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RESEARCH ARTICLE

Large water flea (*Daphnia magna* Straus) and mealworm (*Tenebrio molitor* L.) as potential food sources for rearing common carp (*Cyprinus carpio* L.) juveniles indoors

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Abstract. When rearing common carp fry using intensive technology, expensive rearing feeds can be replaced, or partially replaced, with economically produced live food organisms, which is a solution that is close to a natural one. Natural feeding conditions for common carp (*Cyprinus carpio* L.) juveniles were modeled in indoor studies 49 d in length in two consecutive years in Szeged, Hungary. In 2021, feeding Szeged mirror carp advanced fry with a nutritionally complete formulated feed was compared to feeding them large water fleas (*Daphnia magna*) and yellow mealworms (*Tenebrio molitor*) in rations that were adjusted for fish growth. In 2022, Szeged mirror carp and scaled landrace advanced fry fed water fleas and mealworms were compared with the same fish genotypes fed water fleas and complete feed in rations that were adjusted for fish growth. Feeding natural food resulted in significantly larger fish and better values for average daily gain, specific growth rate, feed conversion ratio, and final condition factor in both experiments, confirming that feeding live arthropods results in faster-growing carp fry with better feed utilization efficiency. The carp genotypes had different growth dynamics, with Szeged mirror carp exhibiting faster development and more efficient feed utilization compared to scaled landrace.

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Introduction

In current practice of large-scale fish farming, the nutritional needs of common carp (*Cyprinus carpio* L.), the second most important fish species in European freshwater aquaculture (Aquaculture Statistics 2023), are met by both natural and supplementary food sources. Common carp is an omnivorous fish consuming a range of natural foods, such as zooplankton organisms, insect larvae, pupae and adults, worms, molluscs, plant parts and seeds, as well as fish eggs, larvae, and smaller fish (Peteri 2005, Woynarovich 2013). In semi-intensive pond systems, supplementary feeding is carried out with cereal grains, legumes, various food by-products and/or mixtures. Where natural food is lacking or inadequate (for example in intensive systems), a nutritionally complete formulated feed is used (Hancz 2011).

The large water flea (*Daphnia magna*), along with other cladoceran species, is an important natural food source not only for juvenile but also adult omnivorous fish in freshwater aquaculture (Horváth and

Urbányi 2000). The propagation of zooplankton species, including *Daphnia*, is a technology recognized by the Food and Agriculture Organization for feeding juvenile fish (Delbare and Dhert 1996).

Using insect proteins in fish feeds primarily to replace fishmeal is relatively new, but it is an extremely promising technological solution (Makkar et al. 2014, Riddick 2014, Rumbos et al. 2021, Alfiko et al. 2022). Currently, insects or insect larvae are only allowed as feed materials for companion animals and fishes in the European Union (Commission Regulation 2017), but the amount of insect protein cannot exceed 50% of the total crude protein content of the feed (Mézes 2018). The high protein, omega-6, monounsaturated fatty acid content, and essential amino-acid composition of insect meal is similar to that of fishmeal, making insect meal a remarkable replacement for fishmeal in fish feeds (Barroso et al. 2014, Révész 2017). Insects processed in the form of flour or pellets provide sufficient quality and quantity of protein to partially replace ordinary fishmeal primarily in the feeding of omnivorous (catfish, carp) or predatory (trout, salmon) fishes (Riddick 2014, Iaconisi et al. 2018). Currently, black soldier fly (*Hermetia illucens*) meal is the supplement under the most intensive research, for example in feeds for catfish and common carp (Xu et al. 2020, Gebremichael et al. 2021, Nguka et al. 2024). The potential of yellow mealworm (*Tenebrio molitor*), both live and in meal form, as a substitute for commercial feed or, for example, fishmeal or soymeal, has also been reported for various fish species such as African catfish, rainbow trout, and common carp (Ng et al. 2001, Gasco et al. 2014, Li et al. 2022, Gebremichael et al. 2023).

The general goal of the current study was to approximate feeding that was close to natural for carp juveniles in an intensive indoor system by replacing a nutritionally complete formulated feed (further – complete feed) with large water fleas and yellow mealworms. Over the two-year-long experiment, the results of experiment 1 with one common carp genotype were utilized in experiment 2 to examine feeding two common carp genotypes. The observations focused on the dynamics of juvenile carp development and assessing growth and feed utilization parameters.

Materials and Methods

Study area

The experiments were carried out on a private estate on the outskirts of Szeged, Hungary (46.256313°N, 20.215081°E) under the constant supervision of experts from the Faculty of Agriculture of the University of Szeged. The indoor room provided constant air and water temperatures of 20 ± 1°C in the experimental tanks.

Water source and quality

The water source for both experiments was a drilled well. The water parameters measured at the start of the experiments were as follows: pH 7.6; general hardness >14 °GH (>250.6 ppm); carbonate hardness 15 °dKH (268.31 ppm). Water temperature was 20 ± 1°C throughout the experiments. No further monitoring of water parameters was done since the internal filters were cleaned weekly and the fish consumed all of the feed offered them.

Experimental design

Experiment 1. From July 5 to August 22, 2021, the effects live arthropod food compared to complete feed on the growth and feed utilization characteristics of common carp (*Cyprinus carpio*) juveniles were investigated. Advanced fry (approximately 6 weeks old) of Szeged mirror carp (further – mirror carp), which is a registered common carp breed of Protected Geographical Indication status, was used in the experiment. The fry were obtained from Szegedfish Ltd., Szeged, Hungary. The initial body weights and lengths were 0.54–0.56 g and 21.5 mm, respectively. Since this was a preliminary experiment, it was performed with 5 specimens placed in

Table 1
Experiment 1 basic setup

	Tank 1	Tank 2	Tank 3	Tank 4
Tank volume	300 l	300 l	300 l	300 l
Carp breed	Mirror Carp	Mirror Carp	Mirror Carp	Mirror Carp
Fish per tank	5	5	5	5
Feed type	*Daphnia* / Mealworm	*Daphnia* / Mealworm	Complete Feed	Complete Feed

Table 2
Experiment 2 basic setup

	Tank 1	Tank 2	Tank 3
Tank volume	900 l	900 l	900 l
Carp breed	Mirror Carp	Scaled Carp	Mirror Carp + Scaled Carp
Fish per tank	40	40	20 + 20
Feed type	*Daphnia* / Mealworm	*Daphnia* / Mealworm	*Daphnia* / Complete Feed

each of four round, plastic rainwater collectors with volumes of 300 l and water depths of 75 cm (Table 1). The technical aspects included illumination from artificial LED-lights (12:12 light:dark photoperiod), an air pump, and an internal sponge filter for each tank. The internal filter was cleaned, and water that evaporated was replaced weekly.

Experiment 2. From June 27 to August 14, 2022, the effects on growth and feed utilization characteristics of two common carp genotypes reared indoors on arthropod food sources compared to a combination of *Daphnia* and complete feed were investigated. The advanced fry of two carp genotypes were obtained from a private fish farm located in Derekegyháza, Hungary; one of them was mirror carp that was also used in experiment 1 and the other was a locally selected scaled landrace (further – scaled carp). Initial body weights and lengths were 0.26–0.30 g and 11–14 mm, respectively. Forty specimens were placed in each of three round, plastic 900 l water tanks with water depths of 90 cm (Table 2). The technical aspects were the same as those in experiment 1.

Production of live food organisms

The large water flea (*Daphnia magna*) stock was kept in 200 and 300 l rainwater tanks with the continuous addition of green microalgae (*Chlorella* sp.) as food. Offspring was harvested daily to feed the fish and avoid overpopulation. *Chlorella* sp. was produced in a two-part recirculation system outdoors: one tank was fed mealworm droppings to provide nutrients, while the other tank contained the pure algal suspension. The yellow mealworm (*Tenebrio molitor*) culture was established in 12 l buckets partially filled with wheat bran. According to the common practice of mealworm rearing, carrot and apple slices were provided to meet nutrient (protein, fat, carbohydrate) and primarily moisture requirements.

Experimental diets

Experiment 1. The feed ration was the same in all four fish tanks and was increased according to the fish growth from 0.8 to 3.2 g fish^{-1} day^{-1}. The fish in tanks 1 and 2 received live food organisms, while those tanks 3 and 4 received complete feed until the end of the experiment (49 days). The total amount of feed consumed per fish was 102.76 g for 49 days (Table 3).

Experiment 2. The feed ration was the same in all three fish tanks and was increased according to fish growth from 0.8 g to 3.8 g fish^{-1} day^{-1}. The total feed consumed per fish was 109.9 g for 49 days. In tanks 1 and 2, 40 mirror carp and 40 scaled carp, respectively, received 100% *Daphnia* for the first seven days, then *Daphnia* and mealworm in gradually increasing rations. In Tank 3, 20 mirror carp and 20 scaled carp were fed *Daphnia* and complete feed in gradually increasing rations (Table 4).

According to the manufacturer's data, the composition of the complete feed was wheat flour, soybean meal, extruded soy, fish meal, meat meal, corn gluten, blood meal, fodder yeast, Cargill fish premix with a proximate composition of 89% dry matter, 40%

Table 3
Experiment 1 feeding regime

	Feed amount (g fish^{-1} day^{-1})		
	Tanks 1 and 2		Tanks 3 and 4
Days	*Daphnia*	Mealworm	Complete Feed
1	1.90	-	1.90
2-4	0.80	-	0.80
5-8	0.90	-	0.90
9-12	1.00	0.02	1.02
13-14	1.18	0.02	1.20
15-18	1.12	0.20	1.32
19	1.05	0.45	1.50
20-23	0.95	0.95	1.90
24-26	0.60	1.40	2.00
27-33	0.41	1.99	2.40
34-42	0.13	3.07	3.20
43-49	0.05	3.15	3.20
Total for 49 days	29.73	73.03	102.76

Table 4
Experiment 2 feeding regime

	Feed amount (g fish^{-1} day^{-1})			
	Tanks 1 and 2		Tank 3	
Days	*Daphnia*	Mealworm	*Daphnia*	Complete Feed
0-7	0.80	-	0.80	-
8-14	0.75	0.35	0.75	0.35
15-21	0.75	0.85	0.75	0.85
22-28	0.75	1.45	0.75	1.45
29-35	0.75	2.05	0.50	2.30
36-42	1.00	2.40	-	3.40
43-49	1.00	2.80	-	3.80
Total for 49 days	40.60	69.30	24.85	85.05

crude protein, 6.8% crude fat, 2.3% crude fiber, 2.3% Ca , 1.2% P, 0.05% Na, 15000 IU vitamin A, 1200 IU vitamin D3, 150 mg kg^{-1} vitamin E. The proximate composition of live mealworm was 62% moisture, 20% protein, 13% fat, and 2% fiber (Mariod 2020). Based on dry weight, the composition was 49.1% protein, 38.3% lipid, 4.1% ash, and 8.5% carbohydrate (Liu et al. 2020). Based on dry weight, the composition of *Daphnia magna* 6.6% moisture, 47.7% crude protein, 6.1% ether extract, 15.6% ash, 20% total carbohydrate, 8.6% fiber (El-feky and Abo-Taleb 2020).

Growth and nutrient recovery parameters

Fry body weights and lengths were measured weekly with a jewelry scale and a ruler, respectively. In experiment 1, all individuals were measured. In experiment 2, 10 randomly chosen individuals each were taken from tanks 1 and 2, and 10 individuals each of both carp genotypes were taken from tank 3. The data recorded were used to calculate the following growth and nutrient utilization parameters:

- condition factor (K) = $W / L^3 * 100$ (W: body weight in g; L: body length in cm) (Htun-Han 1978)
- average daily gain (ADG, g day^{-1}) = $(W_f - W_i) / T$ (W_f: final body weight in g; W_i: initial body weight in g; T: duration of the study in days) (Hawkins et al. 1985)
- specific growth rate (SGR, % day^{-1}) = $(LnW_f - LnW_i) / T * 100$ (Hewett et al. 1991)
- feed conversion ratio (FCR, g g^{-1}) = $F / (W_f - W_i)$ (F: feed consumed in g) (Hewett and Johnson 1992)

Statistical analysis

The experimental data were analyzed statistically with IBM® SPSS® Statistics Version 23. A two-sample t-test and one-way analysis of variance (ANOVA) were used to compare the averages of the treatments. Post-hoc analysis was also performed using Tukey's test at a 5% significance level. The correlation coefficient was calculated for the relationships among feed rations and juvenile growth.

Results

Experiment 1

Figure 1 shows that carp fry reared on live arthropod food grew more intensively and gained more body weight in seven weeks than did individuals fed complete feed (38.28 vs. 9.73 g). Similarly, carp fry fed live food achieved much longer body lengths (98.2 mm) in seven weeks than did the fish fed complete feed (61 mm). After just one week, there was a significant difference ($P < 0.05$) between the data obtained for live food and that for complete food in relation to both body length and weight (Fig. 1).

A strong positive correlation was found between body weight and body length when the fish were fed both live food ($r = 0.961$; $P < 0.01$) and complete feed ($r = 0.983$; $P < 0.01$). Similarly, the correlation between

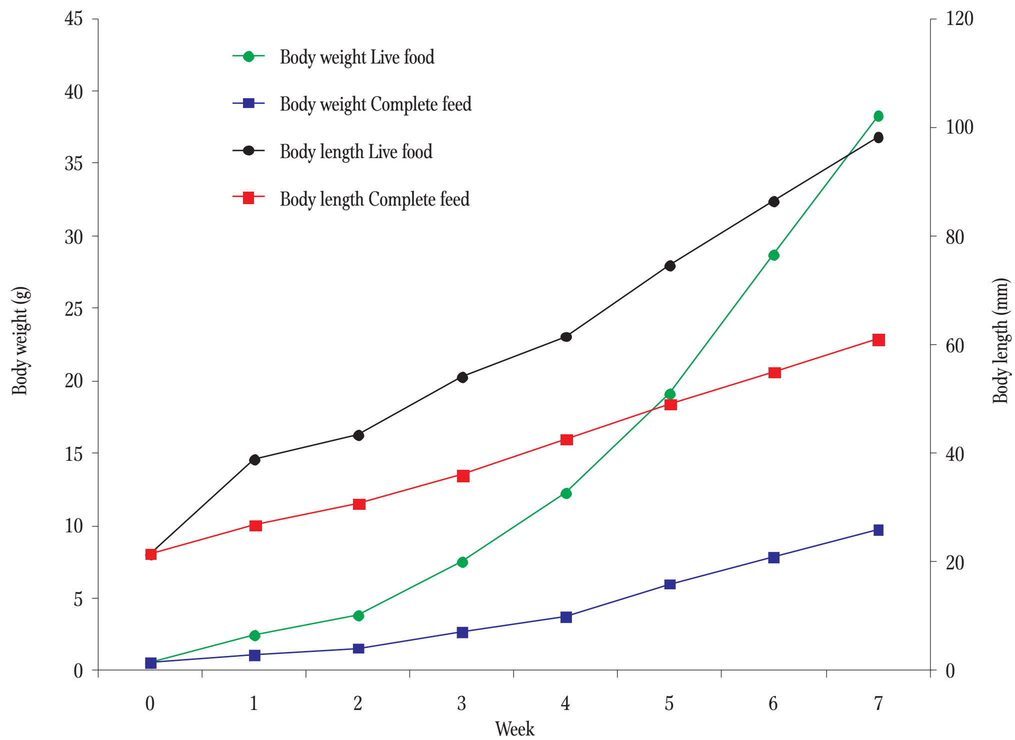

Figure 1. Body weight and body length of common carp advanced fry reared on live food and complete feed (n=10).

Table 5
Growth and feed conversion parameters of *Cyprinus carpio* fry in experiment 1. (Mean ± SD, n = 10)

Parameter	Type of feed: Live	Complete
Initial body weight (g)	0.54 ± 0.09^a	0.56 ± 0.08^a
Final body weight (g)	38.28 ± 8.96^a	9.73 ± 3.59^b
Initial body length (mm)	21.5 ± 0.5^a	21.5 ± 0.5^a
Final body length (mm)	98.2 ± 8.5^a	61.0 ± 2.1^b
Average daily gain – ADG (g)	0.77 ± 0.02^a	0.19 ± 0.01^b
Specific growth rate – SGR (% d^{-1})	8.83 ± 0.02^a	6.06 ± 0.11^b
Feed consumption (g $fish^{-1}$ 49 $days^{-1}$)	102.76	102.76
Final condition factor – K	4.27 ± 0.39^a	4.29 ± 0.18^a
Feed conversion ratio – FCR (g g^{-1})	2.72 ± 0.07^a	11.14 ± 0.34^b
Survival rate (%)	100	100

Different letter superscripts on the same line indicate statistically significant differences ($P < 0.05$)

increasing feed rations and fish body parameters was also significant. The positive correlation between feed ration and body weight was slightly stronger for complete feed ($r = 0.949$; $P < 0.01$) than for live food ($r = 0.927$; $P < 0.01$). However, the positive correlation between feed ration and body length was minimally stronger with live food ($r = 0.990$; $P < 0.01$) than with complete feed ($r = 0.984$; $P < 0.01$).

Among the growth indicators achieved with the two feeding treatments, final body weight and length were significantly better with live food. The condition factor values calculated were extremely high without a significant difference between the two feeding treatments (4.27 vs. 4.29). The difference in average daily gain of 0.77 vs. 0.19 g day^{-1} was highly significantly better with live food. Accordingly, the specific growth rate was also significantly better in fish reared on live food (8.83 vs 6.06% day^{-1}). At the same feed consumption per specimen, the feed conversion ratio for live food was 2.72 g g^{-1}, which was significantly better than that for complete feed at 11.14 g g^{-1}, since the fish needed much less of the live food to produce a unit body weight (Table 5).

Experiment 2

Individuals of both carp genotypes showed strong growth when reared on both live food and the combination of *Daphnia* and complete feed during the seven weeks of the experiment. The growth trends, however, were different (Figs. 2–3). The difference in body weight measured at week two was already significant between the mirror carp reared on live food and *Daphnia* + complete feed and also between the scaled individuals raised on live food and the individuals of both genotypes raised on *Daphnia* + complete feed. At this point, the difference in body weight was significant between the genotypes reared on *Daphnia* + complete feed but it was not significant between those raised on live food. At the end of the experiment, however, the body weight of the two genotypes reared on live food (32.8 and 27.8 g) was significantly different from those reared on *Daphnia* + complete feed (18.1 and 17.0 g). There was no significant difference, however, in body weight between the genotypes raised on *Daphnia* + complete feed (Fig. 2, Table 6).

From the second week, the difference in body length was also significant between the two genotypes fed either live food or *Daphnia* + complete feed. At the end of the experiment, the mean body length of the fish in all four treatments was significantly different from those of all other treatments (Fig. 3, Table 6). By the end of the experiment, the mean body length of the individuals of the two genotypes fed live food (86.5 and 81.1 g) was significantly

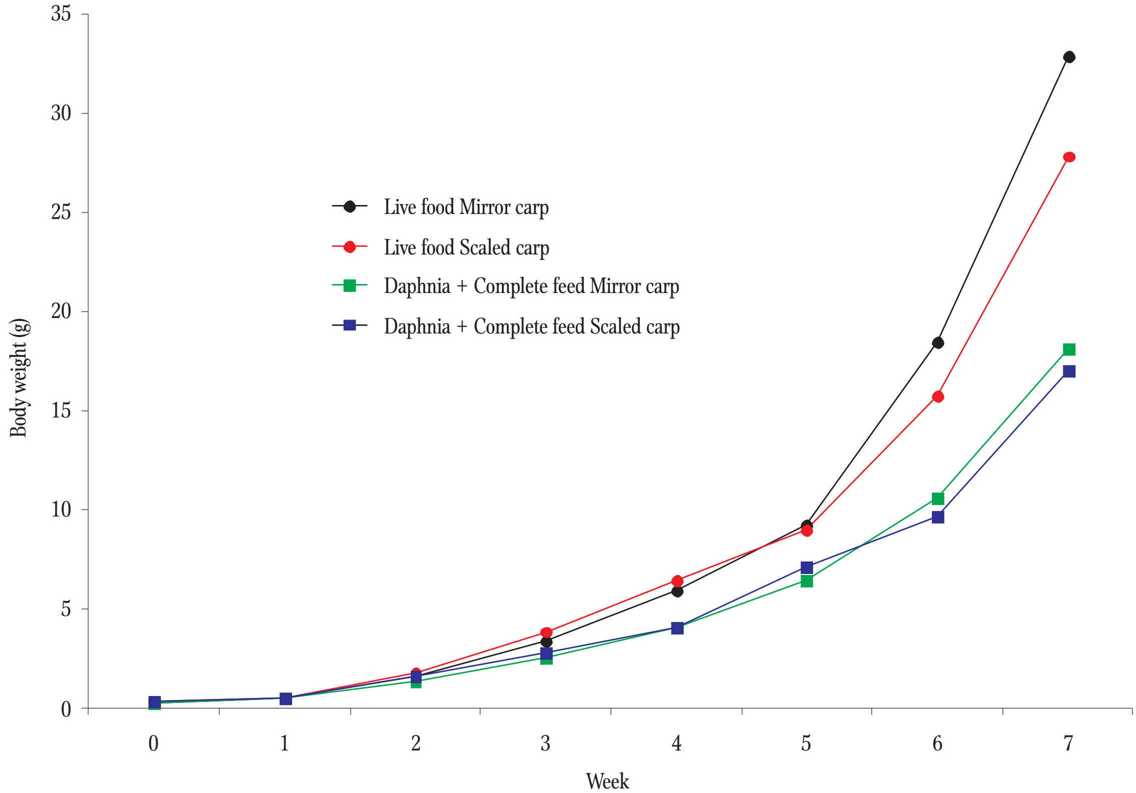

Figure 2. Body weight of mirror and scaled common carp fry reared on live food and complete feed (n=10).

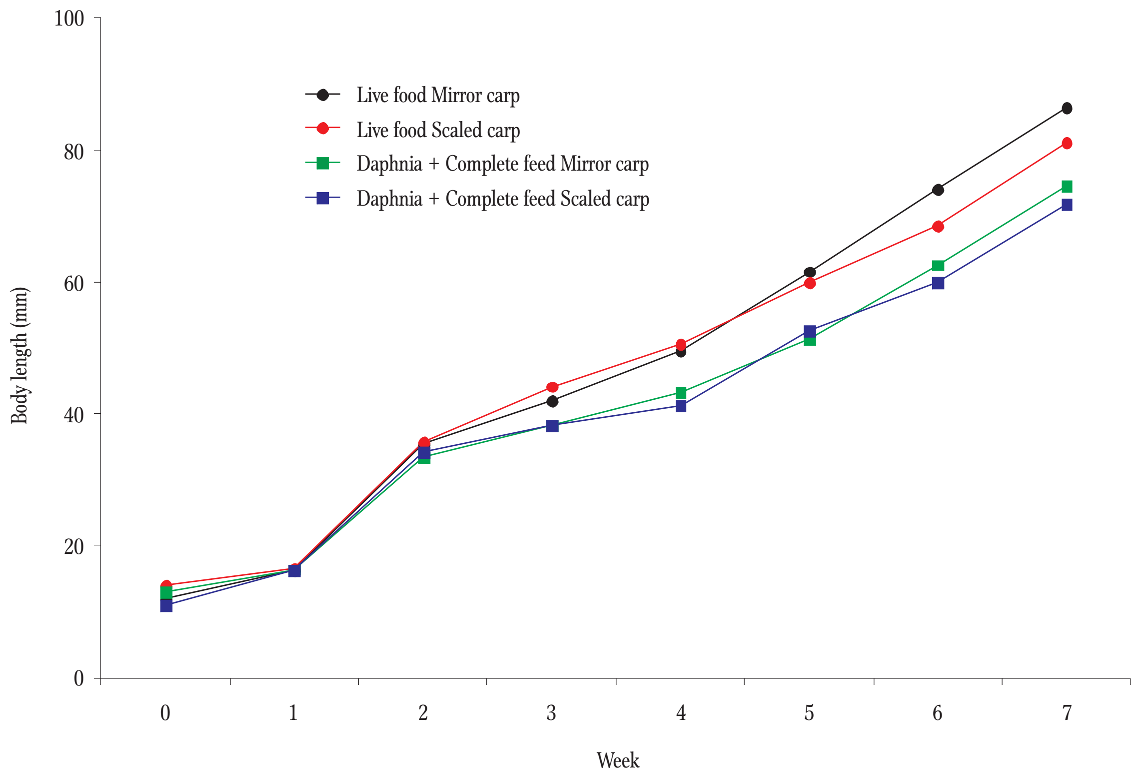

Figure 3. Body length of mirror and scaled common carp fry reared on live and on complete feed (n=10).

Table 6
Growth and feed conversion parameters of *Cyprinus carpio* fry in experiment 2. (Mean ± SD, n = 10)

	Common carp genotype and type of feed			
	Mirror Carp	Scaled Carp	Mirror Carp	Scaled Carp
Parameter	Live food		*Daphnia* + Complete Feed	
Initial body weight (g)	0.27±0.07^{a}	0.30±0.07^{a}	0.26±0.05^{a}	0.28±0.08^{a}
Final body weight (g)	32.8±2.1^{a}	27.8±1.7^{b}	18.1±1.0^{c}	17.0±0.4^{c}
Initial body length (mm)	12	14	13	11
Final body length (mm)	86.5±1.8^{a}	81.1±1.7^{b}	74.6±2.2^{c}	71.8±1.2^{d}
ADG (g)	0.66±0.04^{a}	0.56±0.03^{b}	0.36±0.02^{c}	0.34±0.01^{c}
SGR (% d^{-1})	9.85±0.55^{a}	9.29±0.51^{ab}	8.70±0.32b^{c}	8.45±0.59^{c}
Feed consumption (g $fish^{-1}$ 49 $days^{-1}$)	109.9	109.9	109.9	109.9
Final condition factor – K	5.07±0.14^{a}	5.21±0.11^{a}	4.37±0.16^{b}	4.60±0.14^{c}
FCR (g g^{-1})	3.39±0.22^{a}	4.01±0.25^{b}	6.17±0.35^{c}	6.57±0.17^{d}
Survival rate (%)	100	100	100	100

Different letter superscripts on the same line indicate statistically significant differences ($P < 0.05$).

different from each other and that achieved with *Daphnia* + complete feed (74.6 and 71.8 g).

The growth and feed conversion parameter trends for the two carp genotypes were similar to those determined in experiment 1 with one genotype. Both ADG and the SGR values were higher for mirror carp. The ADG values achieved with live food differed significantly between the two carp genotypes. However, both ADG and SGR values were significantly higher for fish fed live food (Table 6). The final condition factor was slightly higher for scaled carp. When fed complete feed, the difference between the two genotypes was significant. At a total feed consumption of 109.9 g per individual in 49 days, the FCRs were significantly lower for mirror carp fed live food (Table 6).

Discussion

Growth parameters

In the experiments, large water fleas and mealworms were used successfully to feed *Cyprinus carpio* advanced fry in intensive culture indoors. Over seven weeks, common carp advanced fry fed live food exclusively reached and exceeded (27.8–38.28 g) average size (10–40 g) expected for carp fry under typical fish pond conditions in Hungary by the end of the season of the first year (Horváth et al. 2015). Demeterné Pédery et al. (2007) ran an experiment in ponds using zooplankton as well as carp fry and rearing feed in the first weeks followed by a wheat supplement in which Szeged mirror carp advanced fry reached 9.8–25.0 g from 0.68–0.71 g in about seven weeks. This result is similar to that achieved in the present experiment in which carp fry were fed only complete feed for the same period. Supplementing formulated feed with probiotics or humic acid, however, was less efficient compared to the technology presented in the current study. In an intensive indoor system, mirror carp advanced fry with an initial weight of about 0.8 g achieved a maximum weight of approximately 3.5 g at the end of an eight-week feeding experiment (Csorvási et al. 2015). Supporting the present results achieved with natural food sources in an indoor system, during a 12 week study, all growth and feed utilization parameters, for example, weight gain, daily weight, specific growth rate, and food conversion ratio were better for fish fed commercial feed with a *Chlorella* and/or a *Daphnia* supplement compared to those fed a formulated diet without supplements (Baiz 2018).

In the experiments presented here, the SGR showed daily percentage increases were 8.83–9.85 and 6.06–8.45% day^{-1} for advanced fry reared on live food and complete feed, respectively. In the 28-day experiment by Kuzu et al. (2008) with intensive carp rearing feed, SGR values ranged from 3.62 to 4.66 in juveniles of Danube wild carp, which is a less intensive breed than are the Szeged mirror carp or scaled carp used in the present experiments.

The final condition factors were extremely high for carp fry reared on both live food and on complete feed in the system presented here (4.27–5.21 and 4.29–4.6, respectively) showing no significant effect of feeding conditions in experiment 1, even if the actual values of the body size parameters differed significantly. In a three-month experiment with carp yearlings fed a floating trout rearing feed in an intensive indoor system, Demeterné Pédery et al. (2007) observed an improvement in condition factor values from 1.99–3.30 to 2.67–5.16 in all four carp genotypes, with the highest values observed in Szeged mirror carp.

Mealworm meal was a potential substitute for commercial feed, fishmeal, and soybean meal in fish diets (Ng et al. 2001, Gasco et al. 2014, Li et al. 2022, Gebremichael et al. 2023). It proved to be an efficient substitute for dietary fishmeal for carp, providing a promising alternative source of protein. In a 60-day experiment with mirror carps of approximately 200 g average initial body weight, soybean meal was successfully replaced by mealworm meal, improving feed utilization and growth parameters only slightly. The SGR (0.96–1.08% day^{-1}) and condition factor (2.64–2.74) were lower than in the present experiment, while FCR proved to be more favorable (1.58–1.78 g g^{-1}) (Li et al. 2022). In another experiment with carp of similar size (about 209 g initial body weight), the 50% replacement of fishmeal with mealworm meal resulted in a high mortality rate for unknown reasons. If, however, the 50% replacement of fishmeal was shared equally between black soldier fly and mealworm meal, no negative effect on flesh yield or quality parameters was detected compared to the fishmeal control (Gebremichael et al. 2022).

Feed conversion parameter

During intensive rearing of Szeged mirror carp for 42 days, depending on the feed, FCR was between 0.91–1.75 g g^{-1} suggesting more efficient utilization of feed compared to the present experiment even with formulated feed (Feledi et al. 2011). In the experiment cited, however, the SGR was significantly lower (1.0–1.8% day^{-1}) than values from the experiments presented here, which can be attributed to the slower growth rate due to the larger average size of the fish (166.7 ± 2.8 g) (Feledi et al. 2011). Mealworm feed intensified the yellow color of the skin of yellow carp. Based on protein retention efficiency (PRE), the optimal proportion of soymeal replaced by mealworm is 55.35% (Li et al. 2022).

Conclusions

Based on the results presented above, the live food chosen for the experiments presented here can be used efficiently to replace formulated feed, primarily in intensive systems. With this feeding strategy, juvenile carp can be raised efficiently in intensive indoor systems and good growth rates can be achieved. Compared to the results achieved with expensive complete feeding, the production of live food makes the system more economical. Further experiments are needed to investigate up to what age or size of fish this feeding method can be used and to what extent enriching food organisms through their feed can improve results. To extrapolate the results obtained in experimental systems to farm conditions, it is essential, however, to solve the problem of large-scale production of food organisms.

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Author contributions. S.M.T. – experiment design, data collection, funding acquisition, methodology, data curation; P.M.– conceptualization, experiment design, validation; T.M. – supervision, experiment design, statistical analyses, drafting the paper.

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