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EFFECTS OF COMMERCIAL FEEDS ON GROWTH AND CHEMICAL COMPOSITION OF CARP (*Cyprinus carpio* L.) KEPT IN POWER STATION COOLING WATER

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ABSTRACT

The feeding experiment described was run within July 19 – October 18, 1999 on 536 g (±20 g) mean individual weight carp individuals aged 1+. The fish were kept in cages stocked at a 50 ind. cage^{-1} density. Experimental treatments differed in the feed offered. The following feeds were used: Dan–ex 1848 (Dan), Carp Grow–ex (Grow), and AT 35 Starter (AT 35). The daily feed doses, amounting to 2.0% metabolic fish weight ($W^{0.8}$) in each experimental treatment, were applied manually. During the first phase of the experiment (19 July – 13 September), the metabolic growth rate (MGR) values were 17.40; 15.73; and 13.19 g kg$^{-0.8}$ in the Dan, Grow,

and AT 35 treatments, respectively, the respective food conversion ration (FCR) being 1.15; 1.27; and 1.52. During the second phase of the experiment (14 September – 18 October), the respective MGR values amounted to 15.17; 15.77; and 13.24 g $kg^{-0.8}$, while the corresponding FCR values were 1.32; 1.27; and 1.51. On termination of the experiment, the highest lipid level (20.09%) was recorded in the Dan treatment, while the highest oleic acid content (36.11 g 100 g lipid $^{-1}$) was typical of the Grow treatment. The highest contents of DPA and DHA (1.02 and 7.69 g 100 g $lipid^{-1}$) were shown by the fish receiving Dan, while the carp fed AT 35 revealed the highest linoleic acid content (24.01 g 100 g $lipid^{-1}$). As demonstrated by the present study, feeds containing lipids of an appropriate fatty acid composition can produce the required qualitative characteristics of the carp body fat which can be an important source of unsaturated fatty acids for man.

Key words: carp, cooling water, cages, essential fatty acids

INTRODUCTION

Carp requirements for basic nutrients have already been studied by a number of authors [10, 12]. Similarly, nutritional requirements of carp kept in cooling water have been determined as well [2, 3, 4, 6]. In practice, however, there is a paucity of data on the effects of amount and quality of feeds on the chemical composition of carp body. As reported by Sargent et al. [16], it is technically possible to breed fish having a required ratio between the n–3 and n–6 essential unsaturated fatty acids. Steffens [22] suggested that, if fed correctly, the freshwater fish may even be a source of the essential fatty acids superior to the marine fish. It is widely known that the latter are subject to seasonal changes in their lipid content and composition [1, 23], hence their dietary value varies as well. Aquaculture, for the needs of which feeds of a desired lipid content and quality are manufactured, may be a way to obtain a standard product of a required chemical composition. In the case of carp, to address a question if, and to what extent, the feed chemical composition affects the quality of fish meat seems to be practical only in an intensive culture where the fish grow exclusively as a result of consuming the feed offered and the production has a commercial scale. The data on other species, collected so far, do demonstrate the type of diet to affect the fish body chemical composition [8, 9, 13, 24]. To check if this assumption holds true, an attempt was made to determine effects of feeds differing in their chemical composition on the levels of the basic chemical components of the carp body, a particular attention being paid to the content and composition of lipids.

MATERIALS AND METHODS

The feeding tests were carried out within July 19 – October 18, 1999 at the Fisheries Experimental Station (FES) run by the Department of Aquaculture, Agricultural University of Szczecin, situated in the vicinity of the Dolna Odra Power Station at Nowe Czarnowo. The study involved 1–yr–old carp of 536 (±20) g mean individual weight, kept in 2 m^3 working capacity cages stocked at a density of 50 ind. $cage^{-1}$. The experimental design involved three treatments (feeds), each applied in triplicate.

The fish were fed one of the following three commercials feeds, applied manually: the Dan–ex 1848 trout feed (Dana Feed, Denmark), hereafter termed Dan; the Aller Carp Grow–ex carp feed (Aller Aqua, Denmark), hereafter referred to as Grow; and the AT 35 Starter (Cargill) carp feed, hereafter referred to as AT 35. The chemical composition of the feeds is summarised in Table 1. The feed ration, identical in each treatment, amounted to 2.0% fish metabolic weight ($W^{0.8}$). The daily ration was divided into four portions, applied at 2–h intervals.

Table 1. Chemical composition of and fatty acid contents in feeds used in the experiment

Component [% wet weight]			Feed		
			Dana Feed Dan-ex 1848	Aller Aqua Carp Grow-ex	Cargill AT35 Starter
Dry matter			99.06	99.53	98.14
			(0.13)	(0.98)	(0.08)
Crude protein			48.52	32.98	37.26
			(0.16)	(0.37)	(0.77)
Fat			21.02	10.90	10.87
			(0.88)	(0.02)	(0.59)
Ash			6.55	7.23	8.23
			(0.05)	(0.06)	(0.05)
Carbohydrates			22.96	47.41	41.77
Gross energy ($MJ \cdot g^{-1}$)			23.713	20.235	20.265
Fatty acid content [g· 100 g $lipid^{-1}$]	C14:0	myristic	4.788	4.337	0.877
			(0.057)	(0.021)	(0.070)
	C14:1	myristoleic	0.486	0.355	0.109
			(0.050)	(0.007)	(0.007)
	C16:0	palmitic	16.759	14.594	17.148
			(0.141)	(0.693)	(0.106)
	C16:1	palmitoleic	0.620	4.779	1.961
			(0.085)	(0.049)	(0.029)
	C17:0	margaric	1.696	1.224	0.507
			(0.078)	(0.016)	(0.007)
	C18:0	stearic	3.521	2.769	6.801
			(0.078)	(0.043)	(0.025)
	C18:1	oleic	**19.696**	**22.677**	**29.422**
			(0.141)	**(0.031)**	**(0.045)**
	C18:2	linoleic	**12.264**	**12.717**	**35.192**
			(0.070)	**(0.145)**	**(0.135)**
	C18:3	γ -linolenic	**0.000**	**0.000**	**0.000**
			(0.000)	**(0.000)**	**(0.000)**
	C18:3	α -linolenic	**2.939**	**2.994**	**4.627**
			(0.036)	**(0.074)**	**(0.034)**
	C18:4	octadecatetraenic	2.845	2.021	0.564
			(0.099)	(0.016)	(0.045)
	C20:1	gadoleic	6.523	7.853	1.156
			(0.087)	(0.036)	(0.038)
	C20:2	eicosadienic	0.745	0.472	0.372
			(0.085)	(0.014)	(0.007)
	C20:3	eicosatrienic	0.354	0.267	0.047
			(0.070)	(0.007)	(0.004)
	C20:4	eicosanoic	0.674	0.493	0.191
			(0.050)	(0.007)	(0.014)
	C22:1	erucic	**16.068**	**15.559**	**0.623**

			(0.022)	**(0.086)**	**(0.016)**
	C22:5	docosapentaenoic (DPA)	**1.351**	**1.019**	**0.000**
			(0.014)	**(0.013)**	**(0.000)**
	C22:6	docosahexaenoic (DHA)	**8.670**	**5.871**	**0.402**
			(0.048)	**(0.036)**	**(0.008)**

Values in parentheses are standard deviations.
Values denoted with bold letters are described in the text.

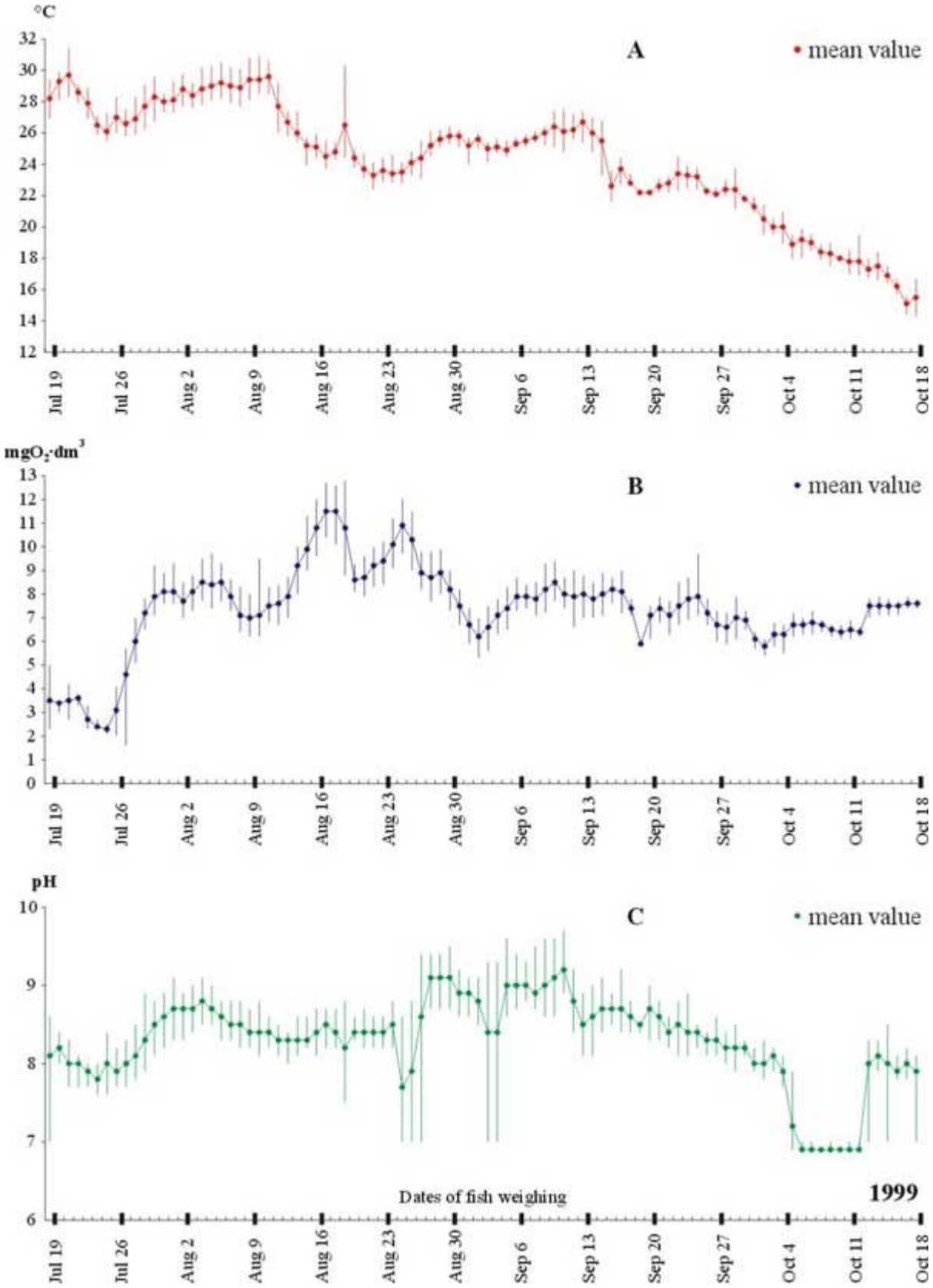
At the beginning of the experiment, 4 individuals were picked out to run (after complete homogenisation) assays for: dry matter content (drying at 105°C for 12 h); crude protein (in Kjeltec 1026 analyser); lipids (8 h ether ethyl Soxhlet extraction); and ash (combustion at 500°C for 12 h) contents. After 56 days and on termination of the experiment (day 91), 4 individuals from each treatment were picked out, beheaded, and gutted. The carcasses and non–edible parts were homogenised separately, the homogenates being assayed for the chemical composition as described above. The contents of individual chemical components in the fish body were calculated as weighted means of values obtained for the carcasses and non–edible parts. Corresponding chemical assays, employing identical methods, were made on the feeds, the carbohydrate content being in each case calculated from the difference between the dry matter content and the sum of crude protein, lipid, and ash contents. The gross energy level in the feeds was calculated by using the following conversion factors: 39.53 kJ g^{-1} for lipids; 23.63 kJ g^{-1} for crude protein; and 17.15 kJ g^{-1} for carbohydrates [11].

To determine the effects of a feed on the fatty acid composition in the fish body, lipid content and composition were assayed both in the feeds and in the fish. In the latter case, fatty acids were assayed in the whole fish homogenate at the beginning of the experiment, while after 56 days and on the termination of the experiment the assays were run separately in homogenates obtained from carcasses and from non–edible parts. The assays were made on lipid samples, Soxhlet–extracted from the homogenates (8 h ethyl ether extraction). The assays were run on a PU 4550 liquid chromatograph (Philips) in a glass column (L = 2.1 m; 216; Ø= 4 mm), filled with GP3%SP–2310/2%SP–2300, on the WAW 100/10 mesh chromosorb (SUPELCO). The FID detector was used at 250°C. The dispenser temperature was 250°C. The column temperature was 120°C for the initial 2 minutes, to be thereafter increased, at a rate of 12°C min^{-1}, until the final temperature of 225°C was obtained and maintained for 20 min. The argon flow rate was 40 $cm^3 \cdot min^{-1}$.

To determine the dynamics of major culture efficiency indices and to adjust the feed ration, all the fish at each cage were weighed (to 0.05 kg) at 7–d intervals. Based on weight data thus obtained, the values of food conversion ratio (FCR), metabolic growth rate (MGR), apparent net protein utilisation (aNPU), energy retained (ER), and apparent lipids retained (aLR) were calculated. To test for significance of differences between the treatments, the results were processed with the LSD test (at P=0.05) using the Statistica for Windows v. 5.1 [21] software.

The power station cooling water temperature, dissolved oxygen content, and pH were recorded automatically. Mean diel values and range of variations in the environmental parameters are shown in Fig. 1.

Fig. 1. Diel changes of temperature (A), dissolved oxygen content (B), and pH (C) in cooling water during the experiment



RESULTS AND DISCUSSION

Environmental conditions

Within the period of the experiment, the mean diel water temperature, dissolved oxygen content, and pH varied within 14.3–31.4°C, 1.6–12.8 mg O_2 dm^{-3}, and 6.9–8.3, respectively (Fig. 1A–C). The respective ranges recorded during the first phase of the experiment were 22.4–31.4°C; 1.6–12.8 mg O_2 dm^{-3}; and 7.0–9.7. In the second phase, the ranges were: 14.3–27.0°C; 5.4–9.7 mg O_2 dm^{-3}; and 6.9–9.2. In spite of the wide variations in the environmental conditions, no apparent adverse effects on fish behaviour and growth were observed.

Feed characteristics

The two Danish feeds used in the experiment (Dan and Grow) were commercial extruded mixes, while AT 35 was a pelleted feed. As reported by the manufacturers, AT 35 and Grow contained no less than a. 35% of crude protein and 8 and 10% of lipids, respectively. Dan was reported to contain 48% of crude protein and 18% of lipids. Those data were corroborated by the chemical assays made prior to the experiment (Table 1). As shown by literature data, the feed protein level required by carp varies depending on fish weight and environmental conditions; different authors determined this requirement as amounting to 30–45% [6, 14, 17, 18, 19]. Filipiak and Trzebiatowski [6] contended that the feed protein level of 30% was appropriate for the fish weighing more than 500 g, smaller (250–500 g individual weight) individuals requiring feeds containing about 35% of protein. Similar results, stressing carp size–dependent requirements, were obtained in other studies [7]. As the last two studies had been carried out under the same conditions, the results reported can be viewed as reflecting optimal levels for the carp kept in cooling water. Similar observations can be made with respect to the lipid level. Research carried out in cooling water demonstrated that the maximum growth rates were obtained using feeds containing more than 10% of lipids [3, 5]. One may therefore assume that the chemical composition of the carp feeds used in the present experiment met the demands posed by nutrition and growth of the carp cultured in cooling water. In terms of both its protein and lipid contents, Dan exceeded the levels required by the carp of the size used in the experiment. The feed was nevertheless used, based on results of earlier tests in which the energy–rich extruded trout feeds produced the best effects in carp cultures [4, 15].

Analysis of the feed fatty acid composition revealed a high content of linolic acid in AT 35 (Table 2). The highest contents of the n–3 acids: 22:5 n–3 docosapentaenoic acid (DPA) and 22:6 n–3 docosahexaenoic acid (DHA) were recorded in the Danish feeds, the lowest contents being typical of AT 35. Similar results were shown for erucic acid. Differences in the fatty acid composition of the feeds resulted from different amounts of various components they contained. The Danish feeds were composed predominantly of marine fish meal and oil, while AT 35 contained chiefly plant products and homoiotherm animal meals, which was reflected in the very high content of linoleic acid of that feed.

Table 2. Mean individual weights and culture effectiveness indices after 56 and 91 days of the experiment

Treatment	Mean fish individual weight		MGR[1]	FCR[2]	aNPU[3]	aLR[4]	ER[5]
	initial	final					
	[g]		[g· kg$^{-0,8\cdot}$ d^{-1}]		[%]		
After 56 days							
Dana Feed Dan-ex 1848	537	1406	17.40^{a}	1.15^{a}	26.93^{c}	87.48^{a}	43.67^{b}
Aller Aqua Carp Grow-ex	537	1295	15.73^{b}	1.27^{b}	39.99^{a}	101.62^{b}	37.04^{a}
Cargill AT35 Starter	536	1135	13.19^{c}	1.52^{c}	29.24^{b}	107.78^{c}	35.56^{a}
MSE			0.32	0.01	1.04	4.84	1.31
After 91 days							
Dana Feed Dan-ex 1848	1406	2228	15.17^{a}	1.32^{a}	22.77^{a}	93.50^{b}	43.77^{b}
Aller Aqua Carp Grow-ex	1295	2093	15.77^{a}	1.27^{a}	36.83^{c}	182.78^{c}	53.11^{c}
Cargill AT35 Starter	1135	1727	13.24^{b}	1.51^{b}	28.06^{b}	66.14^{a}	26.22^{a}
MSE			0.12	0.01	0.35	3.14	0.71

Column values denoted with identical letters are not significantly different (P>0.05).
1 – defined as a ratio between feed ration (g·kg$^{-0,8\cdot}$d^{-1}) and FCR,
2 – ratio between total amount of feed offered to total weight increment,
3 – ratio (percent) between amounts of crude protein in feed offered and crude protein in fish body,
4 – ratio (percent) between amounts of lipids in feed offered and lipids in fish body,
5 – ratio (percent) between gross energy content of feed offered and gross energy content of fish body.

Culture results

All the treatments showed a 100% survival rate. The highest growth rate during the first phase of the experiment was recorded in the fish fed Dan, the protein–richest feed, while feeding with Grow and AT 35 resulted in a lower growth rate (Table 3). The lipid retention indices showed the amount of energy supplied to the fish to be more than adequate, as demonstrated by aLR values higher that 100%. The lowest and the highest FCR values were produced by Dan and AT 35, respectively.

Table 3. Chemical composition [%] of carp body at the start and after 56 and 91 days of the experiment

Treatment	Dry matter*	Crude protein*	Lipids*	Ash*
Start				
	28.98	16.39^{de}	9.50^{a}	2.29
After 56 days				
Dana Feed Dan-ex 1848	34.98	15.54^{b}	16.69^{e}	2.09

Aller Aqua Carp Grow-ex	30.25	16.61^{e}	12.18^{b}	2.04
Cargill AT35 Starter	32.12	16.46^{de}	13.86^{d}	2.10
After 91 days				
Dana Feed Dan-ex 1848	37.16	15.18^{a}	20.09^{g}	1.73
Aller Aqua Carp Grow-ex	35.02	16.15^{c}	17.17^{f}	1.67
Cargill AT35 Starter	31.01	16.23^{cd}	12.83^{c}	1.80
MSE		0.03	0.05	

***% wet weight.**
Column values denoted with identical letters are not significantly different (P>0.05).

During the second phase of the experiment, when the mean and minimum water temperatures dropped from 26.5 to 20.3°C and from 22.4 to 14.3°C, respectively, the highest growth rate was obtained by offering the fish the Danish feeds. The results obtained for AT 35 remained virtually at the level observed during the preceding phase. The highest and the lowest aLR values were produced by Grow and AT 35, respectively. The remaining retention–related indices showed a similar pattern. The reason why the Dan–fed fish decreased their growth rate should be most probably sought in the water temperature decrease which reduced the feed lipid assimilation; this assimilation in warm–water fish increases to the species–specific optimum with increasing water temperature [20]. Water temperature at the second phase was generally lower than optimal for carp. The very good culture results obtained in the Grow treatment were most probably related to the feed manufacturing technology, as extrusion is known to substantially enhance assimilation of nutrients, carbohydrates in particular. This was confirmed by a high lipid retention in fish body (Table 2). The lowest lipid retention recorded in the AT 35 treatment (the feed is manufactured by pelleting) resulted from a lower digestibility and assimilation of, i.a., carbohydrates.

The treatments showed significant differences in fatty acid contents of the fish body (Table 4). The highest content of oleic acid was recorded in the lipids of Grow–fed carp, the lowest content (lower than the initial value) being observed in the Dan–fed fish. The AT 35–fed carp showed the highest linoleic acid content. Compared to the results of the initial assays, the fish in all the treatment showed the presence of γ–linolenic acid. The highest α–linolenic acid content was recorded on day 91 in the AT 35 treatment. The remaining treatments revealed slightly lower contents of the acids, which, however, never decreased below 2 g 100 g lipid^{-1}. The highest DPA and DHA contents were recorded in the Dan treatment, the lowest contents being typical of the AT 35–fed fish. Those data correspond to the contents of the acids in question in the feeds (Tables 1 and 4). It is noteworthy that the DHA content in the Grow treatment decreased slightly in the second phase of the experiment, compared with the first phase. A similar decrease was recorded with respect to the erucic acid the content of which increased in the Dan–fed fish and decreased in the Grow and AT 35 treatments. Changes in the body fatty acid contents of the carp fed the two carp feeds, Grow in particular, were brought about by the synthesis of lipids from carbohydrates or proteins. The high retention of lipids from those feeds (aLR values higher than 100%) was an indirect evidence of the synthesis. The increase in the content of oleic acid and the decrease in that of DHA in the Grow–fed carp body could be explained along the same lines.

Table 4. Fatty acid contents [g·100 g lipid^{-1}] in fish body

Fatty acid		Start	Feed					
			Aller Aqua Carp Grow-ex		Dana Feed Dan-ex 1848		Cargill AT35 Starter	
			after 56 days	after 91 days	after 56 days	after 91 days	after 56 days	after 91 days
C12:0	lauric	0.000	0.042	0.035	0.051	0.046	0.036	0.036
		(0.000)	(0.003)	(0.001)	(0.001)	(0.007)	(0.006)	(0.004)
C14:0	myristic	3.425	3.028	2.562	3.674	3.669	1.698	1.268
		(0.141)	(0.070)	(0.010)	(0.020)	(0.049)	(0.093)	(0.005)
C14:1	myristoleic	0.326	0.433	0.234	0.454	0.350	0.271	0.154
		(0.021)	(0.006)	(0.012)	(0.007)	(0.014)	(0.014)	(0.012)
C16:0	palmitic	17.443	17.572	17.510	18.251	17.875	17.364	15.668
		(0.538)	(0.156)	(0.053)	(0.056)	(0.037)	(0.225)	(0.107)
C16:1	palmitoleic	6.401	6.460	8.045	7.039	8.050	5.357	4.350
		(0.283)	(0.022)	(0.012)	(0.028)	(0.031)	(0.106)	(0.043)
C17:0	margaric	1.128	1.010	0.744	1.231	1.204	0.674	0.571
		(0.118)	(0.063)	(0.005)	(0.007)	(0.009)	(0.001)	(0.024)
C18:0	stearic	3.807	3.421	3.368	2.940	2.837	3.782	4.613
		(0.287)	(0.065)	(0.006)	(0.047)	(0.022)	(0.037)	(0.039)
C18:1	oleic	**30.926^{c}**	**32.367^{d}**	**36.110^{g}**	**25.506^{b}**	**24.876^{a}**	**35.096^{f}**	**34.304^{e}**
		(0.391)	**(0.070)**	**(0.044)**	**(0.173)**	**(0.230)**	**(0.475)**	**(0.027)**
C18:2	linoleic	**10.262^{b}**	**11.541^{d}**	**9.737^{a}**	**11.646^{d}**	**11.003^{c}**	**19.976^{e}**	**24.009^{f}**
		(0.159)	**(0.101)**	**(0.014)**	**(0.143)**	**(0.104)**	**(0.182)**	**(0.103)**
C18:3	γ -linolenic	**0.338^{c}**	**0.073^{a}**	**0.282^{b}**	**0.106^{a}**	**0.293^{bc}**	**0.580^{d}**	**0.780^{e}**
		(0.150)	**(0.017)**	**(0.001)**	**(0.005)**	**(0.019)**	**(0.026)**	**(0.013)**
C18:3	α -linolenic	**2.185^{ab}**	**2.264^{bc}**	**2.085^{a}**	**2.426^{d}**	**2.414^{d}**	**2.377^{cd}**	**2.615^{e}**
		(0.050)	**(0.098)**	**(0.010)**	**(0.007)**	**(0.036)**	**(0.053)**	**(0.042)**
C18:4	octadecatetraenic	1.365	1.221	0.872	1.647	1.679	0.769	0.606
		(0.142)	(0.012)	(0.029)	(0.003)	(0.046)	(0.036)	(0.030)
C20:1	gadoleic	6.895	6.618	6.101	6.376	6.456	3.989	3.387
		(0.147)	(0.119)	(0.035)	(0.120)	(0.124)	(0.074)	(0.125)
C20:2	eicosadieic	0.704	0.658	0.553	0.571	0.645	0.845	1.049
		(0.141)	(0.036)	(0.006)	(0.029)	(0.004)	(0.049)	(0.035)
C20:3	eckosatrienic	0.385	0.355	0.323	0.260	0.312	0.576	0.845
		(0.164)	(0.016)	(0.019)	(0.005)	(0.002)	(0.009)	(0.043)
C20:4	eocosanoic	0.591^{b}	0.478^{a}	0.493^{a}	0.510^{a}	0.594^{b}	0.838^{c}	1.873^{d}
		(0.042)	(0.012)	(0.024)	(0.005)	(0.009)	(0.016)	(0.038)
C22:1	erucic	**7.744^{e}**	**6.724^{d}**	**5.773^{c}**	**9.353^{f}**	**9.008^{f}**	**3.085^{b}**	**1.823^{a}**
		(0.350)	**(0.206)**	**(0.071)**	**(0.401)**	**(0.037)**	**(0.137)**	**(0.014)**
C22:5	docosapentaenic (DPA)	**0.745^{b}**	**0.649^{b}**	**0.530^{b}**	**1.017^{c}**	**0.997^{c}**	**0.281^{a}**	**0.181^{a}**
		(0.249)	**(0.000)**	**(0.048)**	**(0.067)**	**(0.031)**	**(0.010)**	**(0.061)**
C22:6	docosahexaenic (DHA)	**5.329^{c}**	**5.087^{bc}**	**4.643^{b}**	**6.943^{d}**	**7.692^{e}**	**2.407^{a}**	**1.871^{a}**
		(0.282)	**(0.050)**	**(0.042)**	**(0.603)**	**(0.130)**	**(0.048)**	**(0.060)**

Values in parentheses are standard deviations.
Row values denoted with identical letters are not significantly different (P>0.05).
Values denoted with bold letters are described in the text.

Results of the assays demonstrated significant differences in the fish body crude protein and lipid levels, the differences depending on the feed and duration of feeding. The largest differences were recorded in the lipid levels. The highest levels in both phases of the experiment were typical of the Dan–fed fish. During the first phase of the experiment, the lowest lipid level was recorded in the Grow–fed carp, the AT 35 treatment producing the lowest lipid level in the second phase. The latter treatment was the only one in which the lipid level in the second phase of the experiment was lower than that recorded in the first phase. Most likely, this happened because of a worse digestibility and assimilation of pelleted feed, compared to the extruded one, at lower water temperatures.

To sum up the results obtained in the experiment described, it is necessary to emphasise certain clear–cut relationships between contents of some fatty acids in the fish body and in the feeds offered. Such a relationship was particularly visible with respect to DHA the highest levels of which were recorded in the Dan–fed carp. Therefore, should a carp cage culture be based exclusively on a commercial feed, fish body contents of some fatty acids essential in human nutrition and preventing cardiovascular diseases might be controlled by applying feeds manufactured from carefully selected and adjusted components.

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