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The influence of cadmium chloride and hyperthermia on the fatty acid composition of high aquatic plants from Angara River

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Water is the basic component of all living organisms and the biosphere. The intensification of using water in the industrial, agricultural and domestic consumption leads to an increased anthropogenic impact on water ecosystems. High aquatic plants are the most important component of aquatic ecosystems. They take part in the process of exchange of nutrients in self-purification of water, can accumulate and transform organic and inorganic pollutants. Aquatic plants are considered and used as sites for monitoring ecological status of water bodies. In this study we investigated the fatty acid composition of higher aquatic plants from Angara River under the influence of hyperthermia 30 °C, and cadmium chloride 100 mg/l. Macrophytes *Elodea canadensis* Michx. and *Myriophyllum spicatum* L. were gathered at a high flow of Angara River. After cultivation in the laboratory conditions the plants from experimental group were replaced in a solution of cadmium chloride (100 mg/l) during 24 and 48 h. In another experiment the plants were replaced in distilled water, 30 °C heated, and incubated during 24 or 48 h. Lipids were extracted with mixture of chloroform: methanol (2:1). Analysis of fatty acids composition was carried out in form of methyl ethers by the method of chromato-mass-spectrometry. The changes of the fatty acid composition in response to hyperthermia and cadmium chloride were found. The differences in the fatty acid composition changes of the studied species were shown after 24 and 48 h of exposure. Differences in the metabolism of fatty acids should be considered for the development of methods of biomonitoring and bioassay.

Key words: *Myriophyllum spicatum*, *Elodea canadensis*, high aquatic plants, Baikalian region, hyperthermia, cadmium chloride, fatty acids

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INTRODUCTION

Water is the basic component of all living organisms and the biosphere. The intensification of using water in the industrial, agricultural and domestic consumption leads to increased anthropogenic impact on ecosystem of water bodies. The poor water quality is a cause of almost 80% of all diseases in the world. The process of self-purification and maintaining chemical composition balance of the water in natural water reservoirs depends on the interaction of biotic and abiotic factors. A development of methods for assessment and conservation, and restoration of water quality is required in the conditions of increasing anthropogenic pollution and water consumption (Ratkovich, 2003; Ipatova, 2005; Novikova et al., 2005; Fais et al., 2007; Moiseenko, 2009).

High aquatic plants are the most important component of aquatic ecosystems. Along with algae, they are primary producers supplying material and energy in the ecosystem of the water basins. High aquatic plants are involved in the process of exchange of nutritional elements in self-purification of water, are able to accumulate and transform organic and inorganic pollutants. Aquatic plants are considered and used as objects for monitoring of ecological status of water bodies. It is known that water pollution modifies the associations of macrophyte reducing the number of their species. The level and the type of contamination is also reflected in the morphological, physiological and biochemical status of aquatic plants (Rozentsvet et al., 1999; Egorkina et al., 2000; Prasad et al., 2006; Melikhova, Sarapultseva, 2008).

The water bodies of the Baikal region accumulate considerable stores of fresh water, Lake Baikal alone contains up to 20% of the world total surface fresh water. The drain of water occurs from the lake just across River Angara. Flora and fauna of Lake Baikal as well as its catchment area water bodies and Angara River include a considerable variety of endemic taxa and also quite a number of widespread species. The hydrochemical and hydro-physical conditions are characterized by a high oxygen content, low salinity and temperature (Kozhova, Izmest'eva, 1998; Timoshkin et al., 2001; Izhboldina, 2007). In developing the biomonitoring methods of Baikalian region water bodies the specifics of their biotic and abiotic features should take into consideration.

The changes in lipid and fatty acid composition of the plant membranes occur under the influence of environmental factors. These changes are reflected in the physiological processes that are associated with membranes. A comparative study of the organism lipid and fatty acid composition can reveal abnormalities before appearing of symptoms of the morphological and populational changes (Rozentsvet et al., 1999; Los, 2001; Ipatova, 2005; Vereshchagin, 2005). Studies of the aquatic plants physiological and biochemical processes will allow to develop methods for assessing quality and treatment of water.

The aim of the study was to investigate and compare the relative fatty acid composition of the most widely spread higher aquatic plants of Angara River under the influence of hyperthermia and cadmium chloride.

MATERIALS AND METHODS

Macrophytes *Elodea canadensis* Michx. and *Myriophyllum spicatum* L. were gathered at a high flow of Angara River on the left-hand beach using standard hydrobotany methods. An average water temperature during the gathering was 10–12 °C. After the gathering the plants were washed with running water in order to escape from epiphytes separated on species and kept during 14–30 days in aquariums using constant aeration and ½ water volume replacement per 2–4 days. Water for plant keeping was taken from Angara River. The keeping temperature in lab conditions was 19–20 °C, photoperiod – 16 h. The light sources were fluorescent phyto-lamps Sylvania F18W/GRO (Germany) with emission maximum in the red and blue specter regions (the ratio of the red-light intensity for the blue-light intensity

was 1.42). The intensity of the illumination was 1 000 lux.

After cultivation in lab conditions the plants of the experimental group were replaced into a solution of cadmium chloride $CdCl_2 \times 2.5\ H_2O$ (100 mg/l) during 24 and 48 h. In another experiment the plants were replaced into distilled water, 30 °C heated, and incubated during 24 or 48 h. An average probe of biomass for analysis, consisting of some whole shoots (stems with leaves), was 1 g. The plants were washed with a soft brush in running water for escape from epiphytes. Samples of plant material were fixed with liquid nitrogen and grinded in porcelain mortar for obtaining a homogenate mass. Lipids were extracted with a mixture of chloroform: methanol (2:1) (Bligh and Dyer, 1959). Chloroform was moved off lipids extract by vacuum evaporation with rotary evaporator *И*Р-1*Л*Т, Labtex (Russia). In order to receive methanol ethers of fatty acids 5% methanol solution of H_2SO_4 was added after moving solvent and the obtained solution was heated using a water bath at 60 °C during 30 min. After cooling methanol ethers of fatty acids were extracted with hexane three times (Christie, 1993). Additional purification of methanol ethers of fatty acids was carried out by the method of thin-layer chromatography on aluminum plates with silica gel Sorbfil ПТСХ-АФ-В (Russia) in a camera with benzyl. Analysis of methanol ethers of fatty acids was carried out by the method of gas-liquid chromatography using chromatographer-mass spectrometer 5973N/6890N MSD/DS Agilent Technologies (USA). The detector of mass-spectrometer was a quadrupole, the way of ionization was an electron impact (EI), and energy of ionization was 70 eV, conditions of total ion current registration were used for analysis. A capillary column HP-INNOWAX (30 cm × 250 μm × 0.50 μm) was used for separation of methanol ethers of fatty acids. An immovable phase was polyethylene glycol. A movable phase was helium; the speed of gas flow was 1 ml/min. The temperature of evaporator was 250 °C, the temperature of ions source – 230 °C, the temperature of detector – 150 °C, the temperature of the line linking the chromatograph to the mass-spectrometer – 280 °C. The range of scanning was 41–450 amu. The volume of the input sample was 1 μl, the separation of the flows – 5:1. The isocratic chromatography was carried out at 200 °C. The identification of methanol ethers of fatty acids was made by calculation of the equivalent length of aliphatic chain (ECL). The libraries of mass-specters NIST 05, Christie and comparisons of the holding time of the studied samples with the holding time of the standard compounds were also used. A relative content of fatty acids was determined in weight percents of the common content of fatty acids in the studied sample. The index of double bond (IDB) for estimation of degree of fatty acids unsaturation was defined as the summation of weight percents of each acid multiplied by the number of the double bonds it contains per molecule and divided by 100 (Lyons et al., 1964).

The statistical significance of differences in the control and the experimental sampling was estimated with Wilcoxon-Mann-Whitney test (Glance, 1997).

RESULTS

Fatty acid compositions of the studied species have species-specific character. Both species contain fatty acids with carbon chain lengths of 14–22 atoms. As it can be seen from Tables 1 and 2, more than 95% of fatty acids in the studied plant species are acids with chain length of 16 and 18 carbon atoms. Unsaturated fatty acids dominate in both plant species, 79.9 and 75.61%, in *M. spicatum* and *E. canadensis*, respectively. Although the group of saturated fatty acids has less percent content, but is presented by larger numbers of individual acids. Thus, only in this group there are fatty acids with 14, 15, 21, and 22 carbon atoms, in contrast to the unsaturated fatty acids which have from 16 to 22 carbon atoms. By analyzing of the fatty acid composition in the investigated species it can be considered that most of them contain an even number of carbon atoms. Molecules with an odd number of atoms – pentadecanoic (C15:0), heptadecanoic (C17:0), heneicosanoic

Table 1. Fatty acids composition (% weight) of high aquatic plants after exposition to hyperthermia (30 °C)

	M. spicatum			*E. canadensis*		
	control	**30 °C, 24 h**	**30 °C, 48 h**	**control**	**30 °C, 24 h**	**30 °C, 48 h**
C14:0	0.34 ± 0.10	0.8 ± 0.02	0.32 ± 0.06	0.48 ± 0.23	0.70 ± 0.58	0.29 ± 0.03
C15:0	0.09 ± 0.02	0.09 ± 0.01	0.10 ± 0.01	0.15 ± 0.04	0.15 ± 0.09	0.11 ± 0.03
C16:0	17.95 ± 2.37	18.55 ± 1.09	15.14 ± 1.03	19.85 ± 1.80	20.83 ± 5.98	17.49 ± 1.37
C17:0	0.23 ± 0.11	0.30 ± 0.07	0.22 ± 0.01	0.56 ± 0.08	0.55 ± 0.10	0.60 ± 0.10
C18:0	1.24 ± 0.70	1.07 ± 0.17	0.96 ± 0.17	2.63 ± 0.77	2.74 ± 0.88	3.77 ± 0.86
C20:0	0.16 ± 0.05	0.15 ± 0.03	0.13 ± 0.05	0.34 ± 0.10	0.2 ± 0.11	0.40 ± 0.07
C21:0	–	–	–	0.13 ± 0.01	–	–
C22:0	0.22 ± 0.07	0.20 ± 0.03	0.21 ± 0.03	0.39 ± 0.14	0.20 ± 0.19	0.47 ± 0.18
Σ C16:1*	0.66 ± 0.13	0.40 ± 0.08	0.33 ± 0.16	1.35 ± 0.78	0.79 ± 0.29	0.33 ± 0.06
Σ C18:1**	2.33 ± 1.01	3.21 ± 0.93	2.52 ± 0.79	1.66 ± 0.73	1.21 ± 0.50	1.10 ± 0.09
C18:2(n-6)	26.22 ± 5.20	31.81 ± 3.99	28.23 ± 3.96	18.58 ± 2.76	19.53 ± 1.78	18.95 ± 1.81
C18:3(n-3)	50.56 ± 7.48	43.70 ± 6.02	51.65 ± 5.84	54.01 ± 4.24	53.15 ± 6.71	56.46 ± 1.47
C20:1(n-11)	0.25 ± 0.09	0.31 ± 0.26	–	–	–	–
DBI	2.07 ± 0.13	1.99 ± 0.10	2.15 ± 0.09	2.02 ± 0.11	2.01 ± 0.22	2.09 ± 0.06
Σ odd	0.32 ± 0.11	0.39 ± 0.08	0.32 ± 0.01	0.80 ± 0.16	2.01 ± 0.22	2.09 ± 0.06
Σ UFA	20.10 ± 3.16	20.59 ± 1.43	16.95 ± 1.25	24.39 ± 2.93	25.33 ± 7.40	23.17 ± 2.49

Shows the arithmetic mean ± standard deviation, n = 7 for control samples, n = 4 for experimental samples; «–» acid is found in trace amounts or it was not detected; * – sum of isomers palmitoleic acid; ** – sum of *cis*-vaccenic and oleic acids. DBI – the double bond index.

Σ odd – sum of acids with odd number carbon atoms.

Σ UFA – sum of unsaturated fatty acids.

Table 2. Fatty acids composition (% weight) high aquatic plants after exposition in solution of cadmium chloride (100 mg/l)

	M. spicatum			*E. canadensis*		
	control	$CdCl_2$, 24 h	$CdCl_2$, 48 h	control	$CdCl_2$, 24 h	$CdCl_2$, 48 h
C14:0	0.34 ± 0.10	0.52 ± 0.11	0.37 ± 0.06	0.48 ± 0.23	0.62 ± 0.14	0.80 ± 0.04
C15:0	0.09 ± 0.02	0.18 ± 0.05	0.13 ± 0.03	0.15 ± 0.04	0.31 ± 0.09	0.58 ± 0.06
C16:0	17.95 ± 2.37	18.28 ± 2.77	16.62 ± 1.81	19.85 ± 1.80	22.22 ± 2.91	25.05 ± 0.74
C17:0	0.23 ± 0.11	0.19 ± 0.04	0.21 ± 0.07	0.56 ± 0.08	0.79 ± 0.21	0.94 ± 0.07
C18:0	1.24 ± 0.70	1.52 ± 0.53	1.26 ± 0.23	2.63 ± 0.77	4.08 ± 0.77	5.31 ± 0.32
C20:0	0.16 ± 0.05	0.14 ± 0.07	0.15 ± 0.05	0.34 ± 0,10	0.48 ± 0.11	0.81 ± 0.05
C21:0	–	–	–	0.13 ± 0.01	0.15 ± 0.04	–
C22:0	0.22 ± 0.07	0.22 ± 0.05	0.30 ± 0.07	0.39 ± 0.14	0.50 ± 0.19	0.93 ± 0.12
Σ C16:1*	0.66 ± 0.13	0.79 ± 0.23	0.58 ± 0.26	1.35 ± 0.78	1.76 ± 0.64	2.48 ± 0.17
Σ C18:1**	2.33 ± 1.01	3.00 ± 1.40	2.27 ± 0.60	1.66 ± 0.73	2.50 ± 1.04	3.02 ± 0.49
C18:2 (n-6)	26.22 ± 5.20	24.10 ± 1.27	25.27 ± 3.03	18.58 ± 2.76	19.06 ± 0.93	16.77 ± 0.44
C18:3 (n-3)	50.56 ± 7.48	50.97 ± 5.95	52.48 ± 5.15	54.01 ± 4.24	47.51 ± 5.01	43.14 ± 1.30
C20:1 (n-11)	0.25 ± 0.09	0.14 ± 0.06	0.15 ± 0.07	–	–	–
DBI	2.07 ± 0.13	2.05 ± 0.14	2.12 ± 0.10	2.02 ± 0.11	1.85 ± 0.14	1.14 ± 0.04
Σ odd	0.32 ± 0.11	0.37 ± 0.07	0.34 ± 0.09	0.80 ± 0.16	1.26 ± 0.31	1.52 ± 0.12
Σ UFA	20.10 ± 3.16	21.00 ± 3.56	18.96 ± 2.29	24.39 ± 2.93	29.16 ± 3.96	34.42 ± 1.04

Shows the arithmetic mean ± standard deviation, n = 7 for control samples, n = 4 for experimental samples; «-» acid is found in trace amounts or it was not detected; * – sum of isomers palmitoleic acid; ** – sum of *cis*-vaccenic and oleic acids. DBI – the double bond index.

Σ odd – sum of acids with odd number carbon atoms.

Σ UFA – sum of unsaturated fatty acids.

(C21:0) were observed exceptionally among the saturated fatty acids. The total content of these acids was 0.32% in *M. spicatum*, 0.80% in *E. canadensis*. Heneicosanoic acid was found only in *E. canadensis* (Tables 1 and 2).

The fatty acid content in the studied species changed insignificantly under hyperthermia conditions (30 °C) (Table 1). In *E. canadensis* only the contents of palmitic (C16:0) and palmitoleic (C16:1) acids decreased significantly over 48 h of hyperthermia. In *M. spicatum* only palmitoleic (C16:1) acid content decreased. The content of heneicosanoic (C21:0) acid decreased to the trace quantity in *E. canadensis*. During 24 h of the treatment the content of saturated fatty acid remained close to control, and over 48 h the tendency of the decrease of their level was observed in *M. spicatum* from 20.1 to 16.95% and in *E. canadensis* from 24.39 to 23.17%. However, it did not result in statistically significant changes of the double bond index. The content of the fatty acids with an odd number of carbon atoms did not change.

The treatment of the studied species with the solution of cadmium chloride (100 mg/l) for 24 and 48 h resulted in a change of the fatty acids composition in the tissues of the aquatic plants (Table 2). The content of fatty acids in *M. spicatum* remained close to control under the action of cadmium chloride, a statistically significant increase was detected through 24 h exposure with toxicant for myristic (C14:0) and pentadecanoic (C15:0) acids only. The redistribution of the relative content of saturated, mono- and polyunsaturated fatty acids did not affect the value of the double bond index in *M. spicatum*.

The relative content of fatty acids in *E. canadensis* changed otherwise (Table 2). The contents of pentadecanoic (C15:0), heptadecanoic (C17:0), stearic (C18:0), and arachidic (C20:0) acids increased significantly over 24 and 48 h of the experiment. The content of palmitic (C16:0) and behenic (C22:0) acids increased significantly by 48 h exposure with cadmium chloride. In general, the total content of the saturated fatty acid increased significantly by 48 h of the experiment. In this species, there was an increase of the total content of the fatty acids with an odd number of carbon atoms over 24 and 48 h.

The treatment of *E. canadensis* with a solution of cadmium chloride for 48 h resulted in a statistically significant increase of the content of the palmitoleic acid isomers sum (C16:1) and the amount of *cis*-vaccenic (C18:1n-7) and oleic (C18:1n-9) acids (Table 2). The content of α-linolenic acid (C18:3n-3) decreased significantly over 48 h of the experiment. Changes in mass fractions in fatty acids of *E. canadensis* led to a decrease of the double bond index, however, this change acquired a statistically significant character over 48 h of the cadmium chloride exposure only.

DISCUSSION

The predominance of fatty acids with chain length of 16–18 carbon atoms in the tissues of the studied macrophytes is explained by the fact that they make up a large part of the acids in the membrane lipids of many taxonomic groups of living organisms, including those for higher plants as mostly 16- and 18-carbon fatty acids are part of the cell membrane lipids (Gunstone, 1996; Napolitano, 1998; Heldt, 2005). A large proportion of total fatty acids accounted for C18 unsaturated acids. It occurred more often in natural unsaturated fatty acid containing 18 carbon atoms, they are dominant in the lipid composition of many organisms. Thus, in nature the most common fatty acid is α-linolenic acid. Both studied species contained more than 50% α-linolenic acid of total fatty acids. It is believed that the acid does not play only a structural role in membrane lipids, but also participates in the process of photosynthesis. Therefore, in the tissues of photosynthetic plants this acid is present in significant amounts (Napolitano, 1998; Novitskaya et al., 2000; Vance, Vance, 2002; Heldt, 2005; Vereshchagin, 2007).

A considerable part of the physiologically important processes (respiration, photosynthesis, active transport, etc.) is associated with cell membranes and is dependent on their functional state. In order to perform the func-

tion cell membranes must have a liquid-crystalline structure and possess a certain degree of fluidity and toughness. First of all membrane fluidity and toughness depend on the ratio of saturated and unsaturated fatty acids, as well as the degree of their unsaturation. Fluctuations of the environmental conditions cause changes in the structure of the components and the functional activity of membranes that affects the course of all the physiological processes in the cell. At the cellular level membranes are a natural barrier and the first target exposed to the stress factors; they are also involved in the transfer of the stress signal to the cells. Under the influence of stress factors the degree of fatty acids unsaturation, the carbon chain length and the position of the double bond in the molecule may change. Perhaps these changes characterize the nonspecific reaction of plants and increase the resistance of the cell membrane (Ariizumi et al., 2002; Iba, 2002; Singh et al., 2002; Yaeno et al., 2004; Vereshchagin, 2005; Eeman, Deleu, 2010). The differences in the composition of fatty acids in the studied species were revealed under the conditions of hyperthermia and cadmium chloride. The nature of the changes depends on the type of exposure and species of aquatic plants.

Temperature is one of the most important abiotic factors. Throughout evolution plants as poikilothermic organisms have been developing different mechanisms of adaptation to changes in the temperature conditions of the environment. Some papers deal with investigation of the effect of low temperatures on the fatty acid composition of plants. A number of species showed an increase of fatty acids unsaturation degree in response to a decrease in temperature. Studies of genetically modified plants with a capacity for increased synthesis of unsaturated fatty acids showed an increased viability of these organisms in the conditions of hypothermia. Investigations of the influence of hyperthermia on the fatty acid composition of plants received less attention. An increase of temperature leads to an increase in the degree of cell membranes fluidity; in order to maintain "homeostasis fluidity / toughness" cells increase the saturation of membrane lipids (Ariizumi et al., 2002; Iba, 2002; Falcone et al., 2004; Ipatova, 2005; Titov et al., 2006; Karpets, Kolupaev, 2009; Afanaseva, Berezina, 2011; Sham, Aly, 2012). It has been found that temperature of 30 °C does not lead to significant changes in the fatty acid composition of the studied species. Probably, this temperature is not sufficient to significantly affect the activity of desaturases. Apparently, this is due to the fact that there are no significant transition and change in the molecular mobility of membrane lipids in the temperature range 20–35 °C (Los, 2001).

Cadmium is a representative of a heavy metal group, it has a significant toxicity, mobility, permeability and cumulation. It enters the water with sewage, mining, processing and electrolysis industry, as well as agricultural fields using fertilizer. Cadmium has a significant impact on the organisms living in water reservoir with low salinity and low values of pH. Cadmium is toxic, accumulating in the tissues of organisms; it is not biodegradable and is not practically eliminated from the organism. It has been shown that heavy metals, including cadmium, reduce plant growth, a negative impact on their development, interfere with the transport of assimilates and mineral nutrition, water status and affect hormone metabolism, reduce the activity of photosynthesis and respiration (Manahan, 2000; Gerard, 2005; Kvesitadze et al., 2005; Prasad et al., 2006; Kuznetsova et al., 2008; Garmash, Golovko, 2009; Moiseenko, 2009). Probably the identified changes in the fatty acids composition in the studied species are associated in particular with the influence of cadmium on the living processes and lipid metabolism.

A mechanism of the heavy metals toxicity, particularly cadmium, is a connection to the SH-groups of proteins and the initiation of peroxidation and free radical oxidation. Under the influence of heavy metals the functions of membranes are violated, indicators of their transformation are changes in the fatty acids. A number of works propose that changes in the fatty acids composition in the lipids are

non-specific reaction. Nonspecificity occurs in the increasing unsaturation in response to various stressors. However, it has been shown that under the influence of heavy metals the amount of saturated fatty acids increases, making the package of the membrane lipids more compact and thus stabilizing membranes (Kholodova et al., 2005; Kuznetsova et al., 2008; Nesterov et al., 2009; Hu et al., 2009). Changes in the fatty acid composition of the studied higher plant species under the influence of cadmium chloride were expressed in different degrees. It can be assumed that the effect of the toxicant on lipid metabolism of each species has its own characteristics. Membranes of *E. canadensis* appeared to undergo more marked modifications over the membranes of *M. spicatum*, because in the first species there is a significant decrease in the content of linolenic acid (C18:3n-3). Decline in the proportion of this acid may be due to activation of lipid peroxidation, decrease of respiration activity or the combined impact of both factors. The content of pentadecanoic (C15: 0), stearic (C18: 0) and arachidic (C20:0) acids is also significantly increased in this species, and the double bond index is reduced. It should also be noted that in this species the content of fatty acids with an odd number of carbon atoms is significantly increased. The synthesis of these acids is through propionyl-CoA. Probably the metabolism of fatty acids in *E. canadensis* undergoes significant changes that affect even the synthesis of fatty acids across the propionyl-CoA. At the same time, the fatty acid composition of *M. spicatum* is more stable, and it is likely that the lipid metabolism is less affected by cadmium chloride. It is known that this species is recommended for phytoremediation of heavy metal pollution, including cadmium (Kvesitadze et al., 2005).

CONCLUSIONS

Thus, we can conclude that the fatty acid composition of the studied species is changed in various ways under the exposure to cadmium chloride solution for 24 and 48 h. These changes are less expressed in *M. spicatum*. In general, the fatty acid composition in *M. spicatum* is more stable to the toxicant effects. These features suggest the existence of differences in the metabolism of fatty acids in *E. canadensis*. This species, evolved in North America, is introduced to Eurasia and has been pronounced invasive. For a short period of time it was able to spread widely, giving pressure to native vegetation of many reservoirs (Barrat-Segretain et al., 2002; Barrat-Segretain, Elger, 2004; Azovsky, Chepinoga, 2007). It is possible that this species is so well settled by the specific features of metabolism.

The character profile of the fatty acids of total lipids and differences of IDS can probably explained the peculiarities of metabolism of these acids in each of the studied species. In this case the species differences are manifested not only at the morphological level, but also in the specific metabolism of fatty acids. The knowledge about specific metabolism of aquatic plants will allow to make more use of them in the environmental monitoring of the biochemical status of water bodies. In this connection, the identified biochemical differences should be considered during the development of quality assessment and purification of contaminated water.

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References

1. Afanaseva NB, Berezina NA. Introduction to plant ecology. Moscow: Publisher of Moscow University; 2011.
2. Ariizumi T, Kishitani S, Intsugi R, Nishida I, Murata N, Toriyama K. An increase in unsaturation of fatty acids in phosphatidylglycerol from leaves improves the rates of photosynthesis and growth at low temperatures in transgenic rice seedlings. Plant Cell Physiol 2002; 43(7): 751–8.
3. Azovsky MG, Chepinoga VV. Aquatic higher plants of Baikal Lake. Irkutsk, Russia: Publisher of Irkutsk State University; 2007.

4. Barrat-Segretain M-H, Elger A, Sagnes P, Puijalon S. Comparison of three life-history traits of invasive *Elodea canadensis* Michx. and *Elodea nuttallii* (Planch.). Aquat Bot 2002; 74(4): 299–313.

5. Barrat-Segretain M-H, Elger A. Experiments on growth interactions between two invasive macrophyte species. J Veget Sci 2004; 15(1): 109–14.

6. Bligh EG, Dyer WJ. A rapid method of total lipid extraction and purification. Can J Biochem Physiol 1959; 37: 911–9.

7. Christie WW. Preparation of ester derivatives of fatty acids for chromatographic analysis. In: WW Christie (ed.). Advances in lipid methodology. Dundee: Oily Press; 1993, 69–111.

8. Eeman M, Deleu M. From biological membranes to biomimetic model membranes. Biotechnol Agr Soc Env 2010; 14(4): 719–36.

9. Egorkina GI, Zarubina EYu, Kirilov VV. The use of higher water plants to assess the genotoxicity of surface water. Contemporary Problems of Ecology 2000; 6: 686–8 (in Russian).

10. Fais D, Maximov VN, Morichi D, Nazelli-Flores L. Multimedia dictionary of ecology. Moscow: Nauka; 2007.

11. Falcone DL, Ogas JP, Somerville CR. Regulation of membrane fatty acid composition by temperature in mutants of Arabidopsis with alterations in membrane lipid composition. BMC Plant Biol 2004; 4(17).

12. Garmash EV, Golovko TK. Effect of cadmium on growth and respiration of barley plants grown under two temperature regimes. Russ J Plant Physiol 2009; 56(3): 343–7.

13. Gerard J. Principles of environmental chemistry. Boston, USA: Jones and Bartlett Publishers Inc; 2005.

14. Glantz S. Primer of biostatistics. New York: McGraw-Hill Inc.; 1997.

15. Gunstone FD. Fatty acid and lipid chemistry. London: Blackie Academic and Professional; 1996.

16. Heldt H-W. Plant biochemistry. 3rd edition. San Diego, USA: Elsevier; 2005.

17. Hu JZ, Pei DL, Liang F, Shi GX. Growth responses of *Sagittaria sagittifolia* L. plants to water contamination with cadmium. Russ J Plant Physiol 2009; 56(5): 759–67.

18. Iba K. Acclimative response to temperature stress in higher plants: Approaches of gene engineering for temperature tolerance. Annu Rev Plant Biol 2002; 53: 225–45.

19. Ipatova VI. Adaptation of aquatic plants to stressful abiotic environmental factors. Moscow: Grafikon-print; 2005.

20. Izhboldina LA. Guide and key to identification benthic algae and periphyton of Lake Baikal (meio-and macrophytes) with a brief sketch of their ecology. Novosibirsk, Russia: Publisher Nauka-Centr; 2007.

21. Karpets YuV, Kolupaev YuYe. Response of plants on heating: molecular-cellular aspects. The Bulletin of Kharkiv National Agrarian University Series Biology 2009; 1(16): 19–38 (in Russian).

22. Kholodova VP, Volkova KS. Kuznetsov VV. Adaptation of the common ice plant to high copper and zinc concentrations and their potential using for phytoremediation. Russ J Plant Physiol 2005; 52(6): 748–57.

23. Kozhova OM, Izmest'eva LR. Lake Baikal. Evolution and biodiversity. Leiden, Netherlands: Backhuys Publishers; 1998.

24. Kuznetsova TYu, Vetchinnikova LV, Titov AF, Il'inova MK. Effect of cadmium on fatty acid composition of lipids in the shoots of Karelian birch cultured *in vitro*. Russ J Plant Physiol 2008; 55(5): 731–7.

25. Kvesitadze GI, Hatisashvili GA, Sadunishvili TA, Evstigneeva ZG. The metabolism of anthropogenic pollutants in higher plants. Moscow: Nauka, 2005.

26. Los DA. Structure, regulation of expression and function of fatty acid desaturases. Uspekhi Biologicheskoi Khimmii 2001; 41: 163–98 (in Russian).

27. Lyons JM, Wheaton TA, Pratt HK. Relationship between the physical nature of mitochondrial membranes and chilling sensitivity in plant. Plant Physiol 1964; 39: 262–8.

28. Manahan SE. Toxicological chemistry and biochemistry. 3rd edition. Boca Raton, USA: CRC Press / Taylor and Francis Group; 2000.

29. Melikhova OP, Sarapultseva EI (eds.). Biological control of the environment: bioindication and bioassay: a textbook for university students. Moscow: Publishing Center "Academiya"; 2008.

30. Moiseenko TI. Aquatic ecotoxicology: theoretical and applied aspects. Moscow: Nauka; 2009.

31. Napolitano GE. Fatty acids as trophic and chemical markers in freshwater ecosystems. In: MT Arts, BC Wainman (eds.). Lipids in freshwater ecosystems. New York: Springer; 1998, p. 21–5.

32. Nesterov VN, Rozentsvet OA, Murzaeva SV. Changes in lipid composition in the tissues of fresh-water plant *Hydrilla verticillata* induced by accumulation and elimination of heavy metals. Russ J Plant Physiol 2009; 56(5): 97–106.

33. Novikova NM, Volkova NA, Nazarenko OG. Evaluation of the impact of the superficial water regime changes on terrestrial ecosystems. Moscow: Nauka; 2005.

34. Novitskaya GV, Suvorova TA, Trunova TI. Lipid composition of tomato leaves as related to plant cold tolerance. Russ J Plant Physiol 2000; 47(6): 728–33.

35. Prasad MNV, Sajwan KS, Naidu R (eds.). Trace elements in the environment: biogeochemistry, biotechnology and bioremediation. Boca Raton, USA: CRC/Taylor and Francis; 2006.

36. Ratkovich DYa. Water supply issues of the day. Moscow: Nauka; 2003.

37. Rozentsvet OA, Kozlov VG, Dembitsky VM. Comparative study of lipids of four dominant species of freshwater plants and algae in Shulgan River. Biochem (Moscow) 1999; 64(11): 1290–7 (in Russian).

38. Sham A, Aly MAM. Bioinformatics based comparative analysis of omega-3 fatty acids in desert plants and their role in stress resistance and tolerance. Intl J Plant Res 2012; 2(3): 80–9.

39. Singh SC, Sinha RP, Häder D-P. Role of lipids and fatty acids in stress tolerance in cyanobacteria. Acta Protozool 2002; 41: 297–308.

40. Timoshkin OA (ed.). Index of animal species inhabiting Lake Baikal and its catchment area. Volume I. Lake Baikal. Book 1. Novosibirsk, Russia: Nauka, 2001.

41. Titov AF, Akimova TV, Talanova VV, Topchieva LV. Plant resistance in the period of unfavourable temperatures effects. Moscow: Nauka; 2006.

42. Vance DE, Vance JE. Biochemistry of lipids, lipoproteins and membranes. 4th edition. Amsterdam: Elsevier; 2002.

43. Vereshchagin AG. The sixteenth international symposium on plant lipids (Budapest, Hungary, June 1–4, 2004). Russ J Plant Physiol 2005; 52(3): 414–20.

44. Vereshchagin AG. Lipids in plant life. Moscow: Nauka; 2007.

45. Yaeno T, Matsuda O, Iba K. Role of chloroplast trienoic fatty acids in plant disease defense responses. Plant J 2004; 40: 931–41.

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KADMIO CHLORIDO IR HIPERTERMIJOS POVEIKIS AUKŠTESNIŲJŲ VANDENS AUGALŲ RIEBALŲ RŪGŠČIŲ SUDĖČIAI ANGAROS UPĖJE

Santrauka

Vanduo yra pagrindinis visų gyvų organizmų ir biosferos komponentas. Didelis gyventojų, pramonės, žemės ūkio vandens poreikis lemia didesnį antropogeninį poveikį vandens ekosistemai. Aukštesnieji vandens augalai yra vieni svarbiausių vandens ekosistemos komponentų. Jie suteikia vandeniui daug maistingųjų medžiagų, dalyvauja

apsivalymo procese, sukaupdami ar perdirbdami organinius ir neorganinius teršalus.

Šio darbo tikslas – ištirti ir įvertinti aukštesniųjų vandens augalų sudėtį Angaros upėje po 30 °C hipertermijos ir 100 mg/l kadmio chlorido poveikio. Makrofitai *Elodea canadensis* Michx. ir *Myriophyllum spicatum* L. buvo surinkti aukštutiniame Angaros upės baseine. Po kultivavimo laboratorijos sąlygomis eksperimentinės grupės augalai buvo paveikti kadmio chlorido (100 mg/l) tirpalu iš pradžių 24, vėliau 48 valandas. Kito eksperimento metu augalai buvo papildomai paveikti 30 °C temperatūra ir inkubuojami atitinkamai 24 ir 48 valandas. Lipidai buvo ekstrahuojami chloroformo-metanolio (2 : 1) tirpalu. Atlikus riebalų rūgščių sudėties analizę chromatografijos-masių spektrometrijos metodu, buvo aptikti kadmio chlorido ir hipertemijos sukelti pakitimai. Tam tikrų reikšmingų pokyčių pastebėta po 24 ir 48 valandų. Riebalų rūgščių metabolizmo pakitimai turi įtakos naujų biomonitoringo ir biologinių metodų vystymuisi.

Raktažodžiai: *Myriophyllum spicatum*, *Elodea canadensis*, aukštesnieji vandens augalai, Baikalo sritis, hipertermija, kadmio chloridas, riebalų rūgštys