Foods and Raw Materials. 2027;15(1)

ISSN 2308-4057 (Print)
ISSN 2310-9599 (Online)

Research Article
Open Access

Available online at http://jfrm.ru/en
https://doi.org/10.21603/2308-4057-2027-1-703
https://elibrary.ru/XNACFJ

Aqueous extract of *Atriplex hortensis* and *Betulae folia* as actoprotector in rats

Irina Yu. Sergeeva[1,*], Andrey V. Anshukov[1], Larisa A. Ishchuk[1], Victor V. Atuchin[1,2], Elena A. Mukhlynina[3], Yang Li[4], Yuyang Huang[5], Alexander S. Markov[1], Larisa V. Permyakova[1], Tatyana F. Kiseleva[1], Semyon Yu. Kleymenov[1]

[1] Kemerovo State University, Kemerovo, Russia
[2] Institute of Semiconductor Physics, Novosibirsk, Russia
[3] Institute of Immunology and Physiology, Yekaterinburg, Russia
[4] Northeast Agricultural University, Harbin, China
[5] Harbin University of Commerce, Harbin, China

* e-mail: sergeeva.76@list.ru

Received 12.08.2025; Revised 10.10.2025; Accepted 13.01.2026; Published online 20.04.2026

Abstract:
Saltbush (*Atriplex hortensis* L.) and birch leaves (*Betulae folia*) are ubiquitous raw materials with a wide range of useful properties. This research focused on the actoprotective effect that a mixed aqueous extract of these two plants had on laboratory rats subjected to forced swim test.

The experiment included an intact group (control), rats that received treatment but underwent a forced swim test, and rats that were administered with the experimental aqueous extract of *A. hortensis* and *Betulae folia* followed by the forced swim test. The mixed extract of *A. hortensis* and *Betulae folia* (Kemerovo Region, Russia) was administered intragastrically to three-month-old male Wistar rats (4 mL/100 g body weight) who performed daily 2-h swimming sessions for two weeks.

The chemical analysis of the extract revealed the presence of flavonoids (quercetin, luteolin, kaempferol), 8 essential amino acids, and 17 amino acids, including amino acids with a branched side chain (valine, isoleucine, leucine). The forced swim test made it possible to study the effect of the extract on the hematological parameters of peripheral blood. The hematological analysis showed that the administration of the extract restored leukocytes, lymphocytes, and hemoglobin to the levels demonstrated by the animals in the intact group. As for the electrocardiographic parameters, the swimmers demonstrated a faster depolarization of the heart chambers while maintaining normal heart rate, which denoted an efficient compensation for the hypertrophic changes in the myocardium caused by the physical exertion.

In this *in-vivo* research, the extract of *Betulae folia* and aerial parts of *A. hortensis* had no cardiotoxic effect and helped restore the level of blood oxygenation after physical exertion. In the future, the synergetic actoprotective effect of these two widespread plants can be used in dietary supplements and functional foods.

Keywords: *Betulae folia*, *Atriplex hortensis* L., adaptogens, adaptive response, physical exertion, cardiovascular system, electrocardiogram, hematological analysis, rats, *in vivo*

Please cite this article in press as: Sergeeva IYu, Anshukov AV, Ishchuk LA, Atuchin VV, Mukhlynina EA, *et al.* Aqueous extract of *Atriplex hortensis* and *Betulae folia* as actoprotector in rats. Foods and Raw Materials. 2027;15(1):195–206. https://doi.org/10.21603/2308-4057-2027-1-703

INTRODUCTION

The fast-paced rhythm of modern life and unfavorable environmental conditions affect human health by reducing adaptive potential and provoking stress reactions. Eventually, these two factors may contribute to the demographic pitfall by triggering the development of fatal diseases[1].

According to the World Health Organization, about 80% of deaths in the world are caused by chronic non-communicable diseases[2], especially cardiovascular disorders. The list of cardiovascular risks involves chronic stress and increased allostatic loads [1, 2]. Strenuous physical activity and psycho-emotional stressors activate the sympathoadrenal system by increasing the cardiac rate and contractility, which results in high blood

[1] World health statistics. 2023. World Health Organization Data. [cited 2025 Jul 8]. Available from: https://data.who.int/ru

[2] World health statistics...

Copyright © 2026, Sergeeva *et al.* This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), allowing third parties to copy and redistribute the material in any medium or format and to remix, transform, and build upon the material for any purpose, even commercially, provided the original work is properly cited and states its license.

pressure [3, 4]. While this activation has an adaptive value when caused by short-term stress, chronic stress to sympathetic nervous system, on the contrary, may have detrimental effects on the cardiovascular system [5]. Disrupted oxidative phosphorylation boosts the generation of reactive oxygen species, intensifies lipid peroxidation, and reduces energy supply to cells [6–8]. The increased blood flow rate damages the vascular endothelium [3, 4]. The high levels of stress in modern society make scientists search for effective means to promote adaptation and increase stress resilience [4, 9, 10].

Atriplex, commonly known as saltbush or orache, boasts a variety of pharmacological properties, confirmed both *in vivo* and *in vitro* [11–13]. For instance, *Atriplex halimus* L. was reported to have an antidiabetic effect [11] while *Atriplex farinosa* Forssk. and *Atriplex nummularia* Lindl. [12] demonstrated reliable antihyperglycemic, antihyperlipidemic, and antioxidant properties. *Atriplex hortensis* L. exhibited an actoprotective effect in animals subjected to cold stress [13].

Betulae folia, or birch leaves, contain an antioxidant called botulin [14, 15]. *Betulae folia* extracts were reported to exercise antibacterial effect against gram-negative bacteria *Staphylococcus aureus* [16]. They are anti-inflammatory and antinociceptive [17], hypolipidemic [18, 19] and low-toxic [17, 20].

Extracts obtained from various types of *Atriplex* plants demonstrate reliable antioxidant properties [21]. Their antibacterial and antiurease activity is associated with the high content of triterpene glycosides [22, 23].

Atriplex and *Betula* plants contain substances with a wide range of physiological activities that can be used in medicinal compositions. In this regard, the adaptogenic properties of aqueous extracts of *Betulae folia* and aerial parts of *A. hortensis* should be studied *in vivo*, i. e., on laboratory animals under physical exertion.

In this study, we examined the effect of a mixed aqueous extract of *Betulae folia* and *A. hortensis* on the adaptive response to forced physical exertion in animal models.

STUDY OBJECTS AND METHODS

Preparation. *Betulae folia* and aerial parts of *Atriplex hortensis* L. were collected near the village of Osinovka (coordinates: latitude 55°23′22″N, longitude 86°18′15″E), Kemerovo Region, Russia, in May and June, 2022 (Fig. 1).

The species were identified at the Department of Ecology and Nature Management, Kemerovo State University (Kemerovo, Russia). The plants were dried without access to direct sunlight in a ventilated room at 25 ± 2°C. Then, we ground them in a vortex mill with a classifier (TW200, Japan) to obtain fine powder with a particle size of 40–50 μm.

Physicochemical properties of plant powder. We addressed the Kjeldahl method to determine the content of crude protein in the plant powder [24]. The quantitative assessment of reducing sugars relied on the method proposed in [25]. The optical density test involved



a

b

Figure 1 Appearance of experimental plants: a – *Betulae folia*; b – *Atriplex hortensis* L.

a UV-1200 spectrophotometer (Shanghai Mapada Instruments, China); the light transmission was measured at 440 nm. To define the mass fraction of crude ash, we performed dry ashing [26] at 550–650°C in an LF-7/11-G1 muffle furnace (Russia). In the mineralized samples, we determined contents of calcium, phosphorus, iron, zinc, and copper. The amount of calcium was analyzed in line with the complexometric method while the photometric method made it possible to reveal the contents of phosphorus and iron [26]. The optical density test involved an UV-1200 spectrophotometer, which measured the light transmissions at 440–465 nm (phosphorus) and 450–490 nm (iron). The mass fraction of copper and zinc was revealed by the inversion voltammetry method. The procedure involved a voltametric analyzer AKV-07MK (Russia) with a three-electrode sensor and data collection, provided with the Aquilon processing software.

We used titration to measure total tannins [27] and high-performance thin-layer chromatography to identify and measure terpenoids (isoprenoids) and phenolics. The experiment was conducted on Sorbfil PTS-AF-A plates (Russia). The mobile phase consisted of a mix of *n*-butanol, acetic acid, and water at a ratio of 60:15:25 [28].

Antioxidant profile. Potentiometry made it possible to measure the ability of the extract to remove free radicals. This method measures the electric transient negative signal with a flow-type platinum electrode detector by the composition change in a redox-reagent solution [29].

Vitamin profile. The vitamin composition was studied using the method of high-performance liquid chromatography (HPLC) with gradient elution [30] and standard vitamin solutions (ECOS-1, Russia).

Amino acid profile. The amino acid composition was also analyzed by HPLC in an Agilent 1260 Infinity II chromatograph (Agilent Technologies, USA) equipped

with a multi-wave detector and an analytical column. After grafting the C18 carrier onto a high-purity silica gel base, we applied the gradient elution. The procedure also involved an Agilent ZORBAX Eclipse AAA device (4.6×150 mm, 3.5 μm, reversed phase). The eluents included phosphate buffer, methanol (ECOS-1, Russia), and water at a ratio of 45:45:10. The phosphate buffer was based on sodium hydrogen phosphate (Na_2HPO_4, 0.5M; Elabscience Biotechnology, China) and acetonitrile (ECOS-1, Russia). The elution rate was 2.0 mL/min; the column temperature was 40°C. The chromatograph calibration [31] relied on the following list of amino acids: aspartic acid, glutamic acid, serine, histidine, glycine, threonine, arginine, alanine, tyrosine, cysteine, valine, methionine, phenylalanine, isoleucine, leucine, lysine, and proline (Agilent Technologies, USA; Item: 5,061–3,332).

***In vivo* studies.** All manipulations with laboratory animals followed the standard recommendations issued by the International Ethics Committee. The permission to conduct the study was obtained from the Ethics Committee of the Institute of Immunology and Physiology, Ural Branch of the Russian Academy of Sciences (no. 05/23, May 24, 2023). The experiment involved 30 three-month-old male Wistar rats. The rats were kept under standard vivarium conditions with natural illumination and free access to water and food.

The rats were divided into three groups, 10 animals in each. Group 1 consisted of intact animals. Group 2 included rats that received no experimental treatment but underwent a forced swim test. Group 3 consisted of rats that were administered with the experimental aqueous extract of *A. hortensis* and *Betulae folia* followed by the forced swim test.

The physical load was simulated using the method of 2-h forced swimming sessions for 14 days [32]. The water temperature was 30 ± 1°C. The amount of plant powder in the extract based on the available pharmacological data for other types of these plants (Table 1).

The mixed aqueous extract was prepared as follows. We poured 7 g of *Betulae folia* powder and 4.3 g of *A. hortensis* powder with 200 mL of hot water (85 ± 2°C). The extraction lasted for 12 h, with subsequent filtering. Group 3 rats received the extract in an amount of 4 mL/100 g body weight for 14 days. The rats in Groups 1 and 2 received an equivalent volume of drinking water.

Cardiovascular parameters. After two weeks of daily forced swimming, the cardiovascular parameters to be analyzed on animal model involved peripheral blood hematology, electrocardiography, blood pressure, heart rate, and blood oxygenation. The rats were sacrificed under anesthesia with 20 mg/kg xylazine and 10 mg/kg Zoletil-100 intramuscularly.

The electrocardiographic examination was performed using a Zoomed iE300 veterinary electrocardiograph (Zoomed, China). The animals were placed on a warm mat (37°C); electrodes were fixed on their limbs at spots lubricated with conductive gel. We used a Microlux ML-410 Vet veterinary tonometer (Microlux, Russia) to assess the heart rate and blood pressure. The blood oxygenation test involved an M3S veterinary monitor (TooTooMeditech, China).

Peripheral blood was sampled from the tail vein in the morning after a 12-h fast. The samples were added into test tubes with K3-EDTA anticoagulant. The parameters were assessed using a veterinary hematology analyzer MindrayBC-2800Vet (Mindray, China). The list of parameters to be assessed was as follows: absolute granulocyte count (Gran, 10^3/μL); relative granulocyte count (Gran, %); hemoglobin content (Hb, g/L); hematocrit (Hct, %); absolute lymphocyte count (Lymph, 10^3/μL); relative lymphocyte count (Lymph, %); average hemoglobin content in an erythrocyte (MCH, pg); mean corpuscular hemoglobin concentration (MCHC, g/L); mean corpuscular volume (MCV, fl); absolute monocyte count (Mon, 10^3/μL); relative monocyte count (Mon, %); mean platelet volume (MPV, fl); platelet crit (PCT, %); platelet size distribution (PDW, %); platelet content (PLT, 10^3/μL); absolute erythrocyte count (RBC, 10^6/μL); erythrocyte size distribution (RDW, %); and absolute leukocyte count, (WBC, 10^3/μL).

Statistical analysis. The primary processing was carried out in the MS Excel 365 program. The data were presented as the arithmetic mean (m) ± standard error (SD). To test the hypothesis of homogeneity of two independent samples, we used the nonparametric Mann-Whitney U test and the nonparametric Wilcoxon test for dependent samples. When testing the statistical hypotheses, we applied a 5% significance level. The calculations were performed using the Origin 201 software.

RESULTS AND DISCUSSION

Figure 2 and Tables 2–5 illustrate the chemical components in *Atriplex hortensis* L. and *Betulae folia* that affected the rats' metabolism under physical loads.

Table 1 Justification of plant powder dose in the extract

Plant species	Amount	Property tested	Reference
Atriplex halimus L.	200 mg/kg body weight	Antidiabetic	[11]
Atriplex farinosa Forssk., *Atriplex nummularia* Lindl.	200–400 mg/kg body weight	Antihyperglycemic, antihyperlipidemic, antioxidant	[12]
Atriplex hortensis L.	2 mL/100 g body weight	Actoprotective (in animals under induced cold stress)	[13]
Betula platyphylla Sukacz.	400 mg/kg body weight	Anti-inflammatory, anti-nociceptive	[17]
Betula pendula Roth	1.5 g/100 g diet	Hypolipidemic (polysaccharides)	[18]
Betula pendula L., leaves	3 g/100 g diet	Hypolypidemic (polysaccharides)	[20]

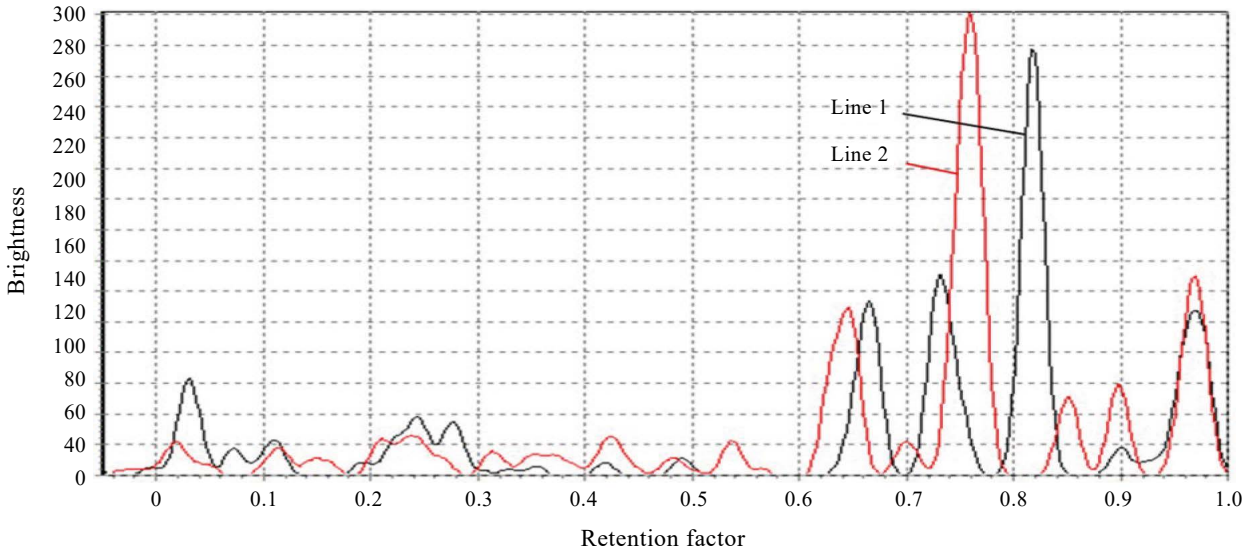


Figure 2 Densitogram of aqueous extracts: Line 1 – *Atriplex hortensis* L.; Line 2 – *Betulae folia*

Table 2 Physicochemical analysis of *Atriplex hortensis* L. and *Betulae folia* (m ± SD)

Constituents	*Atriplex hortensis* L.	*Betulae folia*
Mass fraction, %:		
crude protein	30.45 ± 0.61	9.69 ± 0.65
reducing sugars	0.86 ± 0.02	0.61 ± 0.02
tannins	2.74 ± 0.08	1.04 ± 0.05
flavonoids	1.10 ± 0.02	1.60 ± 0.03
ash	18.24 ± 0.36	1.27 ± 0.36
calcium	2.43 ± 0.06	0.27 ± 0.04
phosphorus	0.371 ± 0.009	0.140 ± 0.002
iron	0.0157 ± 0.0003	–
Contents, mg/kg:		
copper	0.442 ± 0.011	4.11 ± 0.08
zinc	6.73 ± 0.13	34.15 ± 0.70

Table 3 Vitamin composition of *Atriplex hortensis* L. and *Betulae folia* (m ± SD)

Constituents	Contents, mg/100 g	
	Atriplex hortensis L.	*Betulae folia*
Ascorbic acid (C)	98.6 ± 1.9	56.9 ± 0.9
Pantothenic acid (B_5)	105.0 ± 2.1	30.7 ± 0.5
Pyridoxine (B_6)	9.31 ± 0.20	0.80 ± 0.02
Nicotinamide (B_3)	3.20 ± 0.11	0.30 ± 0.01
Thiamine (B_1)	4.40 ± 0.08	0.80 ± 0.02
Folic acid (B_9)	1.10 ± 0.02	0.70 ± 0.01

The aerial parts of *A. hortensis* proved to be rich in crude protein (Table 2), as well as in vitamins C, B_5, and B_6 (Table 3).

Intense physical activity exhausts metabolic processes, inducing an increased need for vitamins B, PP, C, etc. Vitamins, especially group B, and their derivatives are involved in the biosynthesis of enzymes responsible for biochemical reactions associated with the oxidation of nutrients and energy production. Their consumption has to be increased to inhibit the lipid peroxidation processes, which get stronger under heavy psychophysical stress. These processes trigger the need in antioxidant vitamins, in particular, vitamin C [33].

Calcium is one of the valuable constituents of *A. hortensis* Physical exercise may decrease the levels of circulating serum calcium while increasing the levels of parathyroid hormone and bone resorption. These disturbances in calcium and bone metabolism can be reduced by taking calcium supplements immediately before exercises [34].

Iron, copper, selenium, cobalt, manganese, and zinc are essential microelements affected by physical exercise [35]. *Betulae folia* contained significantly more copper and zinc than *A. hortensis* If consumed as supplements, these mineral components may restore the metabolic and microelement status of the body during physical exercise. The modulation of zinc and selenium homeostasis is especially important [35].

The high-performance liquid chromatography detected 17 amino acids in the plant extracts under study. *A. hortensis* had 26,115 mg of total amino acids while *Betulae folia* contained as little as 4,793 mg/100 g body weight. The *Amaranthaceae* plants of genus *Atriplex* contain record amounts of protein and amino acids, depending on the species [13, 36–40]. *Betulae folia* had the same amino acids as *A. hortensis*, but in much lesser quantities. However, the combination of these plants can enhance the biological effect. Figure 3 illustrates the data obtained on the ratio of amino acids, color red marking particularly high percentages.

The amino acid profile of *A. hortensis* differed significantly from that of *Betulae folia* in such amino acids as alanine, cystine, lysine, and proline. Their proportion in the total amino acids for *A. hortensis* was 2–3 times higher than in *Betulae folia*. Both plants demonstrated very similar balance of essential amino acids, except

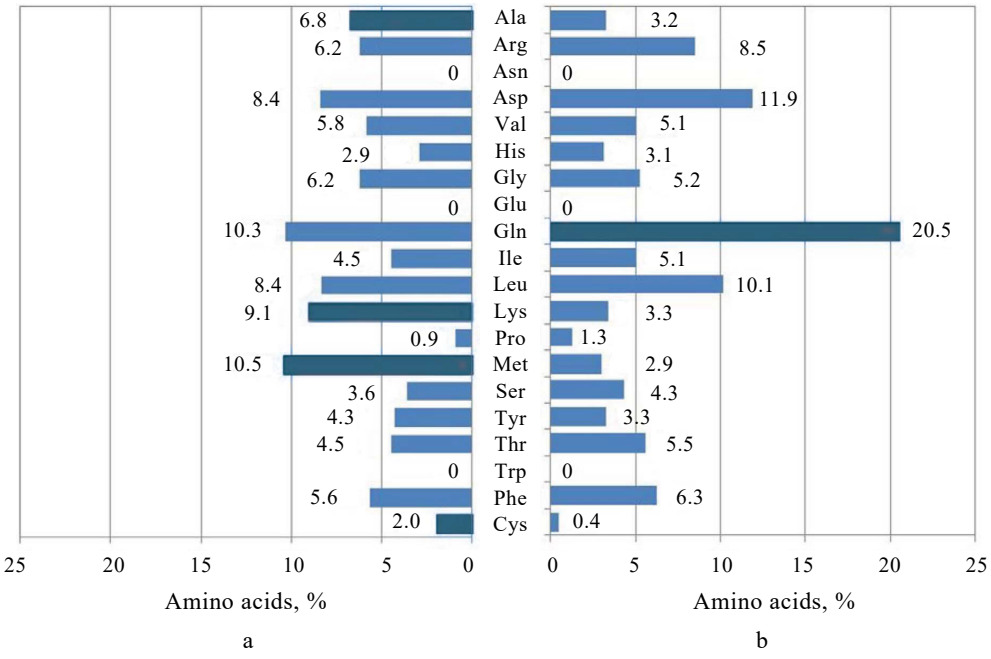


Figure 3 Amino acids in *Atriplex hortensis* L. (a) and *Betulae folia* (b)

for lysine: its proportion in *A. hortensis* was three times as high as in *Betulae folia*. However, *Betulae folia* contained twice as much glutamic acid as *A. hortensis* Glutamic acid is not essential, but it plays a very important role in nitrogen metabolism. The species and geographic location seemed to have no significant effect on the vitamin and amino acid composition of the studied plants. Our research results were consistent with publications regarding *Betulae folia* [41, 42] and other species of *Atriplex* from different regions of the world [39, 43, 44].

The antioxidant activity of the aqueous plant extracts was determined by the potentiometric method: 0.260 ± 0.005 mmol-Eq/L for the extract of *Betulae folia* and 0.271 ± 0.005 mmol-Eq/L for the extract of *A. hortensis*. The high antioxidant capacity means that the plant extracts remove free radicals, rendering protection from various stresses and physical exertion [45].

Flavonoids are antioxidants that can be consumed with food; they are important components of the cellular antioxidant system [46–52] and provide antimicrobial protection [53]. Flavonoids owe their antioxidant properties to their ability to trap free radicals and chelate metal ions involved in peroxidation [54, 55]. Polyphenolic compounds (Phen) are able to interact with hydroxyl (L-O•)-radicals and peroxyl (L-OO•)-radicals of lipids (alkoxyls) due to their ability to donate an electron (or a hydrogen atom). This phenomenon leads to the formation of phenol radicals (phenoxyls, which do not participate in oxidation). Their molecule has a unique structure associated with the electron cloud stabilization [56, 57]:

$$\text{L-OO}^{\bullet} + \text{Phen-OH} \rightarrow \text{L-OOH} + \text{Phen-O}^{\bullet}$$
$$\text{L-O}^{\bullet} + \text{Phen-OH} \rightarrow \text{L-OH} + \text{Phen-O}^{\bullet}$$

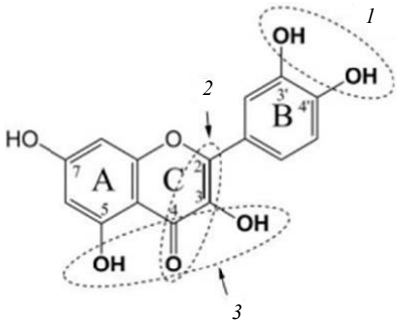


Figure 4 Quercetin molecule

Flavonoid molecules have three regions responsible for the binding of free radicals: (*1*) a group of two adjacent hydroxyls on the *B*-ring called the catechol group; (*2*) a 2,3-double bond conjugated with a 4-oxo group, which presumably initiates the delocalization of *B*-ring electrons; and (*3*) hydroxyl groups in positions 3 and 5, which capture radicals (Fig. 4) [46].

Oxidants usually target the hydroxyls of the catechol group of the *B*-ring or the hydroxyl group at the C-3 position. When these groups are oxidized, short-living semiquinone anion radicals are formed, followed by orthoquinones [58, 59]. Depending on the number and location of hydroxyl groups, flavonoids have the highest activity in the presence of the diphenylpicrylhydrazine radical [46]: quercetin → luteolin → kaempferol. Both *A. hortensis* and *Betulae folia* contain these highly active flavonoids (Fig. 3, Table 3).

Currently, no general theory links the structure of flavonoids with their antioxidant activity, but it can be assumed that flavonoids have different specializations in protecting the body from various damaging agents.

Table 4 Hematological parameters across rat groups

Blood parameters	Group 1 (intact)	Group 2 (water + swim test)	Group 3 (extract + swim test)
Absolute leukocyte count, 10^3/μL	7.68 ± 0.40	5.63 ± 0.69[a]	5.95 ± 0.64
Absolute lymphocyte count, 10^3/μL	5.16 ± 0.32	3.38 ± 0.37[a]	4.39 ± 0.48
Absolute monocyte count, 10^3/μL	0.40 ± 0.03	0.20 ± 0.04[a]	0.25 ± 0.04
Absolute granulocyte count, 10^3/μL	2.12 ± 0.08	2.05 ± 0.60	1.31 ± 0.21[a]
Relative lymphocyte count, %	66.94 ± 0.85	61.40 ± 6.37	73.79 ± 2.59
Relative monocyte count, %	5.06 ± 0.50	3.93 ± 0.44	4.38 ± 0.61
Relative granulocyte count, %	28.02 ± 0.72	34.68 ± 6.68	21.83 ± 2.32[a, b]
Absolute erythrocyte count, 10^6/μL	10.02 ± 0.14	9.67 ± 0.23	9.94 ± 0.15
Hemoglobin content, g/L	160.80 ± 2.18	147.25 ± 3.59[a]	156.00 ± 1.22
Hematocrit, %	55.94 ± 0.73	53.28 ± 1.48	55.45 ± 0.69
Mean corpuscular volume, fl	55.90 ± 1.32	55.20 ± 1.17	55.85 ± 0.71
Average hemoglobin content in an erythrocyte, pg	16.02 ± 0.36	15.20 ± 0.33	15.64 ± 0.19
Mean corpuscular hemoglobin concentration, g/L	287.20 ± 1.50	276.00 ± 1.08[a]	280.90 ± 1.93[a]
Erythrocyte size distribution, %	12.38 ± 0.37	12.08 ± 0.26	12.17 ± 0.16
Platelet content, 10^3/μL	1,319.24 ± 62.66	1,003.75 ± 38.25[a]	1,660.40 ± 44.56[a, b]
Mean platelet volume, fl	6.04 ± 0.04	6.20 ± 0.15	6.03 ± 0.07
Platelet size distribution, %	15.68 ± 0.04	16.03 ± 0.13	15.89 ± 0.07[a]
Platelet crit, %	0.80 ± 0.03	0.62 ± 0.03[a]	0.60 ± 0.01[a]

[a] – significant difference with Group 1 ($p < 0.05$); [b] – significant difference with Group 2 ($p < 0.05$)



Figure 5 Forced swim test

To claim that some flavonoids are more effective than others, we would have to take into account the specific experimental conditions and the structural features of free radicals. A wide variety of flavonoids in nature allows these substances to provide a comprehensive protection of organisms from many different environmental threats. As in the case of vitamin and amino acid composition, the species and geographic location had no effect on the antioxidant capacity index [40, 60–62].

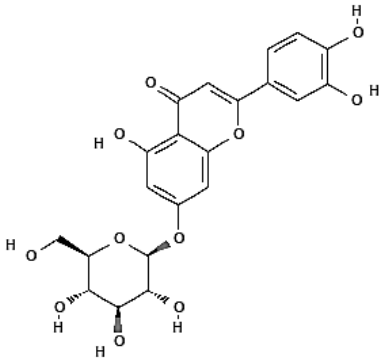
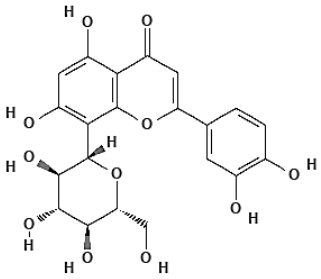
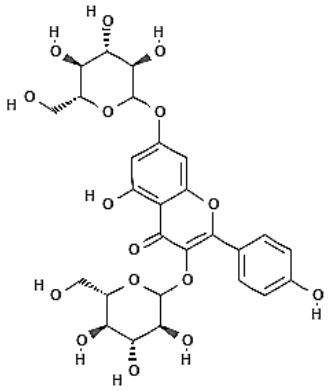
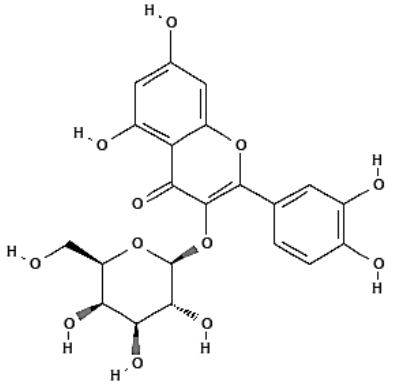
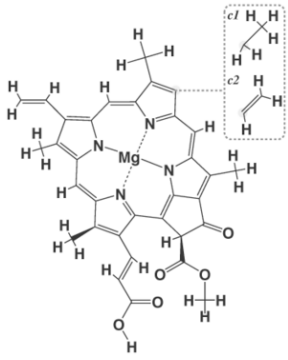
Effect of mixed aqueous extract on peripheral blood hematology in rats after forced swim test. Physical and stress loads, in synergy or separately, are known to have a significant effect on hematological indices [4]. The forced swim test (Fig. 5) took place daily in two-hour sessions for two weeks, thus leading to the third stage of stress. It reduced the total leukocyte content in the blood of the test rats, affecting the lymphocyte and monocytic lineages. Table 5 also visualizes the lowering hemoglobin content in red blood cells, as well as the average concentration of hemoglobin in red blood cells, platelets, and platelet crit.

Different hematopoietic lineages have different sensitivities to stress hormones. Lymphopenia can apparently be associated with the activation of the sympathoadrenal system and the inhibitory effect of glucocorticoids on lymphopoiesis. For the erythrocyte and platelet lineages, the effect of glucocorticoids usually manifests itself in hyperplastic phenomena, which we did not detect in this research. On the contrary, we detected a response decrease in the platelet count, which was consistent with other publications on the effect of repeated physical activity [32]. A slight decrease in hemoglobin could be a sign of anemia [63], indicating a lack of plastic resources for adequate hematopoiesis under conditions of strenuous physical activity [64]. However, this indicator for Group 3 (experimental) approached the indicator for Group 1 (intact) due to the additional supply of iron from the combined aqueous plant extract.

The intragastric administration of the extract to the experimental rats restored the total content of leukocytes, lymphocytes, and hemoglobin to the level recorded in the intact animals (Table 4). Both the plants contained branched-chain amino acids, i. e., leucine, isoleucine, and valine (Table 5[3]). They are known to boost immune resistance and adaptive potential during physical exertion [65, 66]. The platelet content in the

[3] Quickly find chemical information. PubChem. [cited 2025 Jul 8]. Available from: https://pubchem.ncbi.nlm.nih.gov

Table 5 Flavonoids and pigments in *Atriplex hortensis* L. and *Betulae folia*

Retention factor	Substance	Structural formula
0.65–0.67	Luteolin-7-glucoside	
0.73–0.76	Luteolin-8-glucoside	
0.82–0.85	Kaempferol 3,7-di-O-glucoside	
0.90	Quercetin-3-o-galactoside	
0.97	Chlorophyll	

experimental group was higher than in the intact rats (Group 1) and those rats that received water instead of the plant extract. This fact requires a more detailed study since it might indicate an increase in the thrombogenic potential while the functional aggregation activity is undoubtedly important [67]. The low content of various types of leukocytes in the blood is a typical reaction of the blood system to a high-intensity physical activity [68]. At the stage of urgent adaptation, the counts of neutrophils, monocytes, and lymphocytes go down. At the stage of long-term adaptation, leukocytes restore to the level of various classes in the following order: neutrophils, monocytes, and lymphocytes [69]. In our research, the aqueous extract affected the sequence of restoration of leukocytes in the experimental rats (Group 3).

Effect of mixed aqueous extract on cardiovascular system in rats after forced swim test. For Group 2 (water + swim test) and Group 1 (intact), the two-week forced swim test for 2 h daily led to a slight decrease in the blood pressure and blood oxygenation by 8 and 10%, respectively (Table 6). Apparently, the short-term loads used in the experiment caused no sharp breakdown of the adaptive mechanisms in the cardiovascular system. However, the blood pressure and heart rate in the experimental rats in Group 3 (extract + swim test) decreased by 15 and 18%, respectively, with a simultaneous increase in the saturation level to the indicator of the intact animals (Group 1). This fact further contributed to the development of a long-term adaptive mechanism by preventing injury to the vascular endothelium as a result of intensified blood flow [3, 4]. We may conclude, however, that the experimental extract had no cardiotoxic effect in the applied amount.

Effect of mixed aqueous extract on electrocardiogram parameters in rats after forced swim test. We performed an electrocardiographic analysis to assess the effect of the experimental plant extract on the cardiac activity of the rats during physical exertion (Fig. 6, Table 7).

Table 6 Cardiovascular system parameters across rat groups

Cardiac indicators	Group 1 (intact)	Group 2 (water + swim test)	Group 3 (extract + swim test)
Systolic blood pressure, mm Hg	166.80 ± 9.66	153.00 ± 10.00[a]	142.00 ± 8.95[a, b]
Diastolic blood pressure, mm Hg	101.60 ± 5.23	93.00 ± 5.73[a]	85.20 ± 5.81[a, b]
Blood oxygenation, %	87.20 ± 2.63	79.00 ± 2.12[a]	89.80 ± 3.26
Heart rate, bpm	181.60 ± 9.18	176.75 ± 8.00	149.80 ± 15.03[a, b]

[a] – significant difference with Group 1 ($p < 0.05$); [b] – significant differences with Group 2 ($p < 0.05$)



a b c

Figure 6 Electrocardiograms across groups: a – Group 1 (intact); b – Group 2 (water + swim test); and c – Group 3 (extract + swim test)

Table 7 Electrocardiogram parameters across groups

Electrocardiogram	Group 1 (intact)	Group 2 (water + swim test)	Group 3 (extract + swim test)
P-wave height	1.18 ± 0.08	1.50 ± 0.20	0.85 ± 0.09[a, b]
P-wave time	1.56 ± 0.12	1.38 ± 0.08	1.13 ± 0.10[a]
R-wave height	8.60 ± 0.87	9.38 ± 1.43	6.63 ± 0.58
R-wave time	1.46 ± 0.10	1.43 ± 0.14	1.08 ± 0.04[a, b]
QRS time	6.20 ± 0.20	6.88 ± 0.31	4.38 ± 0.80
R-R interval	15.40 ± 1.48	14.88 ± 0.77	15.00 ± 0.91
Height of T-wave (II lead)	2.84 ± 0.55	6.00 ± 0.35[a]	3.88 ± 0.84
T-wave time (II lead)	2.40 ± 0.24	3.38 ± 0.31	2.88 ± 0.10

[a] – significant difference with Group 1 ($p < 0.05$); [b] – significant difference with Group 2 ($p < 0.05$)

The electrocardiogram demonstrated no significant differences in the heart rate and R-R intervals with a stable sinus rhythm, which indicated the absence of significant changes in the cardiac conduction system (Fig. 6, Table 7). The 2-h daily swimming sessions for 14 days doubled the amplitude of the T-wave, and a 40% longer T-wave time was a tendency. These changes, together with the overall slight increase in the P-waves, R-waves, and the QRS complex, indicated the development of compensatory (physiological) left ventricular myocardial hypertrophy in response to the increased physical load [70].

The experimental animals (Group 3), which received the mixed aqueous extract of *A. hortensis* and *Betulae folia*, demonstrated a lower heart rate and no change in R–R intervals in comparison with the swimmers that received no experimental treatment and with the intact animals (Fig. 6, Tables 6 and 7). The trends included a significant decrease in the amplitude of the P-wave (by 43%) and the R-wave time by (by 24%), as well as a shorter QRS complex (by 36%). Compared to the intact animals, the height and time of the P-wave went down by 28 and 27%, respectively. Also, the R-wave time decreased by 26% relative to the physiological norm.

The main differences in the electrocardiogram parameters in the experimental rats that received the extract consisted in a more rapid depolarization of the heart chambers while maintaining the heart rate, which led to longer relaxation periods, i. e., a longer rest time for the myocardium [13]. These differences may indicate a compensation for the hypertrophic changes in the myocardium caused by the physical exertion. The compensation mechanism may consist in a change in the electrolyte composition of blood plasma [71], which leads to a more rapid depolarization of all heart chambers but a slower repolarization than in the control group.

CONCLUSION

The intragastric administration of the aqueous extract of *Betulae folia* and aerial parts of *Atriplex hortensis* L. restored the total leukocytes, lymphocytes, and hemoglobin in the rats after two weeks of daily forced swim test. The experimental extract obviously demonstrated good prospects as an actoprotector. In addition, the extract affected the sequence of restoration of leukocytes during physical exertion. The test animals also showed a faster restoration of hematological parameters and hypertrophic compensation in the myocardium induced by physical exertion.

The obtained results indicate that the mixed aqueous extract of birch leaves and saltbush may become part of a an actoprotective supplement.

CONTRIBUTION

All authors contributed to the study conception and design. I.Yu. Sergeeva and T.F. Kiseleva developed the research concept; I.Yu. Sergeeva and A.V. Anshukov designed the research methodology; A.S. Markov was responsible for the software; L.V. Permyakova and Y. Huang provided validation; V.V. Atuchin performed the formal analysis; A.V. Anshukov and E.A. Mukhlynina conducted the experiments; Y. Li wrote the review; S.Yu. Kleymenov provided data curation; L.A. Ishchuk and E.A. Mukhlynina drafted the manuscript; I.Yu. Sergeeva reviewed and proofread the manuscript; A.S. Markov was responsible for the visualization; A.V. Anshukov and I.Yu. Sergeeva supervised the project; V.V. Atuchin provided funding acquisition. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declared no potential conflict of interest regarding the publication of this article.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Center for Shared Use, Institute of Immunology and Physiology, Ural Branch of the Russian Academy of Sciences.

REFERENCES

1. Bongers-Karmaoui MN, Jaddoe VWV, Roest AAW, Gaillard R. The cardiovascular stress response as early life marker of cardiovascular health: Applications in population-based pediatric studies – A narrative review. Pediatric Cardiology. 2020;41:1739–1755. https://doi.org/10.1007/s00246-020-02436-6
2. Sobolevskaya EV, Shumkov OA, Smagin MA, Guskov AE, Malysheva AV, *et al*. Markers of restenosis after percutaneous transluminal balloon angioplasty in patients with critical limb ischemia. International Journal of Molecular Sciences. 2023;24(10):9096. https://doi.org/10.3390/ijms24109096
3. Fletcher GF, Ades PA, Kligfield P, Arena R, Balady GJ, *et al*. Exercise standards for testing and training: A scientific statement from the American Heart Association. Circulation. 2013;128(8):873–934. https://doi.org/10.1161/cir.0b013e31829b5b44
4. Paluch AE, Boyer WR, Franklin BA, Laddu D, Lobelo F, *et al*. Resistance exercise training in individuals with and without cardiovascular disease: 2023 update: A scientific statement from the American Heart Association. Circulation. 2024;149(3). https://doi.org/10.1161/cir.0000000000001189
5. McEwen BS. Neurobiological and systemic effects of chronic stress. Chronic Stress. 2017;1. https://doi.org/10.1177/2470547017692328
6. Green DJ, Hopman MT, Padilla J, Laughlin MH, Thijssen DH. Vascular adaptation to exercise in humans: Role of hemodynamic stimuli. Physiological Reviews. 2017;97(2):495–528. https://doi.org/10.1152/physrev.00014.2016

7. Reichman LB. An effective compromise. International Journal of Tuberculosis and Lung Disease. 2005;9(10):1061.
8. Losenok SA, Brovkina IL, Prokopenko LG, Nasedkin DS. Immunometabolic disorders and their correction in overtraining syndrome in athletes. Military Medical Journal. 2008;329(2):70–71. https://elibrary.ru/HNUBOR
9. Salishcheva OV, Prosekov AYu. Antimicrobial activity of mono- and polynuclear platinum and palladium complexes. Foods and Raw Materials. 2020;8(2):298–311. http://doi.org/10.21603/2308-4057-2020-2-298-311
10. Panossian AG, Efferth T, Shikov AN, Pozharitskaya ON, Kuchta K, *et al*. Evolution of the adaptogenic concept from traditional use to medical systems: Pharmacology of stress- and aging-related diseases. Medicinal Research Reviews. 2021;41(1):630–703. https://doi.org/10.1002/med.21743
11. Bounouar E, Fatiha M, Amari NO, Belabaci FZ, Belabaci S, *et al*. Antidiabetic effect of *Atriplex halimuslong* and short term treatment against streptozotocin induced diabetes in rats. Anales de Biología. 2022;43:21–30. https://doi.org/10.6018/analesbio.44.03
12. Soliman GA, Abd EL, Raheim M. Antihyperglycemic, antihyperlipidemic and antioxidant effect of *Atriplex farinosa* and *Atriplex nummularia* in streptozotocin-induced diabetes in rats. Bulletin of Environment, Pharmacology and Life Sciences. 2015;4(12):10–18.
13. Sergeeva IY, Anshukov AV, Ryabokoneva LA. To study the effect of the aqueous extract of *Atriplex hortēnsis* L. on adaptation to physical and stress loads in an *in vivo* mode. Bulletin of the South Ural State University. Series: Food and Biotechnology. 2024;12(1):76–89. (In Russ.) https://doi.org/10.14529/food240109
14. Kuznetsova SA, Pen RZ, Kuznetsov BN. Optimization of the process of obtaining betulin dipropionate from birch bark. Chemistry of Plant Raw Materials. 2021;(1):309–316. (In Russ.) https://doi.org/10.14258/jcprm.2021017973
15. Savenko AV, Sorokopud AF, Gricenko VV. The production of nettle and birch leaves extracts in the vibration device. Food Processing: Techniques and Technology. 2015;38(3):101–108. (In Russ.) https://elibrary.ru/UKQTMR
16. Vishwakarma RK, Negi A, Negi DS. Anti-oxidant, COX inhibition activity of different extract of bark of *Betula utilis* and molecular docking analysis of its phytochemicals against COX-1 and COX-2 isoenzyme. Materials Today: Proceedings. 2022;57(Part 1):251–258. https://doi.org/10.1016/j.matpr.2022.02.497
17. Huh JE, Hong JM, Baek YH, Lee JD, Choi DY, *et al*. Anti-inflammatory and anti-nociceptive effect of *Betula platyphylla* var. *japonica* in human interleukin-1β-stimulated fibroblast-like synoviocytes and in experimental animal models. Journal of Ethnopharmacology. 2011;135(1):126–134. https://doi.org/10.1016/j.jep.2011.03.005
18. Buiko EE, Kaidash OA. Hypolipidemic activity of birch polysaccharides (*Betula pendula* Roth) in a model of chronic dyslipidemia in hamsters. Chemistry and chemical technology in the 21st century: Materials of the XXI Intern. Sci. and Pract. Conf. Tomsk, 2020:306–307. (In Russ.) https://elibrary.ru/FTJGCP
19. Kuznetsova SA, Kuznetsov BN, Veselova OF, Kukina TP, *et al*. Study of the composition of birch bark hexane extract and its toxic-pharmacological properties. Chemistry of Plant Raw Materials. 2010;(1):137–141. (In Russ.)
20. Buyko EE, Ivanov VV, Kaidash OA, Rybalkina OY, Kiseleva EA, *et al*. Hypolypidemic activity of L-rhamnopyranosyl-6-O-methyl-D-galacturonan, a polysaccharide isolated from birch leaves (*Betula pendula* L.). Bulletin of Experimental Biology and Medicine. 2023;174(3):330–332. https://doi.org/10.1007/s10517-023-05702-8
21. Karomatov ID, Togboev KT. Quinoa – a promising medicinal plant. Biology and Integrative Medicine. 2017;(5):227–231. (In Russ.)
22. Ali B, Tabassum R, Riaz N, Yaqoob A, Khatoon T, *et al*. Bioactive triterpenoids from *Atriplex lasiantha*. Journal of Asian Natural Products Research. 2015;17(8):843–850. https://doi.org/10.1080/10286020.2015.1008463
23. Zhang Y, Zhao YM. Studies on the chemical constituents in seeds of *Atriplex centralasiatica*. Zhongguo Zhong Yao Za Zhi. 2005;30(9):679–681.
24. Benemar HA, Seifdavati J, Achachlouei BF, Kachuee R. Comparison of Hach method with Kjeldahl method for determining of crude protein contents of some animal feeds. Research on Animal Production. 2018;8(18):107–112. https://doi.org/10.29252/rap.8.18.107
25. Hernández-López A, Sánchez Félix DA, Zuñiga Sierra Z, *et al*. Quantification of reducing sugars based on the qualitative technique of benedict. ACS Omega. 2020;5(50):32403–32410. https://doi.org/10.1021/acsomega.0c04467
26. Latypova GM, Kataev VA, Pupykina KA, Krasyuk EV. Quality control of herbal medicines. Ufa: Bashkir State Medical University; 2020, 122 p. (In Russ.)
27. Antonova NP, Kalinin AM, Prohvatilova SS, Shefer EP, Matveenkova TE. Equivalence assessment of quantitative tannins determination methods, used for analysis of herbal drugs. Scientific Centre for Expert Evaluation of Medicinal Products Bulletin. 2015;(1):11–15. https://elibrary.ru/UBDTHT
28. Waksmundzka-Hajnos M, Sherma J, Kowalska T. Thin layer chromatography in phytochemistry. Boca Raton: CRC Press; 2008, 896 p. https://doi.org/10.1201/9781420046786
29. Shpigun LK, Arharova MA, Brainina KZ, Ivanova AV. Flow injection potentiometric determination of total antioxidant activity of plant extracts. Analytica Chimica Acta. 2006;573–574:419–426. https://doi.org/10.1016/j.aca.2006.03.094

30. Bendryshev AA, Pashkova EB, Pirogov AV, Shpigun OA. Determination of water-soluble vitamins in vitamin premixes, biologically active additives and pharmaceutical preparations by high-performance liquid chromatography with gradient elution. Moscow University Chemistry Bulletin. 2010;65:260–268. https://doi.org/10.3103/S0027131410040103
31. Permyakova L, Sergeeva I, Ryabokoneva L, Atuchin V, Li Y, *et al*. Peptides of yeast *Saccharomyces cerevisiae* activated by the malt sprout extract: Preparation, identification and bioactivity. Food Bioscience. 2024;61:104867. https://doi.org/10.1016/j.fbio.2024.104867
32. Shakhmatov II, Alekseeva OV. The influence of repeated exposure to physical activity on the hemostasis system. Fundamental research. 2011;(10–1):181–185. https://elibrary.ru/OCQTNP
33. Uchasov DS. Vitamins in the system of nutritional support of athletes. Science-2020. 2016;4(10):207–213.
34. Coombs CV, Wardle SL, Shroff R, Williams L, Swinkels A, *et al*. The effect of calcium supplementation on calcium and bone metabolism during load carriage in women: Protocol for a randomised controlled crossover trial. BMC Musculoskeletal Disorders. 2023;24:496. https://doi.org/10.1186/s12891-023-06600-w
35. Skalny AA. Physical activity and trace element metabolism. Microelements in Medicine. 2020;21(2):3–12. https://doi.org/10.19112/2413-6174-2020-21-2-3-12
36. Ismatova SN, Isabaev IB, Ergasheva HB. Alternative sources of raw materials for the production of compound feed products. Universum: Technical sciences. 2019;(12–2):18–23. https://elibrary.ru/HISHRC
37. Grabowska K, Pietrzak W, Paśko P, Sołtys A, Galanty A, *et al*. Antihyaluronidase and antioxidant potential of *Atriplex sagittata* Borkh. in relation to phenolic compounds and triterpene saponins. Molecules. 2023;28(3)982. https://doi.org/10.3390/molecules28030982
38. Vereshchaga OS. Phytochemical analysis of *Atriplex fera*. Educational initiative as a key factor in the development of the sphere of knowledge: A collection of scientific papers, 2019:298–303. (In Russ.) https://elibrary.ru/OAPJFQ
39. Sergeeva I, Permyakova L, Markov A, Ryabokoneva L, Atuchin, V, *et al*. Peptides of yeast *Saccharomyces cerevisiae* activated by the aquatic extract of *Atriplex Sibirica* L. ACS Food Science & Technology. 2024;4(1):173–189. https://doi.org/10.1021/acsfoodscitech.3c00455
40. Zine H, Ibrahimi M, Loqman S, Papazoglou EG, Ouhaddou S, *et al*. Chemical composition, antioxidant, and antibacterial activities of essential oil of *Atriplex semibaccata* R.Br. aerial parts: First Assessment against multidrug-resistant bacteria. Agronomy. 2021;11(2):362. https://doi.org/10.3390/agronomy11020362
41. Lazareva IS, Vasilyeva IV. Biologically active substances of medicinal plants of the Novosibirsk region on the example of silver birch (*Betula pendula*). Chemistry and Life: Collection of the XX Intern. Sci. and Pract. Stud. Conf., 2021:71–76. (In Russ.) https://elibrary.ru/IZTQXL
42. Volova AV, Nakvasina EN. Content of macro- and microelements in birch leaves (*Betula pendula* Roth.) of various forms. Forestry Bulletin. 2019;23(6):5–12. (In Russ.) https://doi.org/10.18698/2542-1468-2019-6-5-12
43. Wright KH, Pike OA, Fairbanks DJ, Huber CS. Composition of *Atriplex hortensis*, sweet and bitter Chenopodium quinoa seeds. Journal of Food Science. 2002;67(4):1383–1385. https://doi.org/10.1111/j.1365-2621.2002.tb10294.x
44. Khalil JK, Sawaya WN, Hyder SZ. Nutrient composition of *Atriplex* leaves grown in Saudi Arabia. Journal of Range Management. 1986;39(2):104–107.
45. Kornyakova VV, Badtieva VA, Balandin MYu. Use of biologically active additives with antioxidant properties for physical fatigue and to improve performance in sports. Problems of Nutrition. 2020;89(3):86–96. https://doi.org/10.24411/0042-8833-2020-10032
46. Terao J. Dietary flavonoids as antioxidants. Forum nutrition. Food factors for health promotion. Basel: Karger Publishers; 2009. Vol. 61. pp. 87–94. https://doi.org/10.1159/000212741
47. Kostyuk VA, Potapovich AI. Bioradicals and bioantioxidants. Minsk: BSU; 2004, 174 p. (In Russ.)
48. Asyakina L, Atuchin V, Drozdova M, Kozlova O, Prosekov A. *Ex vivo* and *in vitro* antiaging and antioxidant extract activity of the Amelanchier ovalis from Siberia. International Journal of Molecular Sciences. 2022;23(23):15156. https://doi.org/10.3390/ijms232315156
49. Cheurfa M, Achouche M, Azouzi A, Abdalbasit MA. Antioxidant and anti-diabetic activity of pomegranate (*Punica granatum* L.) leaves extracts. Foods and Raw Materials. 2020;8(2):329–336. https://doi.org/10.21603/2308-4057-2020-2-329-336
50. Koffi BB, Gbotognon OJ, Soro S, Kouadio EJP. Effects of drying methods on the biochemical and antioxidant properties of *Volvariella volvacea* from Côte d'Ivoire. Foods and Raw Materials. 2024;12(2):220–228. https://doi.org/10.21603/2308-4057-2024-2-601
51. Akharaiyi FC, Ehis-Eriakha CB, Olagbemide PT, Igbudu FH. *Hyptis suaveolens* L. leaf extracts in traditional health care systems. Foods and Raw Materials. 2023;11(2):293–299. https://doi.org/10.21603/2308-4057-2023-2-577
52. Babich O, Larina V, Krol O, Ulrikh E, Sukhikh S, *et al.* In vitro study of biological activity of *Tanacetum vulgare* extracts. Pharmaceutics. 2023;15(2):616. https://doi.org/10.3390/pharmaceutics15020616

53. Dmitrieva A, Kozlova O, Atuchin V, Milentieva I, Vesnina A, *et al*. Study of the effect of baicalin from *Scutellaria baicalensis* on the gastrointestinal tract normoflora and *Helicobacter pylori*. International Journal of Molecular Sciences. 2023;24(15):11906. https://doi.org/10.3390/ijms241511906

54. Es-Safi NE, Ghidouche S, Ducrot PH. Flavonoids: Hemisynthesis, reactivity, characterization and free radical scavenging activity. Molecules. 2007;12(9):2228–2258. https://doi.org/10.3390/12092228

55. Korkina LG, Afanas'ev IB. Antioxidant and chelating properties of flavonoids. Advances in Pharmacology. 1996; 38:151–163. https://doi.org/10.1016/S1054-3589(08)60983-7

56. Shahidi F, Wanasundara PK. Phenolic antioxidants. Critical Reviews in Food Science and Nutrition, 1992;32(1):67–103. https://doi.org/10.1080/10408399209527581

57. de Beer D, Joubert E, Gelderblom WCA, Manley M. Phenolic compounds: A review of their role as *in vivo* antioxidants of wine. South African Journal of Enology and Viticulture. 2002;23(2):48–61. https://doi.org/10.21548/23-2-2155

58. Jovanovic SV, Steenken S, Simic MM, Hara Y. Antioxidant properties of flavonoids: Reduction potential and electron transfer reactions of flavonoid radicals. Journal of Physical Chemistry B. 1998:137–161.

59. Bors W, Heller W, Michel C. The chemistry of flavonoids. ChemInform. 1998;29(19):111–136. https://doi.org/10.1002/chin.199819288

60. Ju EM, Lee SE, Hwang HJ, Kim JH. Antioxidant and anticancer activity of extract from *Betula platyphylla* var. *japonica*. Life Sciences. 2004;74(8):1013–1026. https://doi.org/10.1016/j.lfs.2003.07.025

61. Zohra T, Ovais M, Khalil AT, *et al*. Bio-guided profiling and HPLC-DAD finger printing of *Atriplex lasiantha* Boiss. BMC Complementary and Alternative Medicine. 2019;19:4. https://doi.org/10.1186/s12906-018-2416-1

62. Awaad AS, Maitland DJ, Donia AR, Alqasoumi SI, Soliman GA. Novel flavonoids with antioxidant activity from a Chenopodiaceous plant. Pharmaceutical Biology. 2012;50(1):99–104. https://doi.org/10.3109/13880209.2011.591806

63. Potemina TE, Volkova SA, Kuznetsova SV, Pereshein AV. General issues of iron metabolism and pathogenesis of iron deficiency anemia. Bulletin of the Medical Institute "Reaviz": Rehabilitation, Doctor and Health. 2020;(3):125–137. https://elibrary.ru/IWZVLC

64. Zobov VV, Nazarov NG, Vyshtakalyuk AB, Galyametdinova IV, Semenov VE, *et al*. Efficiency of new pyrimidine derivativs influence on physical working capacity of rats in the test 'swimming to failure'. Human Ecology. 2015; 22(1):28–35. https://doi.org/10.17816/humeco17168

65. Trushina EN, Vybornov VD, Riger NA, Mustafina OK, Solntseva TN, *et al*. The efficiency of branched chain aminoacids (BCAA) in the nutrition of combat sport athletes. Problems of Nutrition. 2019;88(4):48–56. https://doi.org/10.24411/0042-8833-2019-10041

66. Salinas-García ME, Martínez-Sanz JM, Urdampilleta A, Mielgo-Ayuso J, *et al*. Effects of branched amino acids in endurance sports: A Review. Nutricion Hospitalaria. 2015;31(2):577–589. https://doi.org/10.3305/nh.2015.31.2.7852

67. Mirzaev KB, Andreev DA, Sychev DA. Evaluation of platelet aggregation in clinical practice. Rational Pharmacotherapy in Cardiology. 2015;11(1):85–91. (In Russ.) https://doi.org/10.20996/1819-6446-2015-11-1-85-91

68. Androsova TV, Bogatov NM, Grigoryan LR, Zlishcheva EI, *et al*. Study of reactions of thermoregulatory system of white laboratory mice during prolonged stress. Biotechnosphere. 2011;(3):15–18. https://elibrary.ru/OFULLD

69. Lomako VV. Effect of different cooling regimens (craniocerebral and immersion hypothermia, surface rhythmic cold exposures and whole body cryostimulation) on leukocyte indices of rat blood. Problems of Cryobiology & Cryomedicine. 2018;28(4):293–310. https://doi.org/10.15407/cryo28.04.293

70. Bychenkova MA, Tyurenkov IN, Mokrousov IS, Perfilova VN, Latypova GM, *et al*. Influence of *Primula veris* dense extract on endothelial dysfunction under conditions of experimental arterial hypertension. Bulletin of the Volgograd State Medical University. 2018;81(9):20–24. https://doi.org/10.30906/0869-2092-2018-81-9-6-12

71. Podoksenov YuK, Svirko YuS. Water and electrolyte metabolism: Pathophysiological, clinical and diagnostic aspects. Tomsk: Siberian State Medical University; 2023, 72 p. (In Russ.)

Additional information about the authors

Irina Yu. Sergeeva ORCID 0000-0002-1686-0131; eLIBRARY SPIN 4207-9166
Andrey V. Anshukov eLIBRARY SPIN 5334-3671
Larisa A. Ishchuk ORCID 0000-0003-3282-9326; eLIBRARY SPIN 4719-2930
Victor V. Atuchin ORCID 0000-0002-7424-5604; eLIBRARY SPIN 3930-1190
Elena A. Mukhlynina ORCID 0000-0002-5159-4465; eLIBRARY SPIN 5440-3666
Yang Li ORCID 0000-0002-5796-4367
Yuyang Huang ORCID 0000-0001-8150-4902
Alexander S. Markov ORCID 0000-0002-3648-7557; eLIBRARY SPIN 3435-6396
Larisa V. Permyakova ORCID 0000-0003-1996-8903; eLIBRARY SPIN 4200-6990
Tatyana F. Kiseleva ORCID 0000-0003-1886-3544; eLIBRARY SPIN 6444-9321
Semyon Yu. Kleymenov eLIBRARY SPIN 1835-1848