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Original Article

Growth performance of common carp, *Cyprinus carpio*, fry at different experimental stocking densities in the environmental conditions of central Iraq

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Abstract: This study aimed to examine the growth performance of common carp, *Cyprinus carpio*, fry in different stocking densities in the environmental conditions of central Iraq. The experiment was performed for 60 days at the central fish hatchery in the Suwayra district, the Kut Province. The study examined four groups: three with different stocking densities (1 million (T1), 1.5 million (T2), and 2 million (T3) fry per hectare) and a control group (T0) without supplementary feeding. The fry were reared in earthen ponds, with water quality parameters constantly monitored and maintained within optimal conditions. The results revealed that stocking density significantly impacted growth performance and survival rates. T2 exhibited the highest survival rate (84.91%) and the greatest final average weight (8.23 g). Furthermore, T2 displayed the highest specific growth rate (SGR) and daily weight gain (DWG), suggesting that this stocking density is optimal for the prevailing conditions in central Iraq. The economic analysis revealed that T2 had the highest profitability, with a benefit-cost ratio (BCR) of 1.2, followed by T1 (BCR = 1.18) and T3 (BCR = 1.00). Feed expenses accounted for the majority of total costs, emphasizing the importance of efficient feed management. The findings underscore the importance of maintaining optimal stocking densities and implementing effective feeding strategies to enhance growth performance and economic sustainability in common carp farming in Iraq.

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Introduction

Fisheries and aquaculture are important for food production, nutrition, and employment worldwide. However, they face many challenges, such as sustainable and responsible management of fish stocks, adaptation to climate change, ensuring equitable benefits for fishermen and fish farms, reducing environmental impacts, and improving access to markets, finance, and technology (Valenti et al., 2018; Maulu et al., 2021). The common carp, *Cyprinus carpio*, is one of the most popular farmed fish in the world. Common carp cultivation has spread globally, covering almost all regions with a warm climate. In 2020, common carp accounted for 8.6% of global aquaculture production and approximately 16% of the total animal protein produced worldwide (Pradeepkiran, 2019; FAO, 2022). Common carp farming in Iraq has experienced rapid growth. Over the past seven decades, production has increased by 100%, and the species has become the country's primary source of fish protein production. Concurrently, common carp farming has significantly contributed to Iraq's economy (Anonymous, 2022).

Growth rates are a well-studied physiological parameter in fish, particularly in aquaculture experiments (De las Heras et al., 2015). The survival and production of fry and fingerlings in the pond system depend on the stocking density, type, and quality of fertilizers and supplementary feeds (Chakraborty and Mirza, 2007; Drew et al., 2007). Common carp fry are small and fragile, with very few surviving beyond a few days in the wild. This early life stage is marked by a high mortality rate, with fewer than 100 fish out of 1,000 surviving the first few weeks. From an economic perspective, this mortality rate is unsustainable, highlighting the need for

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intervention in rearing process to provide vital protection for juveniles and improve survival rates.

Aquaculture has long sought to accelerate the growth of common carp fry to achieve advanced body weights in the shortest time possible, reducing mortality rates and increasing productivity per unit area and time. However, fish farmers in developed countries often overlook the subsequent stage of fry cultivation. Consequently, fry weighing less than 5 grams are often transplanted directly into commercial ponds. In these large bodies of water, often inhabited by predators and exposed to harsh environmental conditions, juveniles are vulnerable to predation and mortality. This vulnerability directly impacts carp survival and, consequently, fish yields. Therefore, growing fry to larger fingerlings (20-30 grams) under optimal conditions is essential. A knowledge gap exists regarding the optimal strategy for growing carp fry to the desired mass, resulting in increased biomass and higher market value. By implementing an improved system, unnecessary losses of valuable common carp fry can be minimized.

Understanding the integration of digestive enzymes is crucial for studying larvae' nutritional status and dietary adaptation (Gisbert et al., 2009). Furthermore, determining the optimal time to initiate compound feeding is critical for survival and optimal growth. Therefore, the initiation of feeding should be based on an understanding of the development of the digestive system (Gawlicka et al., 2000), as fry must be physiologically capable of digesting the artificial food consumed (Vega-Orellana et al., 2006). Therefore, in our experiment, we initiated feeding of the fry with dry feed at 22 days of age, guided by the principle of minimizing feed waste and the fact that the digestive system of fish larvae is morphologically and physiologically developed to handle dry feed at this stage. This timing is consistent with the findings of numerous researchers, who have reported that the digestive system of fish larvae is fully developed and capable of digesting dry feed between the second and third weeks after hatching (Dabrowski, 1982; Furné et al., 2008; Rønnestad et al., 2013; Yúfera, 2018).

The objectives of this study are to develop and implement a low-cost and productive technology utilizing locally available resources for the production of large-sized carp fingerlings (weighing > 5 g) and to enhance the production and survival rate of fingerlings per unit area. Specifically, the study aims to optimize the production of fingerlings of the desired size within the shortest possible time while maintaining competitiveness.

Materials and Methods

The experiment was conducted at the central fish hatchery in the Suwayra district, approximately 40 km south of Baghdad, in the Kut Province, over 60 days from May 20, 2023, to July 19, 2023. It utilized a system of earthen ponds, consisting of seven ponds, each with a surface area of 2000 m². The ponds were drained and cleared of aquatic vegetation. After drying, quicklime (CaO) was applied to the bottom of the pond at a rate of 250 kg/ha to eliminate harmful insects and pathogenic microorganisms. Four days after liming, all ponds were filled with water to a depth of approximately 1.0 m. To enhance the availability of natural feed, the ponds were fertilized with organic manure (cow manure) at a rate of 1 ton/ha and inorganic fertilizers (NH_4NO_3, urea) at a rate of 250 kg/ha. The ponds were fertilized with organic and inorganic fertilizers at 10-day intervals to stimulate primary productivity. Fifteen-day-old common carp post-larvae (1.93±0.41 cm and 0.24±0.035 g), derived from mixed commercial production, were stocked in the ponds on May 20, 2023, at various densities (Table 1). All experimental ponds were 0.2 hectares in size, with an average depth of 1.4 meters and identical conditions. Prior to releasing the larvae into the experimental pond, the initial length and weight were recorded using sensitive portable electric scales.

Experiment design: In this experiment, the practice of the central state fish incubator was considered, based on stocking larvae at 7-10 days old and a density of 1-3 million larvae per hectare. Three treatments were used, differing in the stocking density of the grown larvae, namely, T1: 1 million/ha, T2: 1.5 million/ha, T3: 2 million/ha. The seventh pond was used as a control under the same experimental

Table 1. The mean ± SE and the range of parameters of water quality in experimental ponds. Mean values with different superscripts within a row differ significantly (*P*<0.05).

Parameters		**15-day old larvae stocking day**	**Sampling periods (age [day])**				**Averages and range of parameters**
			7 (22)®	**15 (30)**	**30 (45)**	**45 (60)**	
Water temperature (°C)	T1	24.2	25.6	26.3	27.5	28.8	26.8±0.75/ 23.8-30.6
	T2	24.7	25.6	25.8	27.3	27.8	26.9±0.31/ 23.6-30.7
	T3	23.4	24.8	26.4	28.1	28.4	27.5±0.47/ 23.8-30.6
	Tк	25.2	25.9	27.7	28.2	28.3	27.7±0.27/ 23.5-30.5
Sg		Ns	Ns	Ns	Ns	Ns	
pH	T1	8.1	7.8	8.3	7.8	8.6	7.8±0.06/ 6.5-9.5
	T2	8.2	8.4	8.1	8.3	8.2	8.1±0.13/ 6.8-9.6
	T3	7.6	7.7	8.6	7.9	8.4	7.8±0.05/ 6.8-9.0
	Tк	7.8	7.9	8.5	8	8.3	7.9±0.11/ 6.5-9.5
Sg		Ns	Ns	Ns	Ns	Ns	
DO (mg/L)	T1	6.8b	7.5	7.8	8.2ab	7.8	7.2/ 5.7-8.8
	T2	7.8a	7.1	8.3	7.9ab	8.3	7.1/ 5.7-8.8
	T3	7.2ab	7.1	8	8.4a	7.8	7.5/ 5.7-8.8
	Tк	7b	6.9	7.8	7.5b	7.6	7.4/ 5.9-8.4
Sg		*	Ns	Ns	*	Ns	
Ammonia-nitrogen (mg NH_3-N/L)	T1	0.16b	0.2b	0.18a	0.22c	0.18b	0.18/0.14-0. 23
	T2	0.15b	0.14b	0.18b	0.15b	0.16b	0.15/ 0.12-0.20
	T3	0.18a	0.23b	0.21c	0.17a	0.21a	0.19/ 0.16-0.25
	Tк	0.2a	0.24a	0.19a	0.19ab	0.15a	0.19/ 0.15-0.24
Sg		*	*	*	*	*	

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conditions but without supplementary feeding and with a stocking density of 1.5 million individuals per hectare.

Feed ingredients: To obtain maximum biological and financial returns, the fry would need feeds of suitable protein and fat content and pellet size to ensure their desired growth and survival. The experiment used dry floating granular feed from the Chineh Company, Iran, for fry with a grain size of 0.5 mm for all stages of fry growth. The content of crude protein, crude lipids, crude fiber, ash, moisture, and nitrogen-free extract in the experimental feed was 32.80, 8.53, 7.25, 15.84%, 10.12, and 25%, respectively (own analyses), plus premixes. The amount of feed fed at the rate of 6% of the achieved body weight of fry was adjusted every 15 days in accordance with the total biomass of fish obtained as a result of sampling as part of growth monitoring. The fish were hand-fed twice daily at 8 a.m. and 6 p.m. with two equal portions of the diet. The food was distributed over the surface of the pond water.

Sampling: Sampling was carried out 7, 15, 30, and 45 days after stocking at the age of 22, 30, 45, and 60 days after the larva's hatching. In total, 100 fish were taken from each pond on each sampling date. Fish samples were picked randomly using a fry seine with a suitable mesh size. They were then weighed and measured to obtain the fry's weight and size. The contents of the intestine were also analyzed.

Physicochemical analyses: The physicochemical parameters were measured in the morning before feeding the fry using a device (HI-9829 Multiparameter). Water temperature, dissolved oxygen, and pH were measured daily. The concentration of nitrogen compounds was measured twice a week using a spectrophotometer (Varian 50 Bio UV-visible spectrophotometer, USA).

Growth rates: Growth is expressed as weight gain, relative growth rate, specific growth rate, and condition factor:

Daily weight gain (DWG) = (W2 - W1) / T

Specific growth rate (SGR) = (Ln W2 - Ln W1) / T × 100

Relative growth rate (RGR) = [(W2 - W1) / T] × 100, where: W1 = initial weight of fish in grams and W2 = final weight of fish in grams, and T = period of time

Condition factor value (K) = $(W / L^3) \times 100$, where: W = weight of fish in grams L = length of fish in centimeters

The survival rate was measured after the end of the experiment:

Survival rate (SR) (%) = (number of fry caught / number of fry stocked) × 100

Economic analysis: An economic analysis was done to calculate fingerling production's economic costs and efficiency. The profit, the total return on total variable costs (operating costs), and the total fry cost were analyzed. Variable costs include the cost of larvae, fertilizers, and feed needed for development. The gross profit margin was measured based on the current market price, and the gross yield was calculated based on the products sold. Gross profit margin, variable costs, and total revenue were calculated using the following formulas:

Investment Cost Analysis (ICA) = Cost of feeding (ID) + the cost of keeping fry (ID), all in Iraqi dinars (ID).

Net Production Value (NPV) = Average fish weight gain (g) × Overall survival rate (n) × Cost per piece (ID).

Gross Profit (GP) = NPV – ICA

Benefit-Cost Ratio (BCR) = Total Sales / Total Expenses

Margin (%) = (Selling Price - Cost) / Selling Price × 100.

Statistical analysis: All experimental data are presented as an average ± standard deviation. Statistical analysis was performed using the Student's t-test; the effect was considered significant at $P<0.05$. The total body weight, length, timing, and nature of development in different age groups were subjected to statistical testing. One-way ANOVA and Duncan's multiple range tests were used to obtain significant differences using the statistical analysis software (SAS) package.

Before starting the experiment, and to monitor the accuracy and nature of the larval production process and their development during the hatching, incubation, and development period, the production process was directly observed inside the hatchery itself for 14 days, which is the period of integration of body development and larval growth.

Results

The growing of the hatched larva to 15-day-old fry occurred in the nursery. In the hatchery, the exogenous feeding of larvae and subsequent stages of development began when the first planktonic rotifer cells appeared in the intestinal tube. The intestine began to function at the age of 6 days after hatching when endogenous nutrition ended. At that time, the range of nutrition was very limited, consisting of only two phytoplankton species - *Diatoma* spp. Later, the spectrum expanded to include a certain amount of phytoplankton, represented by some species of diatoms. Within 1-2 days following the first exogenous feeding, the spectrum became wider and contained more zooplankton elements – *Keratella* spp., with the predominance of the genus *Brachionus* from rotifers and diatoms. The size of the cells became larger, and on the 8th to 9th day of life, some species of Cladocera - *Daphnia* nauplii could be distinguished. At the same time, the natural food became wider and contained *Daphnia* spp.; *Keratella* spp.; *Lecana* sp.; *Polyarthra* spp., and many others. Here, the larvae switched from mixed (allogeneic) to exclusively exogenous nutrition, which actively continued as the larvae developed and subsequent stages in age and size. Diatoms predominated after the 10th day and beyond, with few green algae present. *Brachionus plicatilis* was dominant among zooplankton. After this, we accepted the material for further growth and the subject of our research.

Important parameters of water quality were measured in all ponds. During the growing phase, the water temperature varied from 23 to 31°C, and the pH from 6.5 to 9.5. The dissolved oxygen content was generally acceptable for common carp, ranging from 5.7 to 8.8 mg/L. The level of free carbon dioxide was close to zero throughout the study. The content of non-ionized ammonia ranged from 0.122 to 0.210 mg NH_3-N/L. The average values of water quality parameters measured during the fry rearing are shown in Table 1. Throughout the entire study period and in all stocking density variants, they remained within an acceptable range for pond fish farming (Garg and Bhatnagar, 1999; Boyd and Tucker, 2014). Although the water

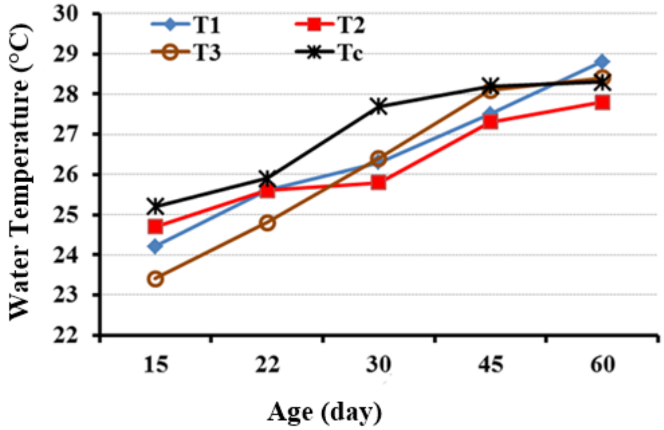

Figure 1. Average water temperature in ponds.

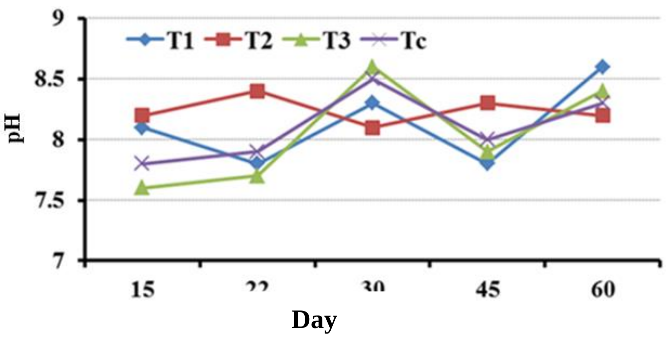

Figure 2. Average pH value of pond water.

temperature tended to increase towards the end of the observation period (Fig. 1), it remained within the acceptable and optimal ranges. Noticeable fluctuations were observed in pH and NH_3-N (Fig. 2, 3), but still within permissible limits. The parameters remained within the limits ensuring good carp growth rates (Billard, 1995).

The average values of the total length and weight of fingerlings in accordance with the stocking density strategy in groups T1, T2, T3, and control T0 are presented in Tables 2 and 3. As follows from the results of the experiment on survival and final weight of grown fingerlings (Table 2), the best results were obtained at the level of treatments and ponds in the T2, where the stocking density was 300,000/2000 m^2 of larvae growing on the pond, and the final survival rate was 84.91%. The final weight in the T2 turned out to be the highest (8.23 g), while the minimum was in the T3 and, of course, the T0 control, with 7 and 4.62 grams, respectively, where the maximum stocking density was 400,000/2000 and 300,000 /2000 m^2 of larvae. In the T3, where the highest stocking density was 2 million/ha, the fry growth was noticeably delayed in the first 30 days and slightly by the age of 45. However, it almost caught up with the T1 weight over the last 15 days, despite the high relative stocking density at the end of the experiment in T3, which was more than twice as high as that obtained in T1 (Fig. 4). The control sample (300,000/2000 m^2 of larvae, without feed) almost lagged all, and this is expected since it was without additional feed. Fry in the T2 showed the greatest increase in weight (8.23±0.27 g), where the density of stocking after harvest (calculated per hectare) was 1.5 ml of individuals/ha compared with T1 and T3 treatments, not to speak of the control. At the same time, DWG (g/day) and SGR (%/day) of fingerlings in the treatment groups significantly differed (P<0.05). The SGR in T2 was noticeably higher (P<0.05) than in T3 and T1.

Day

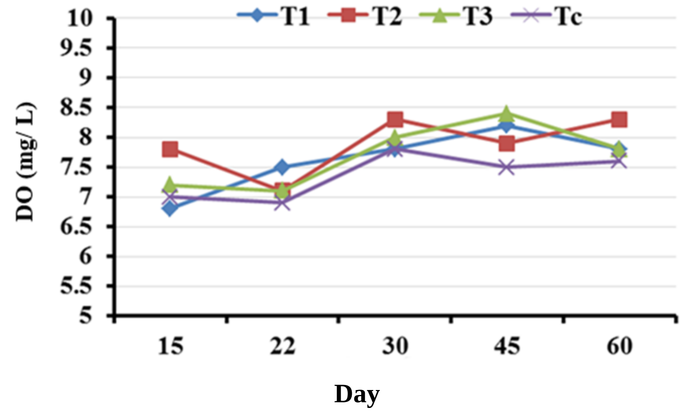

Figure 3. Dissolved oxygen mg/L in the studied ponds.

The survival rate of the control option (T0) was low (44.85%) due to the lack of additional feed and dependence on the natural food supply, which led to a similar result. The average weight obtained from the control was noticeably lower than in other treatments (4.62 g), and the weight range was relatively wide (3.22-9.5 g). Taken together, this makes it less preferable compared to other options.

A comparison of body weight at three stocking densities for 60 days showed that in the first 2 weeks, the average body weight at the three stocking densities did not differ significantly. During the third and fifth

Table 2. Mean ± SE of growth and food intake of fingerlings reared at different stocking densities for 12 weeks in earthen fish ponds. Mean values with different superscripts within a row differ significantly (P<0.05).

Parameters	Stocking density (fish га$^{-1}$)			
	T1- 200000/ 2000 m^2 (1 million/ha)	T2- 300000/ 2000 m^2 (1.5 million/ha)	T3- 400000/ 2000 m^2 (2 million/ha)	Tк- 300000/ 2000 m^2 (1.5 million/ha)
Initial weight (g)	0.26±0.001	0.22±0.002^{b}	0.24±0.001^{ab}	0. 24±0.004^{ab}
Final weight (g)	7.70±0.13^{b}	8.23±0.12^{a}	7.0±0.14^{ab}	4.62±0.19^{b}
Weight gain (g)	7.44±0.08^{b}	8.01±0.27^{b}	6.76±0.35^{a}	4.38±0.43^{b}
DWG (g day^{-1})	0.165±0.06^{a}	0.18±0.44^{a}	0.150±0.16^{a}	0.097±0.07^{b}
SGR (% day^{-1})	7.71±0.13^{a}	8.08±0.32^{b}	7.32±0.04^{b}	6.57±0.01^{a}
FCR	1.62±0.01^{b}	1.96±0.01^{a}	2.36±0.02^{c}	-
Survival rate (%)	78.4 ±0.47^{a}	84.9 ±0.33^{a}	68.84±0.25^{b}	44.85±0.35^{c}

Table 3. The results of the experiment fry production (calculation of stocking density is calculated on bases of 1, 1.5, and 2 mil, advanced larvae per hectare), Average body weight of fry (g) depending on stocking density and (age). Different small letters denote significant differences among the treatments (T1, T2, T3, T4, etc.). Different capital letters denote significant differences among the sampling periods (age [day])

Parameters		15 days old larvae (First day of stocking)	Sampling periods (age [day])				
			7 (22)® On a natural food base	15 (30) Starter compound feed	30 (45) Starter compound feed	45 (60) Starter compound feed	Final survival rate in numbers and/ %
Stocking density, 15 day old larvae / 2000m^2	T1 200000	0.26±0.09^{a} E	1.16±0.17^{a} (0.9) D	2.16±0.18^{a} (1.00) C	4.53±0.93^{a} (2.37) B	7.7±0.13^{ab} (2.47) A 4.33-9.17	156800±26.5^{c} 78.4%
	T2 300000	0.22±0.04^{a} E	0.95±0.23^{ab} (0.73) D	2.7±0.29^{a} (1.75) C	4.94±0.85^{a} (2.24) B	8.32±0.40^{a} (3.38)^{a} 6.27-8.68 A	254730±22.3^{b} 84.91%
	T3 400000	0.24±0.05^{a} D	0.73±0.17^{b} (0.49) C	1.41±0.45^{b} (0.68) C`	4.11±0.52^{a} (2.70) B	7.0±0.42^{b} (3.59) A 4.46-7.87	275360±27.3^{b} 68.84%
	Tcp 900000	0.24±0.01^{a} 0.18-0.57 E	0.95±0.02^{ab} 0.68-1.37 D	2.18±0.04^{ab} 1.53-4.17^{C}	4.54±0.41^{a} 3.17-6.45 B	7.48±0.17^{ab} 4.33-9.17 A	673380±30.2^{a} 74.82%
	T0 300000	0.24±0.05^{aB}	0.68±0.2^{b} (0.44)^{C}	1.17±0.25^{b} (0.49) C	2.85±0.63^{b} (1.68)^{B}	4.62±0.12^{c} (1.77) 3.22–9.5 A	134550±27.6^{c} 44.85%

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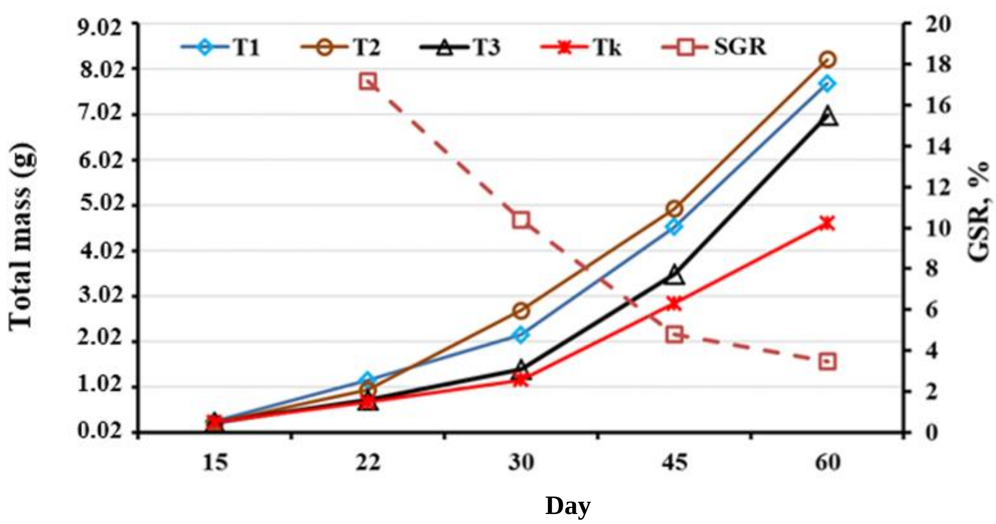

Figure 4. Growth curves of carp fry grown at 8-week maintenance.

weeks, the average body weight values at stockings of 200,000 and 400,000 larvae/2000 m^2 differed slightly, but that of 300,000 showed a significantly higher value than the others (Table 3, Fig. 4).

Table 4. Averaged parameters of the increase in length (cm) and weight (g) of fingerlings of common carp (T1 – T3), recorded at different time intervals during the 60 days of the cultivation period. Different Small letters denote significant differences among the treatments (T1, T2, T3, T4, etc.). Different capital letters denote significant differences among the sampling periods (age [day]).

Parameters	15 days old larvae (First day of stocking)	Sampling periods (age), days			
		7 (22)	15 (30)	30 (45)	45 (60)
Total length (cm)	2.16±0.14^{e}	3.08±0.22^{d}	4.21±0.01^{c}	5.62±0.06^{b}	6.74±0.12^{a}
	1.57 - 3.17	2.11-4.36	3.92-5.26	4.28-6.35	
Weight (g)	0.24±0.01^{e}	0.95±0.02^{d}	2.18±0.04^{c}	4.46±0.41^{b}	7.48±0.17^{a}
	0.18-0.57	0.68-1.37	1.53-4.17	3.17-6.45	5.72-8.16
					4.33-9.17
Increase in length (cm)	-	0.92±0.06^{c}	1.13±0.35^{b}	1.41±0.24^{a}	1.12±0.14^{b}
Weight gain (g)	-	0.71±0.03^{c}	1.41±0.15^{b}	2.1±0.22^{ab}	2.79±0.35^{a}
Daily weight gain (g)	-	0.101±0.01^{b}	0.176±0.02^{a}	0.140±0.02^{a}	0.186±0.025^{a}
Condition factor	2.28	3.22	3.15	2.51	2.4
Specific growth rate (SGR) %/Day		17.19	10.38	4.77	3.45/ 11.46
Relative growth rate (RGR) = [(W2-W1)/T] × 100		10.14±1.24^{c}	17.62±1.79^{a}	14.00±1.5^{b}	18.6 ±1.24^{a}
Mean ind. increase in length (cm)		4.58±0.37			
mean ind. weight gain (g)		7.01±0.52			

From the point of view of gradual weight gain, at most stages of sampling, none of them differed significantly from each other, except for the superiority of T2, which showed a significant difference from the rest. T2 was significantly (*P*<0.05) higher than the rest in the last and previous samples (age 60 and 30 days), despite the superiority of T2 in the final sample with a final weight that was significantly (*P*<0.05) higher than in T1 and T3 (8.32, 7.7, and 7 g, respectively). As for the growth trend, about 2 weeks after stocking, there was a tendency for weight differences between the treatments. A higher weight gain at T2 was observed at the 2nd test. However, after about a month, there was a noticeable growth increase (the last sampling stage, Table 3, Fig. 4). Thus, the effect of stocking density on total body weight was significant (*P*<0.05) (Table 2).

The results showed that the specific growth rates (SGR) of carp fry in T1, T2, T3, and in control were 7.32±0.13, 8.08±0.32, 7.71±0.04, and 6.57±0.01%, respectively (Table 2). There was no significant difference (*P*>0.05) in the SGR between T2 and T3, but a significant difference was observed between them and T1. The control differed significantly (*P*<0.05) from all treatments concerning SGR.

Since the fry were selected at different intervals of weight gain, the actual SGR at a certain point of growth was tracked. SGR shows a downward trend from the study's beginning to the experiment's end (Table 4). The SGR has been shown to decrease gradually. After that, at the last stage of sampling, the lowest SGR value was observed (Fig. 4). More specifically, significantly higher specific growth rates were observed at the first stage of cultivation.

The T2 was characterized on average by two important indicators, namely the survival rate and the feed conversion, which recorded relatively high values, positive (84.91±0.33%) and negative (1.96±0.01), respectively, from the point of view of economic efficiency. The lowest survival rate was in the T3 treatment, which differed from the rest of the treatments by a significant difference (*P*<0.05). The average food conversion index in T1 and T3 was the lowest and highest – 1.62 and 2.36 (Table 2). The daily weight gain (DWG) of fingerlings tended to increase significantly when grown from 1 to 1.5 million/ha and remained relatively high at a density of 2 million/ha (Table 2).

Economic analysis: In aquaculture, feed, with its role in feeding and growth and its impact on production costs, has received and continues to receive special attention in the sector. Thus, it is necessary to supplement our previous techno-biological results with an economic analysis.

Table 5. The results of the most of the economic indicators of growing carp fingerlings

Item	T1	T2	T3	Total T1 – T3
Variable cost:				
Price of fry (approx. 0.5 ID/ fry)	100000	150000	200000	550000
FCR	1.62	1.76	2.36	1.65
Mean final fingerling weight (g)	7.7	8.32	7	7.48
Mean Weight gain of fish (g)	7.44	8.01	6.76	
Consumed feed	1858	3543	4321	9318
Feed (ID 1250/ kg) (% of TC)	2322500 (70.2%)	4428600 (85.3%)	5401250 (81.2%)	11647500
Pond preparation + services	450000	450000	450000	1350000
Miscellaneous (5% var. cost)	136875	232937	302562	639963
Total variable cost (TVC) (ID)	3009375	4891687	6353812	13077919
Fixed cost (Pond rental value) (ID)	300000	300000	300000	450000
Total cost (TC) (ID)	3309375	5191687	6653812	13527919
Production:				
Total survival (wt. 7-9 g)	156800	254730	275360	637375
Marketable fing. (95% of survivors)*	148960	241994	261592	605506
Fish product (wholesale, kg)	1147	2013	1927	4453
Selling as fing. (25 ID/fing.)**	3724000	6049850	6539800	15137675
Gross margin = (Revenue - Cost of goods sold/ Revenue) × 100)	15.16 %	16.66%	0.02%	10.63%
Profit Index = Total value of fish ID / Cost of feeding type	1.6	1.37	1.21	
Benefit Cost Ratio (BCR) = Total sales/ Total cost	1.18	1.2	1.00	

* The number of fingerlings, less than the weight of the sale (< 5 grams), was estimated by the special commission at 5%, which was excluded from the number of survivors. ** Official pricing of fingerlings for the year 2023-2024.

The financial indicators of this experiment are summarized in Table 5. While fixed costs (pond rentals) remained the same, variable costs increased significantly ($P<0.05$) with increasing stocking density. The total cost differed significantly between the three options ($P<0.05$) due to the additional costs incurred during the purchase and use of additional compound feeds. Contrary to expectations, the net profit as a percentage of fingerling sales in the T1, T2, and T3 was 15.16, 16.66, and 0.02%, respectively (Table 5).

The results also showed that total expenses and gross income from T1 and T2 did not differ significantly ($P>0.05$) from each other, but they differed significantly from T3. However, there was a significant difference ($P<0.05$) in the gross income and gross margin of fingerlings raised in ponds T1 and T2, with net profit margins of 15.16 and 16.66%, respectively, while fingerlings raised in pond T3 had the lowest profit margin, at 0.02%. Additionally, carp grown at a stocking density of 2 million/ha had the lowest profitability coefficient, at 1.21 ID/kg, whereas the stocking density of 1.5 million/ha was 1.37 ID/kg, and 1 million/ha had the highest ratio, at 1.6 ID/kg. Thus, the net profit in treatments T2 and T1 was positive, while the third option, T3, was not profitable despite fingerlings' relatively good mean individual weight. The results revealed that feed costs accounted for most of the total cost of raised fingerlings in all treatments. Specifically, feed costs accounted for 70.2, 85.3, and 81.2% of the total cost in treatments T1, T2, and T3, respectively.

For biomass production, fingerlings' growth parameters and profitability have shown that differences in stocking density positively affect pond productivity. An increase in average body weight of more than 5 g over two months is a prerequisite for rapid growth and profit in the ponds of fish farmers in the following months when carp can reach sizes suitable for commercial sale within one season.

Discussions

The reason for choosing a three-week age to start feeding common carp fry with artificial compound feeds in this experiment was based on several principles. Firstly, many researchers have found and established that the 21st-22nd day after hatching marks the end of the second critical stage of development (Dabrowski, 1984). At this age, the formation of the digestive system is anatomically and physiologically fully integrated. Although some researchers claim that carp larvae begin to feed on phytoplankton even before the yolk sac is absorbed, this has been observed in some species of cyprinid fish (Ali and Jawad, 2012; Ahmad et al., 2016). The second reason for this choice was our observations in the hatchery, where we monitored the development of larvae, the completion of the formation of their organic organs, and the transition through critical stages of morphological and physiological development of advanced larvae. By this stage, the larvae had become capable of capturing and digesting relatively large zooplankton cells, similar in size to feed granules.

The development of fish larvae in the first days of life is the most critical phase in aquaculture production when the highest mortality rates can reach more than 75% (Vadstein et al., 2018). The weak development of the larval digestive system and the small size of the oral slit limit the use of inert feeds at these initial stages, making it necessary to use live feeds. In the aquaculture production chain, larval rearing is the most important and critical stage of captive rearing (Abe et al., 2019). Fish in the post-larval stage have a developing gastrointestinal tract in the form of a short intestine (Portella and Dabrowski, 2008; Ali and Jawad, 2012; Hamad et al., 2016), and therefore they do not digest inert food sufficiently (Pedreir et al., 2008; Diemer et al., 2012). Thus, using living organisms for feeding post-larval fish has been recommended for several species, especially marine ones, since it increases survival and growth rates compared to inert diets (Schütz, 2003; Diemer et al., 2012). However, the use of living organisms as feed, as a rule, makes cultivating larvae the most expensive stage of fish farming. This is due to the necessary continuous production and the high cost of such organisms (Kodama et al., 2011; Sanchez et al., 2013). This prompted us to replace them with precious live feeds for a certain time to grow the larva on the enriched, necessary fertilizer, natural feed base of ponds, which led to a tripling of weight growth in 7 days.

A study of our fingerling production methodology conducted within the framework of the "production of high-quality fingerlings" project showed that the production technology of the Iraqi Central fish hatchery is currently characterized by overloaded nursery ponds, which contradicts the recommendations of FAO and the former fisheries research center. This leads to a reduction in the weight of the fingerlings, which is much below the planned weight of 5 g, and a wide range of individual weights of the fingerlings. In addition, repeated catches and sorting leads to the disorder of fingerlings and increases stress, leading to the death and deformation of many of them. Low survival, slow growth, low biomass production, unnecessary losses of fry and fertilizer resources, and low profitability are the inevitable results of the nursery management system used here. This, in turn, leads to the reluctance of the private sector to buy fry produced in the hatchery of the state, which leads to significant losses.

The values of water quality parameters during these experiments fell within the range previously established as acceptable for carp cultivation (Boyd, 1982; Motta et al., 2019). Our experiment's partially changing pond water twice a week effectively maintained water quality parameters within acceptable limits.

Many authors have pointed out that for many fish species, weight gain is dependent on stocking density, with an inverse relationship between stocking density and the individual size of the resulting fish (Ruane et al., 2002; Rahman et al., 2006; Enache et al., 2011; Yang et al., 2011; Oprea et al., 2015). Our results partially reflect this trend, although with a notable exception. While we expected higher individual weights and survival rates at lower stocking densities, our results showed that these parameters were highest at an intermediate stocking density, which was not significantly different from the lower density. This result can be attributed to the fact that the broodstock used for spawning was heterogeneous in terms of genetic and physiological characteristics and the potential for unexpected variations in environmental conditions.

Many studies have proven that the survival and production of fingerlings in ponds depend on stocking density, as well as the type and quality of fertilizers and additional feed (Chakraborty and Mirza, 2007; Ahmed et al., 2012, 2018; de las Heras et al., 2015; Oprea et al., 2015). We gave the feed at the rate of 6% of body weight during the entire growing period in accordance with the methodology of growing fingerlings in the state hatchery and many previous studies that recommend controlling this factor to reduce feed waste. It has been shown that the optimal feeding range is from 4 to 6% of body weight per day for common, Chinese, and Indian carp (Zhen-Yu et al., 2006; Ahmed, 2007; Desai and Singh, 2009; Ahmad, 2012; Khandan Barani et al., 2019).

The economic analysis revealed that T2 had the highest profitability, with a benefit-cost ratio (BCR) of 1.2, followed by T1 (BCR = 1.18) and T3 (BCR = 1.00). Economic efficiency is a context in which technical efficiency and efficiency in using material resources are combined (Battese and Coelli, 1995). A suitable method of growing carp fry is important to ensure a reliable and regular fry supply to the fish market. Stocking density, artificial food, types, and quality of fertilizers supplied to the earthen pond are the determining factors for the growth of fry and fingerlings. However, these requirements and components account for the largest percentage of production costs, and adjusting the calculation of each of them simplifies production management with a positive return suitable for the work performed and successful investments.

Thus, it can be concluded that the survival rate and production of commercial fish biomass, as well as the production of common carp from a grown larva in an incubator for 10-15 days to marketable weight, are directly related to stocking density and additional compound feed. In the stocking density of 1.5 million larvae per hectare from a grown larva, it can be recommended for growing in ponds under the conditions found in Middle Iraq.

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