



## Potential for Improvement of Common Carp Production Efficiency by Mechanical Processing of Cereal Diet

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### Abstract

The effect of supplemental feeding with modified cereals (pressed triticale, barley, rye and pressed wheat in combination with rape) on the growth of common carp was studied under semi-intensive pond farming conditions. Non-pressed triticale, barley and rye were used for comparison. Two groups were selected as a control dependent only on natural zooplankton. For the evaluation, we employed five models designated M1 – linear mixed models with a random intercept; M2 – linear mixed models with a random slope; M3 – a linear mixed model with a random intercept and slope; M4 – written as model M3 with a power variance function, where the error variance was modelled and M5 – written as model M4 with a power variance function, with a different model of error variance. Model M5 took heterogeneous errors with respect to differing strata. Common carp that were fed supplements of modified cereals showed a significant lower variability of weight (lower SD and narrower 95% CI) compared to the non-pressed diets and pressed barley and rye that yielded higher production. These results suggest that pressed cereals increase yield in commercial production of common carp under semi-intensive conditions.

*Keywords:* *Cyprinus carpio*, growth models, pressed cereals, semi-intensive carp farming, variability of weight.

### Introduction

Common carp (*Cyprinus carpio* L.) is the major freshwater fish species farmed in Central and Eastern Europe (Stibranyiová and Adámek, 1998; Mráz and Picková, 2009). In the Czech Republic, carp comprises 86-87% of the total fish production (Czech Ministry of Agriculture 2011) and mainly consists of semi-intensive culture in ponds (Miah *et al.*, 1997; FAO 1997; Reddy *et al.*, 2002; Pokorný and Hauser, 2002). The profitability of pond aquaculture is dependent on the use of economical feeds (Pigott and Tucker, 2002), and the key to efficient semi-intensive systems is the reliance on a combination of natural and artificial feed (Moore, 1985; Kaushik, 1995; Bauer and Schlott, 2006). Artificial supplements used in the Czech Republic are based almost entirely on cereal grains, an easily available economic source of energy (Turk, 1994, 1995; Mráz and Picková, 2009). Compared to pelleted feeds, cereals represent an easy and cheap source of digestible energy in form of carbohydrates, especially starch. Common carp have high activity of  $\alpha$ -amylase and therefore efficient starch digestion; a practical benefit for pond aquaculture (Steffens, 1989). Nevertheless, cereals

represent the highest cost item in common carp culture, with large quantities used in production of 2-3-year-old fish (Hůda, 2009). The availability of low cost feed plays a primary role in pond aquaculture economics (Horváth *et al.*, 1992), and currently, all common cereal grain species are used for artificial feeding (Hůda, 2009).

A proper adjustment of cereals leads to an increased feed efficiency (nutritional value, acceptability and digestibility) and thus to an increase in fish growth. Contemporary fish farming aims to develop new methods of enhancing the production effectiveness of cereals by mechanical adjustment: pressing, grinding, and/or thermal treatment (Zeman, 2002; Urbánek, 2009). The way in which feed is processed affects the availability of nutrients (Tabachek, 1985; Pigott and Tucker, 2002). Current practice is crushing seeds in a cylinder press to improve digestibility. The principle is to rupture the seed coat to give access to microorganisms so that they can begin to digest the carbohydrate (Zeman, 2002). The objectives of the study were to determine the fish growth and condition in semi-intensive pond culture if pre-treated feed would improve productivity.

## Materials and Methods

### Study Area and Experimental Ponds

The experiment was conducted near Třeboň in the Czech Republic at 48°59'N, 14°46'E. This region is characterized as a plain basin with numerous ponds at mean altitudes of 410–450 m above sea level. The climate is temperate with the average annual temperature of 7.5°C. Annual precipitation is approximately 600–650 mm.

The experiment was conducted over 111 days from 23 May 2008 to 11 September 2008 in 9 earthen experimental ponds of the 300m<sup>2</sup> each with continuous water inflow. These experimental ponds had uniform characteristics in terms of size, bottom composition, wall construction, water volume, retention time and physico-chemical properties of water as they were located next to each other and had water inflow from the same pond. The ponds were filled to a depth of 1 m and had an average capacity of 300 m<sup>3</sup>. Ponds were stocked with fish of the same age and the same genetic origin namely three-year-old Třeboň scaly common carp, of mean weight 988±31 g ind<sup>-1</sup> at a density of 363 fish ha<sup>-1</sup>. This density is typical for semi-intensive culture of carp in the Třeboň region.

Individual fish which was stocked into the experimental ponds were marked individually with a microchip in the dorsal musculature using a DataMars Needle Kit. During the experiment (on days 31, 53, 73 and 98) control catches were executed in each experimental pond. Fish were collected and the individual body length and individual weight were measured. After each control measurement, the fish were released back to the same experimental ponds. At the end of the experiment (day 111) individual body length and individual weight were also measured in order to assess individual growth characteristics over the entire rearing period in all experimental ponds of all fish.

Temperature and dissolved oxygen of the water inflow were monitored three times a week at 08:00–10:00 h. Measurements used the MKT 44A INSA (oximeter INSA Company s.r.o., Prague, Czech Republic).

The zooplankton community in each experimental pond was sampled bi-weekly from the

beginning of June to the beginning of September. Samples of zooplankton were taken from all ponds using a 10 L Schindler's quantitative sampler (100 µm mesh). The samples were pooled and preserved with 4% formaldehyde in polyethylene tubes. Quantitative and qualitative analyses were carried out under a stereomicroscope (Olympus BX51 binocular microscope fitted with an Olympus E-510 digital camera) in a Sedwick-Rafter chamber.

### Experimental Supplemental Feeding

Seven fish groups in separate experimental ponds were fed with different supplemental cereal feeds: (i) barley, (ii) pressed barley, (iii) rye, (iv) pressed rye, (v) triticale, (vi) pressed triticale, and (vii) pressed wheat and rape (50%/50%). Two additional groups provided only with naturally available food served as controls. The chemical analysis of the feed showed that the differences among the cereals in digestible energy (DE), protein content and carbohydrates were minimal (Table 1). The pressed form of barley, rye, triticale, wheat, and rape was made using a pressing cylinder (type KB 160/2) to obtain the final particle size of 1.3 mm with the aim of eliminating the losses caused by floating.

### Feeding Management

The cereals were placed three times a week by hand (Monday, Wednesday and Friday) on the feeding pits (concrete panel) at 08:00–09:00 h at an initial rate of 5% of fish stock biomass. Feeding pits consist of a concrete place on the bottom of each experimental pond. There it is easy to check if and how much feed is consumed by the fish.

### Formulae for Growth, Feed Conversion and Feed Retention and Condition

Standard formulae were used to assess growth, feed utilization and other relevant parameters during the feeding trial. The Specific Growth Rate was estimated according to Virk and Saxena (2003). The Feed Conversion Ratio [FCR] was calculated as described by Steffens (1989) and the Fulton coefficient [FC] was estimated according to Arlinghaus and Hallermann (2007)

**Table 1.** Chemical analysis and Digestible energy (DE) in cereals used in the experiment

	Dry matter (g.kg <sup>-1</sup> )	Protein (g.kg <sup>-1</sup> )	Fat (g.kg <sup>-1</sup> )	Starch (g.kg <sup>-1</sup> )	DE <sup>a)</sup>		
					(MJ.kg <sup>-1</sup> )	(MJ.ind <sup>-1</sup> )	(MJ.ind <sup>-1</sup> .day <sup>-1</sup> )
Barley	870	110	21	676	12.489	31.78	0.286
Pressed barley	870	110	21	676	12.489	31.78	0.286
Rye	870	85.6	13.8	721	12.499	31.81	0.286
Pressed rye	870	85.6	13.8	721	12.499	31.81	0.286
Triticale	880	106	19	715	12.928	31.73	0.285
Pressed triticale	880	106	19	715	12.928	31.73	0.285
Pressed wheat and rape	876	180	360	90	14.211 <sup>b)</sup>	28.42	0.255

<sup>a)</sup> Digestible energy; <sup>b)</sup> value obtained as weighted average of values for wheat (60%) and rape (40 %).

## Statistical Analysis and Growth Models

One-way ANOVA with fixed effects was used to test the hypothesis of equal mean weight of stocked fish in all groups. Homogeneity of variance was tested through Bartlett's test (Bartlett, 1937). For planned variance comparisons we used classical two samples  $F$ -test (Mason *et al.*, 2003). Confidence intervals for standard deviation based on normal asymptotic theory are also provided.

Due to the fact that we were primarily interested in the fourth growing season, which is crucial for final production, we used linear models to describe the growth data. The growth trajectory could be roughly characterized as increasing at a constant rate during the experimental period, which could be satisfactorily described through the linear model. To fit linear growth models, we used several linear mixed models that could be expressed in matrix form  $y_i = X_i\beta + Z_i b_i + \varepsilon_i$  (Laird and Ware 1982). We assume the vector of random effect to be  $b_i \sim N(0, \Psi)$  and within-group error  $\varepsilon_i \sim N(0, \sigma^2 A_i)$ .

We employed five models designated M1 – a linear mixed model with a random intercept; M2 – a linear mixed model with a random slope; M3 – a linear mixed model with a random intercept and slope; M4 – written as model M3 with a power variance function, where the error variance was modelled as  $Var(\varepsilon_{ij}) = \sigma^2 |t_{ij}|^{2\delta_{ij}}$  and with one covariate function  $g(t_{ij}, \delta_{ij}) = |t_{ij}|^{\delta_{ij}}$ ; and M5 – written as model M4 with a power variance function, with the error variance modelled as  $Var(\varepsilon_{ij}) = \sigma^2 |t_{ij}|^{2\delta_{ij}}$  and one covariate function  $g(t_{ij}, \delta_{ij}) = |t_{ij}|^{\delta_{ij}}$ . The later model takes heterogeneous errors with respect to differing strata, e.g. different diet, into account.

## Model Selection and Hypothesis Testing

For fitting the linear mixed-effect model we used the maximum likelihood (ML) details of the applied algorithm, provided, for example, by Pinheiro and Bates (2000). This method enables the use of Information Theory for model selection. For this purpose we used Akaike information criterion,  $AIC = -2\log(\theta|X) + 2k$ , which approximates the Kullback-Leibler distance (Burnham and Anderson, 2002) and the Bayesian information criterion (BIC). In this formula,  $\log(\theta|X)$  calculates the numerical value of the log-likelihood function evaluated at its maximum for a particular model. The vector  $\theta$  contains the estimated parameters of the evaluated model and  $k$  is the number of estimated parameters. For more details

on this topic see Akaike (1974). The model with the smallest  $AIC$  value was selected as the most suitable model among the tested models.

## Software

The numerical evaluation was carried out with the programming environment R 2.8.1 (R development core team, 2008). For the estimation of the parameters in linear mixed models we used the library name written by Pinheiro *et al.* (2008).

## Results

### Growth Models and Analysis with Respect to Diet

The hypothesis of homogeneity of the experimental fish groups with respect to their weight at the beginning of the experiment was tested through one-way analysis of variance with result  $F = 1.540$  e.g.  $p = 0.160$ . Therefore, we can conclude that all groups were, on average, of similar weight at the start of the experiment. The hypothesis of equal variance in all groups at the start of the experiment was confirmed by Bartlett's test with results  $\chi^2 = 2.416$  e.g.  $p = 0.933$ .

We provide Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) for each of the fitted models, and also compare the models by the likelihood ratio test. A larger  $p$ -value for the likelihood ratio and smaller AIC and BIC values for the considered model indicate that it should be preferred ( $P < 0.0001$ ). Model M3 is better than model M2 due to smaller AIC and BIC values (Table 2). The preferred model is model M5 with AIC = 7578 and BIC 7702. This model has the following form

$$y_{ij} = (\beta_0 + \gamma_{02}D_{2i} + \gamma_{03}D_{3i} + \gamma_{04}D_{4i} + \gamma_{05}D_{5i} + \gamma_{06}D_{6i} + \gamma_{07}D_{7i} + \gamma_{08}D_{8i} + b_{0i} + (\beta_1 + \gamma_{12}D_{2i} + \gamma_{13}D_{3i} + \gamma_{14}D_{4i} + \gamma_{15}D_{5i} + \gamma_{16}D_{6i} + \gamma_{17}D_{7i} + \gamma_{18}D_{8i} + b_{1i})) \cdot \quad (M5)$$

where  $D_{2i}$  is the binary variable taking the value 1 if the  $i$ -th fish receive barley and 0 otherwise. The coefficient  $D_{3i}$  is a binary indicator variable for the pressed form of barley,  $D_{4i}$  is a binary indicator for rye and so on (Table 3). The coefficient  $\beta_0$  and  $\beta_1$  are, respectively, the average intercept and average slope for fish under natural diet (control groups).

In such parameterization the coefficient  $\gamma_{0k}$  could be interpreted as an average difference in intercept between fish under the natural feeding regime and fish receiving a  $k$ -th specific diet, e.g. fish consuming barley, fish fed pressed barley, rye, and so on. Values of the estimated fixed parameters for the model M5 are shown with standard errors and significance test in Table 3. There is a significant

**Table 2.** Summary statistics for the fitted models

Model	AIC	BIC	$\log(\hat{\theta} X)$	Test	Likelihood ratio	P-value
M1	7973	8053	-3969			
M2	7710	7789	-3837			
M3	7669	7758	-3815	M2 vs. M3	44.31	< 0.0001
M4	7646	7739	-3802	M3 vs. M4	25.33	< 0.0001
M5	7578	7702	-3761	M4 vs. M5	81.96	< 0.0001

**Table 3.** Parameter estimates and associated statistic for fixed effects in the linear mixed model M5

Effect	Parameter	Estimate	Standard error	<i>t</i> -value	P-value
Control	$\beta_0$	1058.80	24.67	42.92	< 0.00001
Day ( $t_{ij}$ )	$\beta_1$	6.30	0.53	11.91	< 0.00001
Barley	$\gamma_{02}$	-11.00	46.14	-0.24	0.8117
Pressed barley	$\gamma_{03}$	-58.10	45.99	-1.26	0.2093
Rye	$\gamma_{04}$	58.00	46.06	1.26	0.2113
Pressed rye	$\gamma_{05}$	-3.60	44.16	-0.08	0.9350
Triticale	$\gamma_{06}$	-109.70	50.76	-2.16	0.0333
Pressed triticale	$\gamma_{07}$	-44.30	44.01	-1.01	0.3169
Wheat and rape	$\gamma_{08}$	57.10	41.16	1.39	0.1690
Barley $\times t_{ij}$	$\gamma_{12}$	2.70	0.95	2.83	0.0048
Pressed barley $\times t_{ij}$	$\gamma_{13}$	3.70	0.95	3.86	0.0001
Rye $\times t_{ij}$	$\gamma_{14}$	4.10	0.95	4.33	< 0.00001
Pressed rye $\times t_{ij}$	$\gamma_{15}$	4.20	0.93	4.46	< 0.00001
Triticale $\times t_{ij}$	$\gamma_{16}$	4.50	1.03	4.35	< 0.00001
Pressed triticale $\times t_{ij}$	$\gamma_{17}$	4.30	0.93	4.59	< 0.00001
Wheat and rape $\times t_{ij}$	$\gamma_{18}$	1.60	0.90	1.73	0.0839

interaction of barley, pressed barley, rye, pressed rye, triticale, and pressed triticale with time (Table 3).

Both forms of triticale and rye have the highest value of the linear regression coefficient, indicating that these cereals are more efficient than the others. Detailed analysis of the weight variability is shown below in Table 5. Random components  $b_{0i}$  and  $b_{1i}$  in each model shown in Table 4 are assumed to be the result of bivariate normal distribution  $N(\mathbf{0}, \Psi)$  where

$\mathbf{0} = (0,0)^T$  and  $\Psi$  is variance-covariance matrix estimated as  $\hat{\Psi} = \begin{bmatrix} 98.298 & 0.144 \\ 0.144 & 2.371 \end{bmatrix}$ . We provide a

predicted growth trajectory for all combinations of experimental fish groups. Pressed feeds produced lower variability and higher daily weight gain than the non-pressed cereals (Figure 1). Only the pressed form of triticale showed a lower average value of daily weight gain than whole triticale (Table 5).

### Individual Fish Weight

At the end of the experiment (111 days),

common carp on diets supplemented with intact rye and those fed pressed rye reached the highest individual weight at  $2225 \pm 330 \text{ g.ind}^{-1}$  and  $2190 \pm 264 \text{ g.ind}^{-1}$ , respectively. The third highest weight  $2145 \pm 296 \text{ g.ind}^{-1}$  was obtained with pressed triticale. Common carp fed a diet supplement of intact non-pressed triticale reached the final weight of  $2128 \pm 554 \text{ g.ind}^{-1}$ . A lower final weight of  $2049 \pm 250 \text{ g.ind}^{-1}$  was found for common carp fed pressed barley and  $1993 \pm 299 \text{ g.ind}^{-1}$  for those fed with non-pressed barley. The group fed pressed wheat and rape had final individual weight  $1940 \pm 296 \text{ g.ind}^{-1}$ . The lowest final weight was found for carp in the control groups at  $1732 \pm 281 \text{ g.ind}^{-1}$  (Table 5).

Significant differences ( $P < 0.05$ ) were observed in standard deviation (SD) values during the course of the experiment (Table 5). At the end of the experiment, the highest SD values were found for supplemental feeding without adjustment: triticale, SD  $554 \text{ g.ind}^{-1}$ ; rye, SD  $330 \text{ g.ind}^{-1}$ ; and barley, SD  $299 \text{ g.ind}^{-1}$ . The average SD value of fish weight in fish fed the non-pressed variants reached  $394 \text{ g.ind}^{-1}$  at the end of the experiment. All fish fed pressed cereals

**Table 4.** Regression models for particular diet based on the mixed model M5

Diet	Fitted model	Variance of $\varepsilon_{ij}$
Control	$1058.8 + b_{0i} + 6.3 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.18349}$
Barley	$1047.8 + b_{0i} + 9.0 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.08062}$
Pressed barley	$1000.7 + b_{0i} + 10.0 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.0857}$
Rye	$1116.8 + b_{0i} + 10.4 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.0834}$
Pressed rye	$1055.2 + b_{0i} + 10.5 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.15207}$
Triticale	$919.1 + b_{0i} + 10.8 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{2.0.10039}$
Pressed triticale	$1014.5 + b_{0i} + 10.6 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.15787}$
Wheat & rape	$1115.9 + b_{0i} + 7.9 \cdot t_{ij} + b_{1i} \cdot t_{ij} + \varepsilon_{ij}$	$Var(\varepsilon_{ij}) = 121.604^2 \left  t_{ij} \right ^{-2.0.20465}$

**Table 5.** Point estimate (mean  $\pm$  SD) of the weight (g) and 95 % confidence interval for standard deviations of the weight with respect to the different diets and time from stocking in grams

Day from stocking	Form of feed	(c) Control (n=22)	(b) Barley (n=11)	(r) Rye (n=11)	(t) Triticale (n=11)	(w) Wheat & rape (n=12)
1	Non-pressed	951 $\pm$ 104 (82.4-150.8)	976 $\pm$ 99 (72.8-182.8)	1050 $\pm$ 82 (60.7-152.4)	947 $\pm$ 121 (88.9-223.3)	Not tested
	Pressed		1002 $\pm$ 88 (65.0-163.3)	997 $\pm$ 85 (62.4-156.6)	988 $\pm$ 92 (67.6-169.9)	956 $\pm$ 89 (66.5-159.4)
31	Non-pressed	1275 $\pm$ 172 <sub>r</sub> (136.3-249.3)	1360 $\pm$ 204 <sub>r</sub> (149.8-376.2)	1469 $\pm$ 172 <sub>r</sub> (126.3-317.3)	1327 $\pm$ 217 <sub>br</sub> (159.3-400.1)	Not tested
	Pressed		1279 $\pm$ 124 (91.46-229.71)	1412 $\pm$ 84 (61.7-155.0)	1330 $\pm$ 166 <sub>r</sub> (121.9-306.3)	1375 $\pm$ 163 <sub>r</sub> (120.9-289.7)
53	Non-pressed	1421 $\pm$ 176 (139.3-254.8)	1582 $\pm$ 192 (141.1-354.5)	1730 $\pm$ 225 (165.2-414.9)	1534 $\pm$ 257 <sub>br</sub> (188.3-473.0)	Not tested
	Pressed		1582 $\pm$ 142 (104.2-261.7)	1635 $\pm$ 148 (108.5-272.6)	1603 $\pm$ 170 (125.2-314.4)	1566 $\pm$ 200 (146.6-368.1)
73	Non-pressed	1506 $\pm$ 223 (176.4-322.9)	1651 $\pm$ 204 (149.5-375.5)	1822 $\pm$ 236 (173.3-435.3)	1680 $\pm$ 342 <sub>brt</sub> (251.3-631.1)	Not tested
	Pressed		1690 $\pm$ 151 (111.3-279.6)	1763 $\pm$ 167 (122.7-308.1)	1774 $\pm$ 198 (145.1-364.4)	1686 $\pm$ 225 (166.8-399.7)
98	Non-pressed	1694 $\pm$ 266 (210.7-385.5)	1987 $\pm$ 274 <sup>a</sup> (201.5-506.0)	2190 $\pm$ 330 (242.4-608.9)	2045 $\pm$ 503 <sub>brtw</sub> (368.7-926.0)	Not tested
	Pressed		2052 $\pm$ 234 (171.5-430.7)	2126 $\pm$ 234 (171.6-430.9)	2096 $\pm$ 267 (195.8-491.8)	1923 $\pm$ 287 (212.4-509.1)
111	Non-pressed	1732 $\pm$ 281 (222.2-406.7)	1993 $\pm$ 299 (219.3-550.9)	2225 $\pm$ 330 (242.1-608.1)	2128 $\pm$ 554 <sup>cb r</sup> <sub>brtw</sub> (406.2-1020.2)	Not tested
	Pressed		2049 $\pm$ 250 (183.4-460.7)	2190 $\pm$ 264 (193.8-486.7)	2145 $\pm$ 296 (217.1-545.4)	1940 $\pm$ 296 (219.2-525.5)

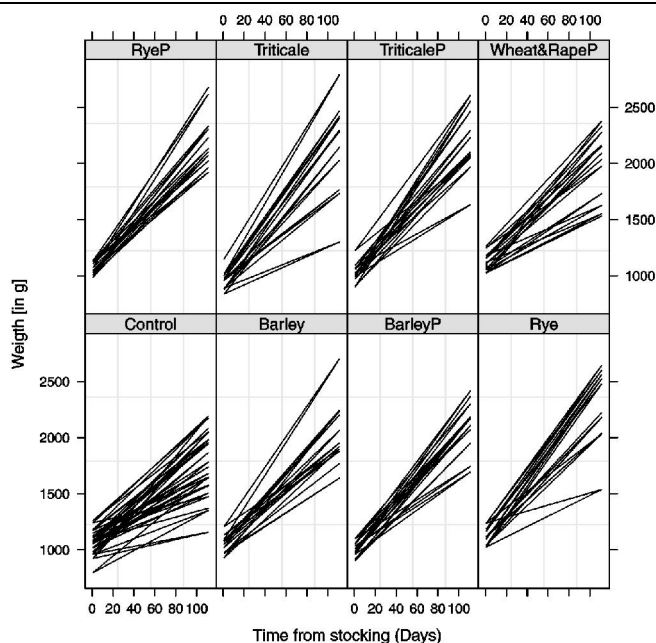
Alphabetical subscripts are used to indicate significant differences among different diets (P-value<0,05; F-test to compare two variances). Alphabetical superscripts are used to indicate significant difference between non-pressed and pressed form of particular feed (P-value<0,05; F-test to compare two variances).

showed significantly lower SD values (P<0.05): pressed barley, SD 250 g ind<sup>-1</sup>; pressed rye, SD 264 g ind<sup>-1</sup>; and pressed triticale SD 296 g ind<sup>-1</sup>. The average SD value for fish fed pressed variants was 270 g ind<sup>-1</sup> at the end of the experiment.

**Weight Gain, Feed Utilization and Condition Factor**

Differences among the cereals in digestible

energy (DE) and content of proteins and carbohydrates were minimal (Table 1). Common carp fed pressed rye showed the greatest individual weight gain, 1.192 kg ind<sup>-1</sup>, with FCR of 2.13 and SGR of 0.7 (Table 6). The non-pressed triticale group showed individual weight gain of 1.180 kg ind<sup>-1</sup> with FCR of 2.08 and SGR of 0.72. Common carp fed non-pressed rye showed individual weight gain of 1.175 kg ind<sup>-1</sup> with FCR of 2.17 and SGR of 0.67. Intermediate individual weight gain 1.156 kg ind<sup>-1</sup> was reached by



**Figure 1.** Predicted growth trajectory based on the linear mixed effect model M5.

common carp fed with pressed triticale with FCR 2.13 and with SGR of 0.69.

At stocking in May, the mean FC for carp was  $3.07 \pm 0.12$ . During the growing season, FC values slowly increased with increasing fish weight. However, in August (at 73 days), a decrease of FC values in the all groups of fish was observed. At harvest (111 days), the highest FC value was seen in the non-pressed triticale group at  $3.36 \pm 0.27$  and the non-pressed barley group at  $3.35 \pm 0.23$ . The group fed pressed wheat and rape reached similar FC values at  $3.23 \pm 0.27$ . The pressed barley had FC  $3.19 \pm 0.49$ , and the control carp had FC  $3.19 \pm 0.24$ . The lowest FC value at the end of the experiment,  $3.13 \pm 0.23$ , was found in the group receiving pressed rye.

### Environmental Parameters and Zooplankton

The mean value of the temperature and dissolved oxygen were  $20.7 \pm 1.7^\circ\text{C}$  and  $6.07 \pm 1.19 \text{ mg L}^{-1}$ , respectively. The lowest values of temperature were observed during the September. Both parameters showed no significant difference among the experimental ponds ( $P > 0.05$ ). Mean abundance of zooplankton was  $135 \pm 87 \text{ ind L}^{-1}$ . Cladocerans (especially *Bosmina longirostris*) were dominant throughout the experiment (94%). Copepods, represented mainly by *Thermocyclops crassus*, comprised 4% of the zooplankton community. Rotifers represented 2%. No significant differences were noted in zooplankton density among the experimental ponds.

### Discussion

The common carp is omnivorous with wide food plasticity (Urán *et al.*, 2008). At the beginning of the

growing season, it filters zooplankton and consumes carbohydrates to fulfil its energy needs, using exogenous enzymes obtained from zooplankton (e.g. cladocerans) for digestion of carbohydrates. Skeletons of cladocerans and copepods aid in the mechanical digestion of food (Jancarík, 1964; Strumbauer and Hofer, 1986).

According to Shimeno *et al.* (1997), in summer a decrease in the activity of glycolytic and lipogenic enzymes occurs, and carp become almost totally herbivorous. In order to digest carbohydrates, endogenous enzymatic activity was found to gradually increase (Shimeno and Shikata, 1993a, b). Hartman (2005) found that unconsumed feed particles appeared on the pond water surface in this period. Their nutritional intake was limited to the necessary essential ration, and only after the ability of the carp to utilize carbohydrates had developed, they started to take up dietary amounts adequate for their growth. This adverse transient period can be shortened by providing pressed cereals, which are more digestible than whole seeds.

In the present study, growth of common carp in the rearing ponds was characterized by two seasonal maxima with the greatest weight increase in June and August. Between the two growth peaks, a reduction in the rate of weight gain was observed, which can be explained both by decreasing quantity of natural food and the gradual adaptation of fish to supplemental feed. It is known, that a reduction in the activity of digestive enzymes at low water temperatures of diet could also be responsible for the decrease in apparent digestibility with the decrease in water temperature. Variations in water temperature have a great effect on fish basal metabolism, because fish are poikilotherms and their metabolic rate is determined by the environmental temperature. A decrease in weight gain

**Table 6.** Main management and production data (non-pressed and pressed cereals)

	Rye	Pressed Rye	Triticale	Pressed Triticale	Barley	Pressed Barley	Pressed wheat and Rape	Control
Experimental pond area (m <sup>2</sup> )	300	300	300	300	300	300	330	300
Stocked (ind.ha <sup>-1</sup> )	363	363	363	363	363	363	363	363
Stocked (ind.)	11	11	11	11	11	11	12	11
Initial total weight (kg)	11.56	10.97	10.42	10.87	10.75	11.03	11.48	10.94
Initial individual weight (kg.ind. <sup>-1</sup> )	1.05	0.99	0.95	0.99	0.98	1.00	0.96	0.95
Harvest (ind.)	11	11	11	11	11	11	12	22
Final total weight (kg)	24.48	24.08	23.41	23.59	21.92	22.53	23.27	19.91
Final individual weight (kg.ind. <sup>-1</sup> )	2.23	2.18	2.13	2.14	1.99	2.05	1.94	1.73
Total weight gain (kg)	12.93	13.12	12.99	12.72	11.17	11.51	11.79	8.98
Individual weight gain (kg.ind. <sup>-1</sup> )	1.18	1.19	1.18	1.15	1.01	1.05	0.98	0.78
Total cereal consumption (kg)	28.04	27.93	27.01	27.09	27.93	27.95	24.06	-
FCR	2.17	2.13	2.08	2.13	2.50	2.43	2.04	-
SGR	0.67	0.7	0.72	0.69	0.64	0.64	0.63	0.54
FCR/SGR	3.24	3.04	2.89	3.09	3.91	3.8	3.24	-

in September could be a combined effect influenced by less efficient digestion, basal metabolism associated with worsening environmental conditions caused by decreasing temperature.

According to Dumas *et al.* (2010) fish weight gain is highly dependent on water temperature. The temperature of most fish species are linked to that of the environment. The digestive system of fish is effectively adapted ambient temperature and the temperature has an influence on fish metabolism. Horn (1998) stated that temperature limits the microbial fermentation in the gut of common carp. Schwarz (1997) reported that common carp digestion is most effective at 23-25°C. When the water temperature decreases from 25 to 18°C, digestion in common carp is significantly reduced (Kim *et al.*, 1998; Yamamoto *et al.*, 2001, 2007; Clements and Raubenheimer, 2006). Water quality parameters (temperature and oxygen) measured during the experimental period corresponded to common values recorded in Czech ponds and remained within the ranges necessary for good growth performance of carp (Billard, 1999). Both parameters showed no significant difference among the experimental ponds ( $P > 0.05$ ), indicating that feeding experiments had not been biased by water parameters.

Daily weight gain of common carp fed pressed rye was 1.45% higher, and the conversion of feed 1.85% lower, than in common carp fed non-pressed rye. The results for barley may have been influenced by higher fibre content (5.40%), which reduces the digestibility of other components (Jirásek, 2005). According to Pigott and Tucker (2002) digestion is the most important factor limiting nutrient availability. When altering grains by pressing, digestibility increases as indigestible constituents are crushed and fibre is split. In the pressed barley group, daily weight gain was 2.88% higher and the feed conversion was 2.80% lower than in the non-pressed barley group. Common carp receiving pressed wheat

and rape showed low growth rate. Jackson *et al.* (1982) found that a high proportion of rape in feed is associated with growth depression in omnivorous fish and  $\alpha$ -amylase inhibitors in wheat appear to reduce starch digestibility (Storebakken *et al.*, 2000). The results for the combination of wheat and rape in the present study confirm this. Higher efficiency of pressed cereals was not shown for triticale. Daily weight gain for the non-pressed triticale group was 2.07% higher, and the conversion was 2.35% lower, than in the pressed triticale group. This result could have been influenced by high variation in fish weight or by the degree of pressing of the triticale, which may have led to higher losses of feed due to its dispersion in the water.

Przybyl and Mazurkiewicz (2004) showed that triticale, wheat and rye had a similar feed conversion factor, when used in extruded feeds. The higher FCR for pressed triticale compared to non-pressed grains in our study could be due to the processing methods. When pressing seeds the hull is crushed and the starch gets in contact with the water. We hypothesize that due to the different starch characteristics and higher amount of small starch granules in triticale compared to for example barley, wheat and rye (Ao and Jane, 2007; Gassner *et al.*, 1989) starch from triticale is leaking to the water to a higher degree than from the other cereals. However this needs to be confirmed in another study.

## Conclusion

Our results indicate that the production efficiency of cultured common carp can be increased by the supplementation of pressed rye or barley instead of non-pressed cereals. Feeding pressed rye or barley resulted in similar or higher weight gain at lower FCR values, and hence a decrease of feeding costs. In addition common carp fed pressed cereals showed lower variation in weight in comparison with

those fed non-pressed cereals. As homogeneous size and weight minimizes manipulation during sorting and hence reduces stress, this finding will positively affect common carp welfare during harvesting. In order to optimise the feeding efficiency, the increased production efficiency of pressed rye and barley needs to be further investigated and verified. There is also a need to investigate why pressed triticale was less effective.

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