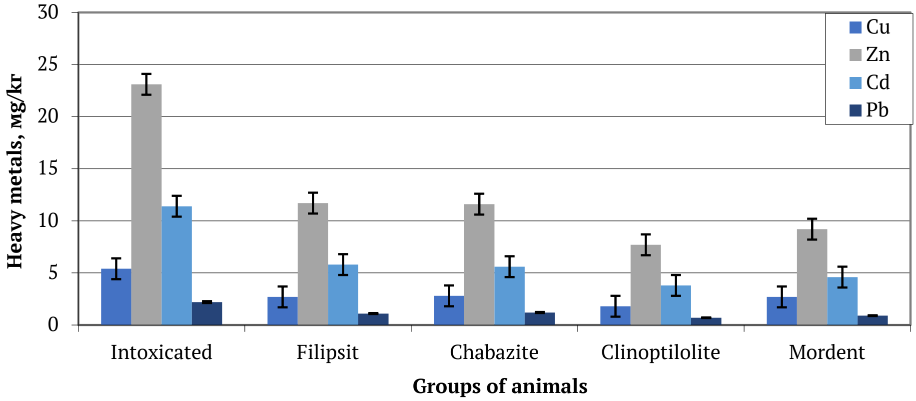

Figure 3. The concentration of heavy metals in the tissues of the kidneys of rats with sorbents (M±m, n=8)

Source: *author's development*

Biochemical indexes of blood indicate the condition of the liver in certain pathological processes, including heavy metal lesions (Tables 1-4). They can be used to determine deviations in the synthetic and detoxification functions of this organ. Functional disorders of hepatocytes are examined for the activity in the serum of indicator enzymes.

Table 1. Biochemical parameters of rat blood serum of copper-poisoned and with sorbents (M±m, n=8)

Indexes	Rats					
	Control	Copper-poisoned	Administered chemical			
			Filipsit	Chabazite	Clinoptilolite	Mordent
ALP, U/L	292.12±26.39	536.31±83.20*	436.12±45.22**	442.31±47.11**	402.62±42.42**	421.82±46.23**
ALT, U/L	78.31±6.33	132.72±10.72*	106.31±10.08**	108.13±10.03**	99.31±9.20**	102.21±10.01**
AST, U/L	163.22±15.85	254.51±20.31*	212.23±18.73	217.02±18.62	182.23±16.31**	196.32±18.26**
γ- GTP, U/L	25.63±1.95	40.13±2.90*	31.61±3.10	32.21±3.26	28.62±2.45**	30.13±2.42
LDG, U/L	324.41±31.11	652.21±53.73*	497.32±47.31**	496.73±48.28**	352.31±43.21**	482.52±45.20**
ChE, U/L	33.23±5.90	42.32±6.12	37.13±4.80	38.32±4.97	35.02±3.97	36.21±4.73
α-Amylase Total, U/L	518.71±89.83	747.21±115.11*	607.21±96.13**	609.51±97.31**	554.21±81.16**	597.12±94.27**
Bilirubin:						
Total, μmol/L	4.11±0.20	4.72±0.19	4.72±0.18	3.63±0.20	3.62±0.18	3.63±0.21
Direct, μmol/L	0.82±0.02	1.31±0.03	0.83±0.01	0.91±0.03	0.91±0.02	1.02±0.02
Creatinine, μmol/L	69.21±6.11	102.32±8.92*	82.61±7.20**	83.32±7.67**	74.22±6.75**	81.31±7.42**
Urea, mmol/L	6.12±0.89	11.31±1.24*	9.02±1.08**	9.31±1.05**	7.31±0.97**	8.23±1.03**
Glucose, mmol/L	5.21±0.69	6.63±1.09*	5.61±0.71	5.73±0.80	5.03±0.61**	5.32±0.70
Albumin, g/L	42.53±3.30	33,71±2.51	40.12±2.84	39.62±2.70	41.21±3.93**	40.13±2.91
Total protein, g/L	74.62±3.71	61.23±2.42	71.14±3.18	69.71±2.63	72.61±3.41	71.21±3.20
Cholesterol, mmol/L	1.21±0.05	0.82±0.01*	1.02±0.02	0.82±0.02	1.03±0.03	1.12±0.01
Triglycerides, mmol/L	1.12±0.01	0.41±0.01*	0.51±0.01	0.53±0.02	0.82±0.03**	0.71±0.01
Chlorides, mmol/L	86.21±7.42	106.02±9.71	89.12±7.37	90.21±7.90	87.71±7.42	88.03±7.97

Table 1. Continued

Indexes	Control	Copper-poisoned	Rats – Administered chemical: Filipsit	Chabazite	Clinoptilolite	Mordent
Magnesium, mmol/L	1.61±0.10	2.23±0.20*	2.13±0.18	2.02±0.21	2.03±0.17**	2.12±0.16
Inorganic Phosphorus, mmol/L	2.42±0.21	1.31±0.09*	1.82±0.15**	1.73±0.13**	2.12±0.18**	2.01±0.17**
Calcium, mmol/L	1.83±0.12	2.81±0.19*	2.03±0.17**	2.01±0.21**	2.13±0.11**	2.13±0.16**
Sodium, mmol/L	144.11±12.32	127.21±11.80*	136.31±12.47	136.82±12.51	139.31±12.42	135.21±12.27
Potassium, mmol/L	5.23±0.29	7.32±0.59*	6.12±0.40	6.31±0.47	5.82±0.30**	6.12±0.38**

Notes: **P<0.05 compared with the intact rats; **P<0.05 compared with the intoxicated rats*

Source*: author's development*

Table 2. Biochemical parameters of rat blood serum of zinc-poisoned and with sorbents (M±m, n=8)

Indexes	Control	Zinc-poisoned	Rats – Administered chemical: Filipsit	Chabazite	Clinoptilolite	Mordent
ALP, U/L	291.12±27.39	537.21±86.10*	438.12±75.30**	440.21±76.25**	401.23±69.23**	422.31±71.28**
ALT, U/L	78.31±6.33	135.23±11.11*	105.51±9.17**	107.32±9.20**	98.51±8.50**	101.12±8.73
AST, U/L	162.22±14.85	254.82±22.40*	207.32±21.26**	210.23±19.33**	192.22±19.71**	198.63±20.13**
γ-GTP, U/L	24.63±2.20	40.41±4.18*	33.53±3.18**	34.02±3.41	29.61±3.20**	31.12±3.26**
LDG, U/L	323.41±32.11	653.32±55.22*	518.02±46.22**	522.31±47.17**	489.32±45.10**	501.53±46.17
ChE, U/L	34.23±4.90	40.03±5.02	37.13±4.13	37.82±4.75	35.13±4.30	36.02±4.96
α-Amylase Total, U/L	517.71±89.83	749.12±123.13*	617.31±112.21**	618.53±112.18**	604.02±117.23**	606.21±117.29
Bilirubin:						
Total, μmol/L Direct, μmol/L	4.11±0.20 0.82±0.02	4.81±0.22 1.12±0.01	4.12±0.19 1.03±0.02	3.72±0.20 1.03±0.01	3.51±0.18 1.02±0.02	3.62±0.20 1.03±0.03
Creatinine, μmol/L	69.21±6.11	104.21±9.21*	85.12±6.74**	87.21±6.68	78.32±6.22**	82.21±6.84**
Urea, mmol/L	6.12±0.89	11.23±1.14*	9.13±0.96**	9.32±0.98	7.73±0.70**	8.52±0.93**
Glucose, mmol/L	5.21±0.69	7.21±1.31*	6.21±0.91	6.23±0.95	5.32±0.51**	5.83±0.81
Albumin, g/L	42.53±3.30	34.82±2.72	37.12±2.40	37.81±2.71	41.13±3.02	39.71±2.70
Total protein, g/L	74.62±3.71	62.03±2.62	69.21±2.51	68.23±2.42	71.42±3.23	70.12±2.33
Cholesterol, mmol/L	1.31±0.05	0.82±0.02*	1.03±0.03	0.82±0.02	1.03±0.04	0.93±0.03
Triglycerides, mmol/L	1.12±0.01	0.41±0.02*	0.81±0.02**	0.81±0.01**	0.72±0.03**	0.71±0.02**
Chlorides, mmol/L	86.21±7.42	105.62±9.49	89.32±7.81	90.12±8.42	85.13±7.22**	86.62±7.30
Magnesium, mmol/L	1.61±0.10	2.31±0.23*	2.03±0.18	2.13±0.17	1.82±0.13**	1.83±0.15**
Inorganic Phosphorus, mmol/L	2.42±0.21	1.42±0.11*	1.72±0.16	1.72±0.15	2.01±0.21**	2.12±0.22**
Calcium, mmol/L	1.83±0.12	2.72±0.24*	2.51±0.21	2.61±0.24	2.12±0.17**	2.03±0.10**
Sodium, mmol/L	144.11±12.32	128.02±11.89*	136.23±11.81	135.12±11.73	139.21±12.41	137.31±11.97
Potassium, mmol/L	5.23±0.29	7.51±0.70*	6.72±0.65	6.83±0.62	6.13±0.50**	6.13±0.42**

Notes: **P<0.05 compared with the intact rats; **P<0.05 compared with the intoxicated rats*

Source*: author's development*

The liver ensures the neutralization of many endogenous and exogenous substances and is the central regulator of metabolic processes and regulation of homeostasis in the organism.

Table 3. Biochemical parameters of rat blood serum of cadmium-poisoned and with sorbents (M±m, n=8)

Indexes	Rats					
	Control	Cadmium-poisoned	Administered chemical			
			Filipsit	Chabazite	Clinoptilolite	Mordent
ALP, U/L	291.12±227.39	589.41±87.15*	462.02±72.22**	468.31±74.31**	434.62±69.72**	446.13±70.22**
ALT, U/L	78.31±6.33	176.12±12.30*	141.13±10.83**	148.42±11.20	135.21±10.23**	138.32±10.47**
AST, U/L	162.22±14.85	338.63±31.23*	273.3 ±27.52**	275.13±27.52**	252.23±27.08*	261.13±27.27**
γ-GTP, U/L	24.63±2.20	43.31±4.84*	36.23±3.71**	37.32±3.80	31.12±2.97**	34.21±3.41**
LDG, U/L	323.41±32.11	724.52±61.13*	602.41±57.02**	605.63±57.62**	561.31±54.10**	572.23±54.18**
ChE, U/L	34.23±4.90	43.13±5.93*	37.12±5.27	37.31±5.32	35.13±5.02	35.81±5.03
α-Amylase Total, U/L	517.71±89.83	809.21±141.24*	651.31±93.87**	653.21±94.11**	619.23±92.17**	632.62±93.06**
Bilirubin:						
Total, μmol/L	4.11±0.20	4.71±0.25*	4.42 ±0.18	4.51±0.21	4.12±0.11**	4.01±0.15**
Direct, μmol/L	0.82±0.02	1.12±0.02*	1.13±0.02	1.02±0.03	1.11±0.02	0.92±0.03
Creatinine, μmol/L	69.21±6.11	118.43±11.53*	95.31±10.13**	94.73±10.17**	91.12±9.83**	92.31±9.85**
Urea, mmol/L	6.12±0.89	12.82±2.31*	10.63±2.08**	10.21±2.03**	8.31±1.61**	9.23±1.73**
Glucose, mmol/L	5.21±0.69	8.23±1.42*	7.12±1.23	7.32±1.27	6.42±1.22**	6.42±1.21**
Albumin, g/L	42.53±3.30	31.31±2.20*	37.13±2.42	36.71±2.81	39.31±2.87**	38.21±2.73**
Total protein, g/L	74.62±3.71	56.12±2.11*	65.31±2.18	64.12±2.23	68.32±2.71	67.23±2.68
Cholesterol, mmol/L	1.31±0.05	0.73±0.02*	0.82±0.03	0.83±0.02	1.13±0.07**	1.12±0.07**
Triglycerides, mmol/L	1.12±0.01	0.31±0.02*	0.43±0.02**	0.51±0.01**	0.62±0.02**	0.53±0.02**
Chlorides, mmol/L	86.21±7.42	112.23±10.91*	95.52±9.90	96.32±10.02	90.21±8.80**	92.21±9.11**
Magnesium, mmol/L	1.61±0.10	2.52±0.27*	2.41±0.20	2.43±0.21	2.12±0.16**	2.12±0.17
Inorganic Phosphorus, mmol/L	2.42±0.21	1.13±0.07*	1.21±0.08	1.32±0.12	1.53±0.13**	1.61±0.11**
Calcium, mmol/L	1.83±0.12	3.41±0.36*	2.72±0.25**	2.81±0.27**	2.41±0.17**	2.62±0.21**
Sodium, mmol/L	144.11±12.32	122.23±11.14*	134.41±11.02	132.23±10.63	130.12±10.43	131.31±10.22
Potassium, mmol/L	5.23±0.29	8.32±0.91*	7.93±0.65	7.62±0.72	7.23±0.53**	7.12±0.62**

***Notes:** *P<0.05, compared with the intact rats; **P<0.05, compared with the intoxicated rats*

***Source**: author's development*

The liver ensures the neutralization of many endogenous and exogenous substances and is the central regulator of metabolic processes and regulation of homeostasis in the organism. The obtained data can be used as a marker of liver function issues in animals in case of heavy metal poisoning.

Table 4. Biochemical parameters of rat blood serum of lead-poisoned and with sorbents (M±m, n=8)

Indexes	Rats					
	Control	Lead-poisoned	Administered chemical			
			Filipsit	Chabazite	Clinoptilolite	Mordent
ALP,, U/L	291.12±27.39	554.61±86.93*	461.23±80.23**	464.12±80.27**	418.13±78.13**	422.21±79.01**
ALT, U/L	78.31±6.33	163.52±12.12*	134.21±11.83	158.63±12.07	117.21±10.24**	121.23±10.73
AST, U/L	162.22±14.85	285.31±23.11*	234.32±22.52	257.21±22.93	223.62±21.13**	227.32±21.41**

Table 4. Continued

Indexes	Rats					
	Control	Lead-poisoned	Administered chemical			
			Filipsit	Chabazite	Clinoptilolite	Mordent
γ-GTP, U/L	24.63±2.20	41.12±4.37*	33.63±4.08	37.43±4.26	29.31±3.22**	31.13±3.97**
LDG, U/L	323.41±32.11	692.31±55.72*	574.32±47.32**	618.72±54.21	524.03±45.32**	536.21±45.51**
ChE, U/L	34.23±4.90	42.23±5.17*	38.21±4.82	38.81±4.96	36.12±4.41	36.72±4.82
α-Amylase Total, U/L	518.71±89.83	792.31±134.22*	651.23±127.26**	708.42±132.17	605.31±126.17*	612.23±126.80**
Bilirubin:						
Total, µmol/L	4.11±0.20	4.62±0.27*	4.51±0.24	4.41±0.23	4.12±0.18	4.04±0.21
Direct, µmol/L	0.82±0.02	1.13±0.02*	1.02±0.07	1.03±0.06	1.12±0.03	1.13±0.03
Creatinine, µmol/L	69.21±6.11	112.51±10.14*	95.51±9.41	96.62±9.77	91.23±9.06	93.32±9.22
Urea, mmol/L	6.12±0.89	12.23±2.22*	10.23±1.73**	10.71±1.91**	9.71±1.61**	10.13±1.72**
Glucose, mmol/L	5.21±0.69	8.24±1.37*	6.82±0.95**	7.23±1.02	6.82±0.72**	6.81±0.81**
Albumin, g/L	42.53±3.30	32.02±2.31*	36.61±2.51**	34.12±2.40	36.43±2.33**	37.23±2.52**
Total protein, g/L	74.62±3.71	58.31±2.20*	65.23±2.83	60.71±2.39	67.21±3.20	66.12±2.63
Cholesterol, mmol/L	1.31±0.05	0.72±0.03*	0.72±0.02	0.73±0.03	0.82±0.03**	0.83±0.02
Triglycerides, mmol/L	1.22±0.01	0.31±0.01*	0.61±0.01**	0.42±0.02**	0.71±0.01**	0.72±0.02**
Chlorides, mmol/L	86.21±7.42	111.23±10.21*	95.23±9.40	96.31±9.31	90.13±9.80**	91.31±9.93**
Magnesium, mmol/L	1.61±0.10	2.62±0.24*	2.21±0.21	2.13±0.20	2.12±0.17**	2.23±0.21
Inorganic Phosphorus, mmol/L	2.42±0.21	1.23±0.11*	1.52±0.15	1.71±0.16	2.21±0.18**	2.12±0.22**
Calcium, mmol/L	1.83±0.12	3.21±0.43*	2.51±0.23	2.72±0.27	1.62±0.17**	1.81±0.17**
Sodium, mmol/L	144.11±12.32	123.12±11.74*	137.23±11.21	136.21±11.16	141.23±11.36	140.12±11.50
Potassium, mmol/L	5.23±0.29	8.03±0.83*	7.12±0.57	7.23±0.60	6.71±0.32**	7.03±0.64**

Notes: **P<0.05, compared with the intact rats; **P<0.05, compared with the intoxicated rats*

Source*: author's development*

The obtained biochemical characteristics of heavy metal poisoning will allow a better understanding of the molecular aspects of the mechanisms of their negative effects on the animal organism, which will in the future provide an opportunity to prevent negative effects on the human organism as well. The liver is actively involved in adaptive reactions during toxicological processes in the animal organism. ALT and AST are one of the most important indicators of the biochemical analysis of animal blood, directly indicating the state of internal organs. An excess of normal values indicates pathological processes occurring in such vital organs as the heart, liver, and kidneys. The transamination reaction is the transfer of an amino group from an amino acid to a fat metabolism product, a keto acid. As a result, a new amino acid is formed, synthesized directly in the animal organism, and α-keto acid. Transaminases are present in every cell of the animal organism. If the integrity of cellular structures is violated, these enzymes enter the bloodstream. Normally, aminotransferases are contained in the blood due to the presence of programmed cell death – apoptosis. This is the norm. However, with massive cell death and the release of a large number of enzymes, the indicators of biochemical research change, they can be exceeded tenfold, depending on the type of pathology and the size of the defect.

An increase in the activity of ALP and an increase in the concentration of bilirubin indicates toxic damage to the liver with manifestations of cholestasis.

The main reasons for the rise in increased activity in α-amylase total, cholinesterase and creatinine blood levels are the development of pancreatitis, renal insufficiency, filtration pathology in renal glomeruli, development of nephritis as are the salt of development of toxic processes. Aminotransferase and LDG activity increased, cholesterol and triglycerides decreased, and glucose increased in the presence of γ-GTP, and ALP are the main reasons for the impaired excretory function of the liver with hepatocellular insufficiency.

The main reasons for the decrease in total protein and albumin in the blood serum in the heavy metal poisonings studied are the cellular damage to the liver and kidneys. Elevated serum urea levels are signs of increased protein catabolism and acute renal failure, indicating a change in the relationship between urea production and excretion in the urine. Urea is the largest reservoir of circulating of nitrogen and its production changes in parallel with the degradation of endogenous proteins. Urea transport is mediated by specific urea transport proteins, which play a central role in urine concentration (Wei *et al*., 2019; Saha & Paul, 2019; Treto-Suárez *et al*., 2020). Inorganic sodium and phosphorus levels decrease in all groups of poisoned animals. However, the concentration of chloride, magnesium, calcium, and potassium increased. All this points to nephritis and disorders of acid-base equilibrium disorder namely compensatory acidosis. The use of sorbents in intoxicated rats and comparison of the obtained results indicates their positive corrective effectiveness, especially when using clinoptilolite and mordent which is consistent with the data (Liu *et al*., 2018; Ma *et al*., 2018; Engwa *et al*., 2019). In the current study, normalization of almost all studied biochemical parameters of blood serum to such values as in intact animals was observed.

Agro-industrial wastes can be used as potential adsorbents of heavy metals. These residues were characterized to determine their structure and composition and to understand the adsorption mechanism. Adsorption is one of the most suitable technologies for removing heavy metals. The adsorbent efficiency and capacity were measured and compared. It is possible to affirm from the obtained results that all biomasses used are good alternatives to synthetic materials, with adsorption efficiencies greater than 50%. The heavy metals were immobilized, with efficiencies over 88.5% (Simon *et al.,* 2022). The results of the current research are consistent with the data presented in other studies in that intestinal adsorption is a very promising method for the removal of various toxins, both in emergencies and in planned detoxification of the organism. Intestinal adsorption is a simple and effective method of cleaning the organism utilizing adsorbent sand is used in the prevention and treatment of several diseases and poisonings, as well as in the amelioration of conditions related to endotoxemia and exotoxemia. Intestinal adsorbents are used to prevent toxic allergic reactions and reduce the metabolic load on excretory and detoxification functions. According to the World Health Organization's Anatomical Therapeutic Chemistry Classification System, enteric adsorbents belong to group A07B "Enteric Adsorbents". This section outlines recent scientific research on the clinical applications of enteric adsorbents, particularly for the removal of toxic metals from the human body. The latest classification of enteric adsorbents and their mechanisms of action are also presented (Fatullayeva *et al*., 2021).

The results are consistent with the data presented in studies on the efficacy of amphoteric cryogens as oral adsorbents (enerosorbents) for the treatment of acute poisoning of small animals (rats) by heavy metals in vivo experiments. The morphological structure of the cryogels was examined by scanning electron microscopy/energy-dispersive X-ray analysis and confocal microscopy, and the use of cryogels to treat rats treated with aqueous solutions of LD50 amounts of $Cd(NO_3)_2$, $CsNO_3$, $Sr(NO_3)_2$, or $HgCl_2$ resulted in the rats treated with cryogel showed higher survival changes in comparison with the control group that did not receive such treatment. Histological and chemical analysis of the internal tissues of experimental animals and biochemical analysis of their blood showed that cryogel protects animals from the damaging effects of heavy metals on the organism, comparable to unithiol, a 2,3-dimercapto-1-propanesulfonate sodium salt-based chelating agent approved for the treatment of acute poisoning by several heavy metals the effectiveness of cryogel in protecting animals from the damaging effects of heavy metals on the organism was demonstrated (Baimenov *et al.*, 2021).

Several authors have established that the introduction of cadmium and lead salts into the organism of rats caused a decrease in organism weight gain compared to intact animals. Reduction of body weight gain in rats under heavy metal poisoning was accompanied by malnutrition and hypertrophy of organs. These changes are associated with the accumulation and sorption capacity of these metal ions, which contribute to the development of endogenous poisoning in the experimental group of rats. Chronic lead-cadmium toxicosis in rats was accompanied by erythrocytopenia and leukaemia with a simultaneous increase in erythrocyte volume and average haemoglobin content in erythrocytes. Which is also consistent with the results (Lopotych *et al.*, 2020).

Chronic effects of three groups of heavy metals on the body of rats were modelled, and biochemical parameters, as well as their changes, were measured and compared with the control group. The results are consistent with the results of this research. The study showed that when combined with chronic poisoning by heavy metal salts, biochemical indicators of the blood may be altered, and this is caused by functional violations of the liver, kidneys, and myocardium. On the background of toxic effects of heavy metals, "Ursodex" and "Schrot Rastoropshy" were used as biologically useful agents, which contributed to the reduction of metal toxicity. The level of adverse effects of these elements on biochemical indicators of blood in experimental animals was reduced (Tazitdinova *et al.*, 2018). Thus, the use of adsorbents showed good results regarding the elimination of the studied heavy metals and had a positive effect on biochemical indicators in rats.

Conclusions

In the case of intoxication of rats with heavy metals, the use of phillipsite, chabazite, clinoptilolite and mordenite was found to be effective for the removal of copper, zinc, cadmium, and lead from all studied tissues. Biochemical parameters of the rat blood indicate that the use of the studied sorbents had a corrective effect on the restoration of biochemical functions of liver cells. In this study, the adsorption behaviour of sorbents for various, health-related heavy metal cations was evaluated. The multifaceted properties of sorbents, especially high-silicon sorbents, indicate the possibility of their use as heavy metal detoxifiers. Conducting a comparative assessment of the results of research on the corrective effectiveness of the use of various sorbents indicates the possibility of their use as heavy metal detoxifiers. Zeolites are ecological absorbents of the active groups based on the way metal ions interact with the adsorbent, as well as their radius. Several factors control the adsorption process of heavy metals, including the type and distribution of active groups on the adsorbent, the way the metal ions interact with the adsorbent, and the radius of the metal ion. The adsorbents proved to be perfectly effective with a high degree of removal from various animal tissues. The results show that the adsorbent can be used for the following purposes obtain ecologically clean products of animal husbandry, for animals located in regions polluted by heavy metals.

In further research, protein and lipid metabolism should be investigated more deeply. Further studies of metabolic indicators in animals can be continued with the aim of implementing them into practice for the study of pathological conditions that cause the toxic effects of heavy metals or other xenobiotics. Further continuation of research can be in animal husbandry, veterinary medicine, and toxicology.

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Conflict of Interest

None.

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Виведення важких металів за допомогою сорбентів і біохімічні показники у щурів

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Анотація. Широкий спектр негативного впливу важких металів на організм ссавців спрямовує дослідників на пошук способів зниження токсичної дії цих хімічних сполук. Вирішити цю проблему можливо завдяки використанню сорбентів. Мета наукового дослідження полягала у визначенні впливу сорбентів на вміст важких металів (кадмію, міді, свинцю та цинку) в тканинах щурів. Для цього використовували токсикологічні, фізико-хімічні та біохімічні методи. Встановлено, що застосування сорбенту філіпситу сприяло зниженню вмісту міді і цинку в крові щурів в 1,6 раза, кадмію в 2 рази та свинцю в 2,6 раза. У печінці щурів уміст міді і цинку зменшувався в 1,4 раза, а кадмію і свинцю – в 2 рази. В тканинах нирок уміст досліджуваних металів зменшувався вдвічі. Аналогічне зниження рівня в тканинах відзначалося і при використанні сорбенту шабазиту для всіх досліджуваних важких металів. Введення в організм щурів сорбенту клиноптилоліту сприяло зменшенню вмісту в крові міді і цинку в 2 рази, кадмію і свинцю в 2,6 і 3 рази відповідно. В тканинах печінки виявляли зниження рівня міді і цинку в 1,6 раза, кадмію і свинцю в 3 рази. За введення тваринам сорбенту морденіту вміст міді і цинку в крові знижувався в 1,5 раза, а кадмію і свинцю в 3 рази порівняно з контролем. Уміст всіх досліджуваних металів у печінці щурів зменшувався в 2,4 раза. Застосування в тваринництві зазначених сорбентів сприятиме зменшенню вмісту важких металів у тканинах тварин, що забезпечить отримання якісної та безпечної продукції, а також сприятиме збереженню здоров'я людини

Ключові слова: тканини тварин; кадмій; мідь; свинець; цинк