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Changes in the nutritional parameters of muscles of the common carp (*Cyprinus carpio*) and the silver carp (*Hypophthalmichthys molitrix*) following environmental exposure to cyanobacterial water bloom

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Abstract

The present study evaluated the effect of naturally developing cyanobacteria on the composition of muscles of two commercially important freshwater fish species. Fish were exposed to cyanobacterial biomass including *Microcystis aeruginosa* and *Microcystis ichthyoblabe* for 4 weeks. Then, they were transferred to dechlorinated potable water without any cyanobacteria for another 4-week period, thus modelling their preparation for consumers. Samples of muscles were collected every week during exposure and subsequent stay in dechlorinated potable water. The cyanobacterial water bloom of 3.9–6 $\times$ 10^5 cells mL^{-1} (133–383 $\mu g\, g^{-1}$ of total MC DW) induced statistically significant effects only in the content of fatty acids ($P<0.05$; $P<0.01$) in the common carp (*Cyprinus carpio*), while all studied parameters including the content of dry matter and fat ($P<0.01$), proteins ($P<0.05$), fatty acid composition ($P<0.05$; $P<0.01$) and some amino acids ($P<0.05$) were affected in the silver carp (*Hypophthalmichthys molitrix*). This study has shown that cyanobacteria in the environment of commercially produced fish may decrease the dietetic value of fish muscles.

Keywords: freshwater fish, amino acids, fatty acids, blue green algae

Introduction

Fish are considered to be food of high dietetic value owing to their characteristic composition of amino acids (AA), fatty acids (FA), vitamins and easy digestibility (Steffens 1997; Murray & Burt 2001; Buchtová, Svobodová, Kocour & Velíšek 2007). The composition of fish muscles is considerably influenced by many biotic and abiotic factors such as fish species, age, gender, breeding technology, environmental conditions, nutrition, stress and others (Henderson & Tocher 1987; Fajmonová, Zelenka, Komprda, Kladroba & Sarmanová 2003). The high dietetic value of fish muscles is also due to the content of oils, in particular, n-3 unsaturated fatty acids (Steffens 1997; Mareš 2003). Polyunsaturated fatty acids (PUFA) such as eicosapentaenoic acid (EPA) (20:5n-3), docosahexaenoic acid (DHA) (22:6n-3) and arachidonic acid (ARA) (20:4n-6) are most important for human nutrition. Their essential precursors are linoleic acid (LA) (18:2n-6) and α-linolenic acid (LNA) (18:3n-3). These acids play a major role in the prevention of several diseases (Glade 2003). To evaluate fats, a profile of fatty acids based on the ratio of saturated FA, monounsaturated FA, n-3 and n-6 PUFA, EPA and DHA levels and, in particular, the ratio of n-3/n-6 and EPA+DHA/n-6 is used (Komprda, Zelenka, Fajmonová, Fialová & Kladroba 2005).

Water bloom cyanobacteria represent a dominant component of phytoplankton of eutrophic aquatic environments and their metabolites are known to influence fish (Malbrouck & Kestemont 2006). Depending on the environmental conditions, cyanobacteria produce many biologically active substances. Regarding hazards posed by cyanobacteria, it is necessary to understand their chemical and physical

properties, study their occurrence in waters used by humans as well as control their production under conditions of natural ecosystems (Chorus, Falconer, Salas & Bartram 2000). The chemical composition of cyanobacteria and algae depends considerably on environmental conditions and varies considerably with individual species. Cyanobacteria of the *Microcystis* genus are relatively rich in some fatty acids, the total content of which, however, is lower than that in green algae and diatoms (Ahlgren, Gustafsson & Boberg 1992; Dunstan, Volkman, Barrett, Leroi & Jeffrey 1994). The composition of amino acids in cyanobacteria and green algae is similar despite considerable variation in the content of dry matter (14–61%) in relation to the species and environmental conditions (Ahlgren *et al.* 1992).

Many authors have recently carried out studies concerning the accumulation of toxic cyanobacterial metabolites and microcystin LR, in particular, in fish tissues (Magalhães, Soares & Azevedo 2001; Marinho, Domingos, Oliveira, Costa, Azevedo & Azevedo 2003; Soares, Magalhães & Averezo 2004; Xie, Xie, Guo, Li, Miyabara & Park 2005; Chen, Xie, Zhang, Ke & Yang 2006; Smith & Haney 2006). Interestingly, recent studies on the effect of cyanobacteria on the quality of fish products report the finding that exposure of the rainbow trout (*Oncorhynchus mykiss*) to cyanobacterial biomass causes osmoregulation imbalance (Best, Eddy & Codd 2003) resulting from stimulation of the drinking response, increased volume of fluid in the gut and inability to remove excess water.

Tadesse, Boberg, Sonesten and Ahlgren (2003) studied the effects of algal diets on the content of FA and the ratio of PUFA n-3/n-6 in Nile Tilapia (*Oreochromis niloticus*) and found that it seems to have a rather huge capacity to modify FA from algal food into their own species-specific FA patterns because, to some extent, short-chained fatty acids in the diets could be traced in the long-chained counterparts in the fish tissue.

There are increasing problems with eutrophication of the aquatic environment and growth of cyanobacteria (Chorus & Bartram 1999; Maršálek, Bláha, Turánek & Neèa 2001). However, there are only a few studies concerning the influence of cyanobacterial water bloom on fish muscle composition and the resulting nutritional value (Domaizon, Desvilettes, Debroas & Bourdier 2000; Tadesse *et al.* 2003). The objective of this study, therefore, was to determine whether and how the presence of the cyanobacterial water bloom influences the quality of fish muscles, with special attention to the basic chemical composition (i.e. content of dry matter, fat and nitrogenous substances) and the composition of FA and AA. Experimental animals were selected so as to include the common carp (*Cyprinus carpio*), which does not actively forage and digest cyanobacteria, and the silver carp (*Hypophthalmichthys molitrix*), which ingests cyanobacteria but in which digestion of cyanobacteria is only limited (Voros, Oldal, Presing & Vonbalogh 1997; Jančula, Míkovcová, Adámek & Maršálek 2008).

Materials and methods

Experimental fish and design

Yearling fish of the common carp (*C. carpio* L.) and silver carp (*H. molitrix* Val.), obtained from a single artificial stripping (Fishpond Management Pohorelice, Czech Republic), were used for the study. Fish measured 130–170 and 300–390 mm in length and their body weight was 30–55 and 230–500 g respectively. Following 2 weeks of acclimatization, experimental fish were kept in groups in cages in the rearing pond and exposed to naturally developing cyanobacterial bloom from weeks W0 to W4 (i.e. for 4 weeks) during August and October 2005. Control fish were kept under the same conditions, but without exposure to cyanobacteria (i.e. in another pond without apparent cyanobacterial bloom formation). Both experimental and control fish were reared without additional feeding and foraged natural food during this 4-week period (W0–W4). Then, experimental and control fish were transferred into 1000-L tanks containing dechlorinated potable water without any cyanobacteria for another 4-week period (from weeks W4–W8), thus modelling their preparation for consumers. Water in these tanks was changed daily and fish were exposed to a 12-h light/12-h dark photoperiod. Fish were not given any feeds during this period. Fish from this experiment have also been examined for microcystin concentrations in muscles, liver and skin (Adamovský *et al.* 2007).

Habitat and aquatic environment description

The study was performed in fish farming ponds (Fishpond Management Pohorelice, Czech Republic, 48°57′56.267″N latitude, 16°32′39.095″E longitude, 175 m.a.s.l.). All rearing ponds at this aquaculture farm have the same source of influent water lacking

cyanobacteria. Therefore, differences in algal communities of individual ponds (including the ones for keeping experimental and control fish from weeks W0 to W4) at the study locality were due to the population density and size of fish. Cyanobacteria were not present in ponds with older fish, while the opposite was true in ponds with fingerlings. Another factor that might have influenced the presence or absence of cyanobacteria in a pond was when and for how long the pond had been filled with water and how long it had been without water before filling.

Water parameters during the experiments (given for the experimental and control group respectively) were as follows: water temperature 19.2 ± 1.1 and 19.6 ± 1.1 °C, dissolved oxygen 10.0 ± 3.2 and 11.1 ± 2.8 mg L^{-1}, pH 8.9 ± 0.6 and 9.1 ± 0.2, ammonia 0.38 ± 0.14 and 0.45 ± 0.14 mg L^{-1} N-NH_4^+ and nitrite 0.058 ± 0.010 and 0.070 ± 0.011 mg L^{-1} N-NO_2^-. Water saturation by oxygen, temperature and pH was measured using a WTW Oxi 340i dissolved oxygen meter and a WTW pH 340i pH meter (WTW GmbH, Germany). Ammonium ions were determined using the Nessler method and nitrites using the *N*-(1-naphthyl)-ethylenediamine method (APHA 1981).

Phytoplankton and microcystins

Cyanobacterial and algal biomass was evaluated every week by chlorophyll *a* concentrations (ISO 10260, 1992) and by the number of cells counted in the Bürker's counting chamber (Meopta, Czech Republic). Cyanobacterial biomass (dominated by coccal *Microcystis aeruginosa* and *Microcystis ichthyoblabe*) estimated by the chlorophyll *a* cell concentration varied from 198 to 598 μg L^{-1} (3.9–6 × 10^5 cells mL^{-1}) in the experimental pond. The algal biomass (dominated by chlorococcal green algae – genus *Scenedesmus* and *Coelastrum*), also estimated by the chlorophyll *a* cell concentration, varied from 216 to 445 μg L^{-1} (1.3–5.4 × 10^4 cells mL^{-1}) in the control pond.

Concentrations of microcystins in the cyanobacterial and algal biomass were determined by a previously published method using HPLC (Agillent 1100 system, Supelcosil ABZ+Plus C18 column, Agilent Technologies Inc., Santa Clara, CA, USA) coupled with a photodiode array detector (Bláha & Maršálek 2003). The concentrations of microcystins in the experimental and control breeding ponds are presented in Table 1. The concentrations are well comparable with microcystin levels from other ponds in the Czech Republic (Maršálek *et al.* 2001).

Sample collection

Fish were killed by mechanical stunning and bleeding from a cut through gill vessels. Muscle samples from 10 specimens of both fish species were collected at weekly intervals, chilled and transported to the laboratory for analytical processing. Sampling of these animals was performed in compliance with laws for the protection of animals against cruelty and was approved by the Ethical Committee of the University of Veterinary and Pharmaceutical Sciences Brno, Czech Republic. To evaluate the experiment, standard parameters of the chemical composition of muscles (dry matter, content of proteins, fats and ash), composition of amino acids (AA) and fatty acids (FA) were used. Lipids were determined according to Soxhlet using a 12-h extraction by diethylether. Dry matter content was determined by drying

Table 1 Microcystin concentrations during the experiment

	Experimental pond								Control
	Biomass DW (μg g^{-1})		IC (μg L^{-1})		EC (μg L^{-1})		IC+EC (μg L^{-1})		IC+EC (μg L^{-1})
Duration of the experiment (days)	MC-LR	Total	MC-LR	Total	MC-LR	Total	MC-LR	Total	Total
0	99.0	243.5	3.5	6.9	0.2	0.5	3.7	7.4	<LOD
7	157.0	187.0	–	–	–	–	–	–	<LOD
14	372.1	382.3	3.3	4.6	0.5	1.0	3.8	5.6	0.14
21	317.1	383.9	1.5	1.9	0.5	0.9	2.1	2.8	0.12
28	133.4	133.4	2.8	3.6	0.1	0.1	2.9	3.7	0.23

DW, dry weight; IC, intracellular; EC, extracellular; LOD, limit of detection (0.05 μg L^{-1}).

the sample up to a constant weight at 105 °C (for 24 h). Ash level was determined using a gravimetric method of incineration in an electric oven at 550 °C. The content of nitrogenous substances was measured using the method by Kjehldahl and a Kjeltec 23 apparatus (Tecator, Sweden), with the net nitrogen determined being recalculated for nitrogenous substances ($N \times 6.25$) and proteins respectively. The fatty acid composition was determined using gas chromatography (HP 4890D chromatograph, Hewlett Packard, USA) following extraction with a mixture of methanol and chloroform (Folsch, Lees & Sloane-Stanley 1957). Samples for the analysis of amino acids were hydrolyzed using oxidative acid hydrolysis by HCl ($c = 6\ \mathrm{mol\,dm^3}$). After this, amino acids were determined using an AAA 400 unit (INGOS Prague, Czech Republic), sodium citrate buffers and ninhydrine detection (Kráčmar, Gajdùšek, Kuchtík, Zeman, Horák, Doupovcová, Matíjková & Kráèmarová 1998).

Statistical analyses

Basic statistical values (means ± SD) of the parameters investigated were processed in EXCEL 2003. Statistical significance was evaluated using the analysis of variance, ANOVA (UNISTAT 5.1).

Results and discussion

Chemical composition of muscles

Dry matter content in muscles of the common carp varied during the experiment from 19.71% to 23.48% and from 19.16% to 22.80% in control and cyanobacteria-exposed fish respectively. There were, however, no statistically significant differences induced by cyanobacteria on comparing summary data from weekly samplings of experimental and control fish as well as data from individual sampling occasions (i.e. W1–W8). The highest values were found during the first week following transfer of experimental and control fish into tanks containing dechlorinated potable water, i.e. on W5 sampling. Cyanobacteria also had no statistically significant effects on the content of fats and nitrogenous substances in muscles of the common carp. Fat content varied during the experiment from 3.15% to 5.23% in control fish and from 3.47% to 5.05% in the experimental group. The respective ranges were 16.36–19.39% and 14.96–18.09% in terms of nitrogenous substances. Values of the above parameters were in

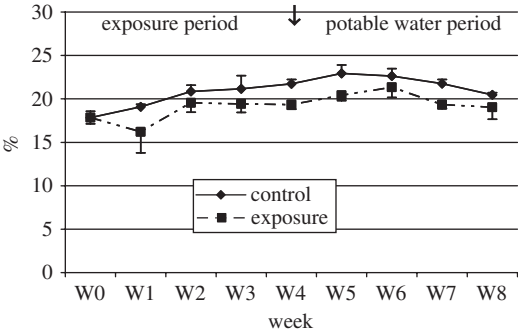

Figure 1 Dynamics of changes in dry matter in muscles of the silver carp (%). Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

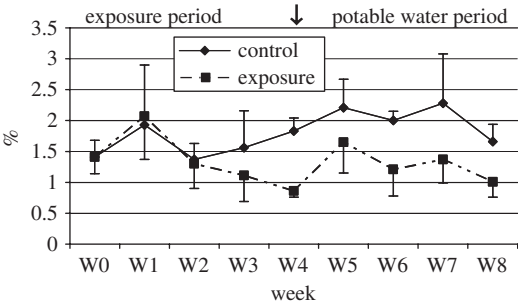

Figure 2 Dynamics of changes in fat contents in muscles of the silver carp (% of fresh weight). Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

agreement with those already found in the common carp under conditions of artificial pond rearing (Kmínková, Winterová & Kuèera 2001; Murray & Burt 2001; Fajmonová *et al.* 2003; Mareš 2003).

Values of individual parameters in the control silver carp were within reference levels (Vácha 1996; Domaizon *et al.* 2000). As shown in Fig. 1, there were statistically highly significant effects on the dry matter in muscles of the silver carp exposed to cyanobacterial bloom ($P < 0.01$), because they had a lower dry matter content of muscles compared with the control. Fat content was influenced by exposure to

cyanobacteria in a similar way ($P < 0.01$). Except for the first sampling, experimental fish always showed lower levels in comparison with controls (Fig. 2). Protein content was lowered on exposure of fish to cyanobacterial bloom and was statistically significant ($P < 0.05$; cf. Fig. 3). The Nile Tilapia (*O. niloticus*), which ingests as well as digests cyanobacteria, was found to contain higher levels of dry matter, fats and nitrogenous substances when supplied with an addition of 0–5.85% of dried cyanobacteria to feeding mixtures (Zhao, Xie, Zhu, Yang, Gan & Song 2006). In contrast to these results, the results of the present study demonstrate that the contents of dry matter, fat and protein in muscles of silver carps exposed to cyanobacteria are lower than in controls (cf. Figs 1–3). This is probably due to differences in the metabolism and digestion of cyanobacteria in these two fish species (Voros *et al.* 1997; Jančula *et al.* 2008).

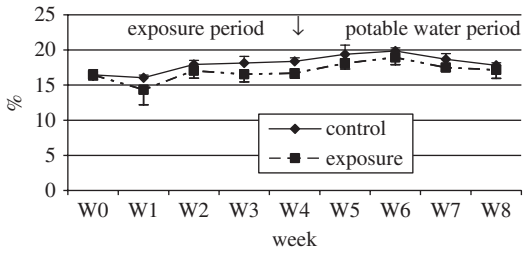

Figure 3 Dynamics of changes in protein contents in muscles of the silver carp (% of fresh weight). Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

Dynamics of changes in the composition of amino acids

As shown in Table 2, the presence of cyanobacteria in the aquatic environment had a highly statistically significant ($P < 0.05$) effect on the proportion of individual FA analysed in muscles of the common carp. On comparing the dynamics of changes in controls and cyanobacteria-exposed fish, however, statistically significant differences were only found in the ratio of sums of FA n-3 and n-6. The ratio of FA n-3 and n-6 in muscles of the control carps increased evenly from an initial value of 1.04 up to 1.72 (Fig. 4). This value was achieved within 4 weeks of the experiment; the difference was statistically significant ($P < 0.05$) when compared with exposed fish (0.768). The value found in control fish was nearly the same as the values published by Steffens (1997) reporting natural pond conditions. During the phase

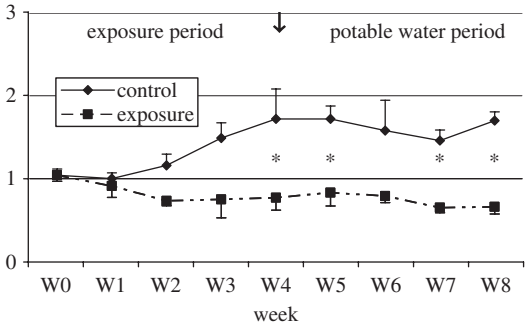

Figure 4 Dynamics of changes in the ratio of n-3 and n-6 fatty acids in the common carp. Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

Table 2 Effects of the presence of the cyanobacterial water bloom on the contents of individual fatty acids analysed in muscles of the common carp

FA	Significance (*P*-value)	FA	Significance (*P*-value)	FA	Significance (*P*-value)
C 14:0	0.0002	C 18:3n-3	0.0000	C 22:6n-3	0.0009
C 16:0	0.5050	C 20:1n-9	0.0342	SFA	0.5335
C 16:1	0.8282	C 20:4n-6	0.0000	MUFA	0.0370
C 18:0	0.0091	C 20:5n-3	0.0000	PUFA	0.0066
C 18:1n-9	0.0189	C 22:4n-6	0.0000	n-6	0.0000
C 18:2n-6	0.0008	C 22:5n-6	0.0042	n-3	0.0000
C 18:3n-6	0.0339	C 22:5n-3	0.0013	n-3/n-6	0.0000

Samples were collected on a weekly basis. Statistical comparisons were made using summary data from weekly samplings of experimental and control fish.

of clearance (weeks W5–W8), these values decreased in both groups of fish (to respective values of 1.459 and 0.651). The statistically significant level of difference was maintained, with the exception of the sixth week of the experiment (W6). The differences noticed were based on changes in the content of PUFA n-3 and n-6 (Figs 5 and 6); however, differences between both groups of fish did not achieve statistically significant levels.

Effects of cyanobacteria on the silver carp resulted in differences ($P < 0.05$; $P < 0.01$) in the composition of FA (Table 3). On comparing the dynamics of changes between both groups of fish, statistically significant differences (W4) ($P < 0.05$) were only found in the ratio of PUFA n-3 and n-6 (Fig. 7). These differences were due to changes in the content of n-6 fatty acids, in particular, of fish exposed to the cyanobacterial water bloom (Fig. 8).

The content of n-6 fatty acids increased during the exposure of both fish species. There was no increase in n-3 PUFA in the silver carp capable of digesting cyanobacteria, despite the fact that cyanobacteria are known to contain PUFA (Ahlgren *et al.* 1992) as well as to influence the profile of fish muscles (Tadesse *et al.* 2003). Unfortunately, in the present study, it was not possible to collect the cyanobacterial biomass in the quantity required for available FA analysis methods. Both groups showed a similar course of development without considerable FA variation, with levels of around 30%. Cyanobacteria of the *Microcystis* genus have a higher content of palmitic acid and palmitoleic acid, as well as n-3 FA and α-linolenic acid in particular; there are, however, only traces of EPA. The total FA ranged from 1.5% to 2.5% in the dry matter of samples (Ahlgren *et al.* 1992). Control fish were kept in the environment of green algae and

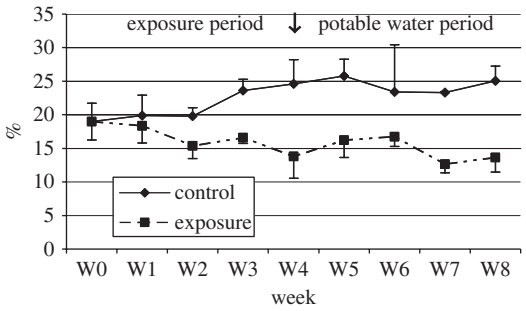

Figure 5 Dynamics of changes in the ratio of n-3 fatty acids in the common carp. Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

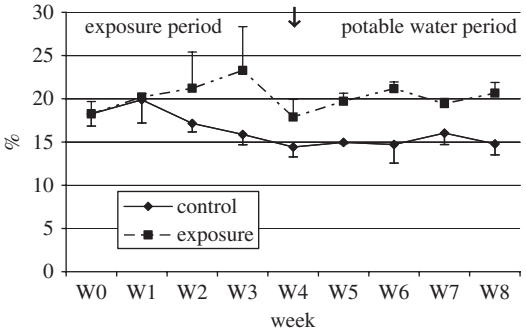

Figure 6 Dynamics of changes in the ratio of n-6 fatty acids in the common carp. Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

Table 3 Effects of the presence of the cyanobacterial water bloom on the contents of individual fatty acids analysed in muscles of the silver carp

FA	Significance (*P*-value)	FA	Significance (*P*-value)	FA	Significance (*P*-value)
C 14:0	0.0053	C 18:3n-3	0.4435	C 22:6n-3	0.9723
C 16:0	0.4566	C 20:1n-9	0.0247	SFA	0.0084
C 16:1	0.0001	C 20:4n-6	0.0072	MUFA	0.0003
C 18:0	0.0001	C 20:5n-3	0.7768	PUFA	0.0183
C 18:1n-9	0.0014	C 22:4n-6	0.0014	n-6	0.0000
C 18:2n-6	0.0000	C 22:5n-6	0.0000	n-3	0.4389
C 18:3n-6	0.0103	C 22:5n-3	0.1896	n-3/n-6	0.0000

Samples were collected on a weekly basis. Statistical comparisons were made using summary data from weekly samplings of experimental and control fish.

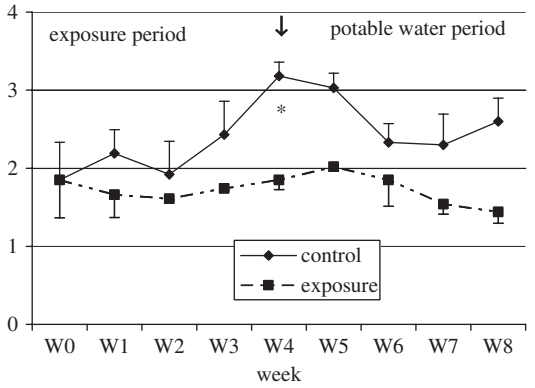

Figure 7 Dynamics of changes in the ratio of n-3 and n-6 fatty acids in the silver carp. Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

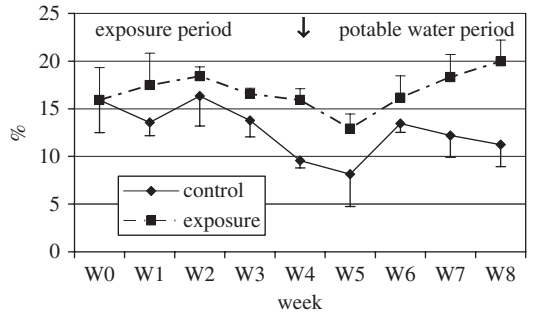

Figure 8 Dynamics of changes in the ratio of n-6 fatty acids in the silver carp. Experimental fish were exposed to cyanobacteria from weeks W0 to W4 (i.e. for 4 weeks) and kept in dechlorinated potable water from weeks W4 to W8. Control fish were kept under the same conditions but without exposure to cyanobacteria. The arrow indicates the moment of transfer from exposure and control ponds to dechlorinated potable water.

diatoms, which, compared with cyanobacteria, have a higher content of FA (5.2–8.9%) as well as a higher content of linoleic acid and oleic acid (Ahlgren *et al.* 1992). The composition of FA in cyanobacteria and algae depends on their growth condition; there is an increase in FA during the exponential stage of growth (Ahlgren *et al.* 1992; Dunstan *et al.* 1994). The content of n-3 fatty acids (LNA in particular) in muscles of control carps, not digesting cyanobacteria, increased especially during the first weeks of the experiment (W1–W4) from the initial 20% up to 25% of FA. The influence of different trophic spectra of both fish species was most pronounced in the content of EPA. Muscles in the silver carp contained nearly twice as much EPA than in the common carp (8.0–12.7% and 4.4–6.6% FA respectively).

Table 4 Ranges of essential amino acids in fish muscles (g kg^{-1} of dry matter of muscles) obtained from weekly samplings during 8 weeks of experiment (i.e. 4 weeks of exposure to cyanobacteria and subsequent 4 weeks of stay in dechlorinated potable water)

	Common carp		Silver carp	
EAA	**Control**	**Exposure**	**Control**	**Exposure**
Cys	4.73–8.18	5.30–8.18	5.48–8.39	7.18–8.64
Met	16.6–26.7	18.3–26.3	19.6–29.1	20.2–28.3
Thr	38.8–48.7	39.2–48.6	37.7–52.6	42.9–56.2
Val	38.8–43.8	38.6–42.6	42.2–47.1	41.4–47.6
Ile	30.7–33.4	29.8–33.8	32.9–36.3	34.5–36.9
Leu	59.0–66.2	59.8–66.6	67.6–74.0	70.4–73.7
Phe	0.48–1.32	0.75–1.51	0.83–1.67	0.92–2.17
His	11.6–15.3	11.8–13.7	11.2–15.7	8.95–14.8
Lys	67.7–77.6	49.8–73.6	71.3–89.1	69.9–82.3
Arg	26.1–39.4	23.1–41.2	22.5–42.7	25.9–43.2

Dynamics of changes in amino acid content

No statistically significant effects of cyanobacterial water bloom on the content of amino acids in muscles were found in the common carp, because the variation in amino acids in experimental fish and controls was similar. The results are comparable with those published by Buchtová *et al.* (2007).

The action of cyanobacteria in the silver carp resulted in changes in threonine, glycine and glutamic acid. Exposure of fish to the cyanobacteria-containing environment caused a statistically significant increase in the above-mentioned amino acids ($P < 0.05$). This increase may be due to the content of AA in *Cyanophyceae* (cyanobacteria) and *Chlorophyceae* (controls) mentioned by Ahlgren *et al.* (1992). However, on comparing the development of values during exposure and the subsequent clearance, overall differences between fish groups and terms of sampling were not statistically significant. The ranges of essential amino acids in fish muscles (g kg^{-1} of dry matter of muscles) are shown in Table 4.

Considering differences between both the fish species studied, environmental exposure to cyanobacteria resulted in changes in the content of FA only in

the common carp and all the studied parameters including the content of dry matter and fat, proteins, FA composition and some AA in the silver carp. This study has also shown that cyanobacteria in the environment of commercially produced fish may decrease the dietetic value of fish muscles.

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