



International Journal of Agriculture and Nutrition

ISSN Print: 2664-6064
 ISSN Online: 2664-6072
 NAAS Rating (2026): 4.69
 IJAN 2026; 8(8): 25-34
www.agriculturejournal.net
 Received: 12-05-2026
 Accepted: 17-06-2026

Mohamed F Al-Janabi
 Al-Musaib Technical College,
 Al-Furat Al-Awsat Technical
 University, Babylon, Iraq

Ali AA El-Hamadani
 Al-Musaib Technical College,
 Al-Furat Al-Awsat Technical
 University, Babylon, Iraq

Ali AR Al-Darwesh
 Department of Pathology and
 Poultry Diseases Faculty of
 Veterinary Medicine,
 University of Kufa, Al-Najaf
 Al-Ashraf, Iraq

Corresponding Author:
Mohamed F Al-Janabi
 Al-Musaib Technical College,
 Al-Furat Al-Awsat Technical
 University, Babylon, Iraq

Optimizing stocking density and dietary protein level for cage culture of common carp (*Cyprinus carpio* L.) in the Euphrates River, Babylon, Iraq

Mohamed F Al-Janabi, Ali AA El-Hamadani and Ali AR Al-Darwesh

DOI: <https://www.doi.org/10.33545/26646064.2026.v8.i8a.732>

Abstract

Cage culture in Iraqi rivers has expanded rapidly, yet stocking density and dietary crude protein (CP) content the two variables that most strongly govern biological performance and profitability are still chosen by convention rather than from evidence generated under local river conditions. A 120-day factorial experiment (1 April - 1 August 2025) evaluated three stocking densities (70, 90 and 120 fish m³) and two practical diets (16% and 25% CP), each in triplicate (18 cages of 18 m³), in the Euphrates River at Al-Hamiya (Al-Musaib district, Babylon Governorate, Iraq), using common carp of ~100 g initial weight. Water temperature ranged from 18.5 to 28.6 °C, dissolved oxygen from 7.75 to 8.15 mg L and pH from 7.4 to 7.9. Cumulative mortality did not exceed 1.9% in any treatment and ceased after the first month. Individual growth declined monotonically with density and improved with dietary protein: final weight was highest at 70 fish m³ on 25% CP (1043.5 g; SGR 1.95% day; FCR 2.26) and lowest at 120 fish m³ on 16% CP (861.5 g; SGR 1.79% day; FCR 2.36). Protein efficiency ratio ranked in reverse, being higher on the low-protein diet (2.52-2.58 vs 1.70-1.76), indicating more efficient protein use when protein was limiting. Net production per unit volume reversed this ranking, increasing with density, peaking at 96.06 kg m³ (1728.99 kg cage) at 120 fish m³ with 25% CP. Net income per cubic metre followed net production, rising from 152.12 to 230.40 thousand IQD m³. The optimum therefore depends on the production objective: 70 fish m³ with 25% CP maximises individual size and feed efficiency, whereas 120 fish m³ with 25% CP maximises volumetric yield and net income per cage under the price structure prevailing at the site.

Keywords: *Cyprinus carpio*, cage aquaculture, stocking density, dietary protein, feed conversion ratio

1. Introduction

Aquaculture is now the dominant source of aquatic animal food worldwide. FAO reports that aquaculture production of aquatic animals exceeded 100 million tonnes for the first time in 2024, reaching 103 million tonnes and accounting for 53% of the 195 million tonnes of aquatic animals produced globally, with capture fisheries supplying the remaining 47% [1]. Common carp (*Cyprinus carpio* L.) remains one of the most widely farmed freshwater species because of its tolerance of variable water quality, its efficient use of low-cost practical diets, and its established position in regional markets.

Aquaculture supplies 53% of world aquatic animal production [1] and close to 95% of Iraq's, almost all of it common carp (*Cyprinus carpio* L.) in ponds and floating cages; water scarcity, water quality, feed supply and hatchery capacity constrain the sector [2, 3]. Cage culture has expanded fastest. Salman *et al.* [4] put practice at 60-70 fish m³, roughly two thousand 100 g fingerlings per cage — convention, not an experimentally derived optimum.

Density pulls two ways, since what suits the individual fish does not suit output per cubic metre. Crowding depresses growth and feed conversion through competition, stress and local water-quality decline. Tripling density cost Ramteke *et al.* [5] about a third of the final weight of cage-reared Amur carp, plus survival and feed efficiency; their densest cages held the most biomass yet the poorest benefit-cost ratio. Li *et al.* [6] found the same in gibel carp at 0.30 against 0.15 kg m³, with a return on investment of 5.75% against 15.98%. Debnath [7] placed the largest standing crop at an intermediate density over 20-80 fish m³, and Aura *et al.* [8] treat density as a quantity to optimise rather than raise.

That verdict is not universal: Kebtieneh *et al.* [9] found the densest Nile tilapia treatment the most profitable per hectare. The outcomes differ in what is scarce. Where feed and fingerlings dominate cost, as on Volta Lake [10] and Lake Victoria [11], efficiency per fish decides; where the cage is the fixed asset, output per unit volume does.

Dietary protein behaves the same way: growth rises to a plateau shifting with species and size, while protein efficiency ratio (PER) falls once protein exceeds requirement [12, 13]. Protein makes feed expensive, hence the search for alternatives — insect meals [14], plant and microbial proteins [15], algae [16]. Yet the published optima come from fingerlings in tanks: 33.99–35.26% crude protein for 51.6 g Yellow River carp [13].

A cage in a flowing river is neither pond nor recirculating tank. The current exports the metabolic load — Komba *et al.* [17] document the enrichment that follows — and Shamsuddin *et al.* [18] could not separate riverine tilapia cage sites statistically on water quality over 120 days. Euphrates cages face steep spring-to-summer warming and hold ~100 g fingerlings for a market pricing by size as well as weight. This study therefore quantified the effects of stocking density (70, 90 and 120 fish m³) and dietary crude protein (16% and 25%) on growth, feed utilisation, survival, net production, muscle composition and economics, separating the biological from the financial optimum.

2. Materials and methods

2.1. Study site

The experiment was conducted from 1 April to 1 August 2025 (120 days) in floating cages on the Euphrates River at Al-Hamiya, Al-Musayyib district, north-west of Babylon Governorate, Iraq, approximately 40 km from the governorate centre at Al-Hillah. The experiment was laid out as a colony of 18 cages. The trial period covers the seasonal warming of the river from spring to mid-summer.

2.2. Cage system

Each cage had a frame of square-section steel tube (2 in, 2 mm wall) measuring 3 m × 3 m × 2.5 m, of which 2 m was submerged; the upper 0.5 m carried the attachment of the inner net. The working volume of each cage was therefore 18 m³ (3 m × 3 m × 2 m submerged), and stocking densities and production are expressed on that basis. The battery was linked to the bank by four ribbed-steel bridges (3 in) 6 m long and 0.80 m wide, and service walkways 0.70 m wide decked with 1.5 in timber ran alongside each cage. Flotation was provided by compressed-cork floats (25 bar) in two lengths, 270 cm and 130 cm, each 0.50 m wide and 0.33 m high, sheathed in canvas against abrasion and current and lashed beneath the walkways. A 1.5 m perimeter fence enclosed the battery.

Two nets were used per cage. The outer protective net was plastic-coated BRC steel mesh of 3 cm aperture, fixed to the frame and removable only by lifting the cage. The inner retaining net was knotless nylon of Thai manufacture with a 2 cm aperture, mounted so that it could be raised and worked to crowd fish into one corner for sampling, treatment, grading or harvest. Two mechanical feeders of 40 kg capacity each were mounted on steel posts on the inner fence of every cage.

2.3. Experimental design and fish

A 3 × 2 factorial arrangement was used in a completely randomised design, combining three stocking densities (70,

90 and 120 fish m³) with two practical diets differing in crude protein content (16% and 25% CP), giving six treatment combinations. Each combination was assigned to three replicate cages (n = 3), so that the experiment occupied a colony of 18 cages. The cage — not the individual fish — was the experimental unit, since both diet and density were applied at the cage level; every value reported below is a cage-level mean, and all means and standard deviations are over the three replicate cages.

A total of 30 240 common carp (*Cyprinus carpio* L.) of about 100 g mean weight were obtained from a hatchery in Al-Mahaweel district, Babylon, and transported to the site. On arrival the fish were bathed in potassium permanganate at 25 g per 100 L of water for 30 s to remove ectoparasites and other pathogens, then distributed among the 18 cages. At the three densities and a working volume of 18 m³, the cages held 1260, 1620 and 2160 fish respectively, i.e. 3780, 4860 and 6480 fish per density treatment across its three replicate cages. Initial mean weight was standardised at approximately 100 g and did not differ significantly among treatments at stocking (Table 5).

2.4. Experimental diets

A preliminary survey of fish-farming enterprises in Babylon Governorate indicated that the great majority use feeds formulated for pond culture containing 16–18% crude protein, and that adopting commercial diets meeting the reported requirement of common carp (34–38% CP) exposes the enterprise to economic risk, because raw-material prices are high while farm-gate fish prices fluctuate and often fall. The two diets tested were chosen to represent this decision directly: Diet 1 is the formulation in prevailing local use (16% CP) and Diet 2 a higher-protein alternative (25% CP). Ingredient composition is given in Table 1 and analysed proximate composition in Table 2.

Both diets were manufactured as pellets of 3–5 mm diameter at the Al-Mukhtar feed mill, Al-Iskandariya district. Fish were fed by hand-charged mechanical feeder four times daily (07:00, 11:00, 15:00 and 19:00 h) at 5–6% of body weight per day. Rations were recalculated for each cage from that cage's own biomass after every fortnightly biometry, so feeding intensity was maintained independently in each replicate, and the feeders were adjusted at each visit to avoid feed loss. Ration size was set as a fixed percentage of biomass rather than optimised against a growth model [19].

Gross energy was calculated as: crude protein (%) × 5.56 + carbohydrate (%) × 4.45 + crude lipid (%) × 9.2 [20].

2.5. Water quality

Physicochemical variables were measured at the cage site once weekly, all readings being taken between 09:00 and 11:00 h on each sampling day. Water temperature and dissolved oxygen were measured with a digital meter (Martin, Romania), the probe being lowered to depths between 30 and 200 cm within the cage and the readings averaged. pH was measured with a digital pH meter (Hanna, Italy), verified on each reading day against pH 4, 7 and 9 standard buffers. Salinity was derived from a digital EC meter (Hanna, Italy) as salinity (g L⁻¹) = (EC reading × 0.64) / 1000. Transparency was measured with a 25 cm black-and-white Secchi disc on a graduated tape, taking the mean of the depth of disappearance and the depth of reappearance with the sun behind the observer. Current velocity was measured with a current meter (Tokyotodentant, Japan)

and recorded in cm s^{-1} . Total ammonia nitrogen, nitrite and nitrate were not monitored.

2.6. Sampling and performance indices

Fish were sampled at 15-day intervals on eight occasions (15 April, 1 May, 15 May, 1 June, 15 June, 1 July, 15 July and 1 August). Fish were not fed before weighing, so that gut content would not inflate the recorded weight; each sample was weighed three times and the mean of the three weighings taken. Rations for the following fortnight were then recalculated from the new cage biomass and the prevailing water temperature. Cages were inspected at each visit for disease and for feeder performance.

The following indices were calculated per cage, where W is mean body weight (g), N is fish number, t is duration in days, F is total feed offered (g) and CP is the analysed dietary crude protein fraction:

Total weight gain, $\text{WG (g)} = W_f - W_i$

Daily growth rate, $\text{DGR (g fish day)} = (W_f - W_i) / t$

Relative growth rate, $\text{RGR (\%)} = 100 \times (W_f - W_i) / W_i$

Specific growth rate, $\text{SGR (\% day)} = 100 \times (\ln W_f - \ln W_i) / t$

Feed conversion ratio, $\text{FCR} = F / [(N_f \times W_f) - (N_i \times W_i)]$

Feed conversion efficiency, $\text{FCE (\%)} = 100 / \text{FCR}$

Protein efficiency ratio, $\text{PER} = [(N_f \times W_f) - (N_i \times W_i)] / (F \times \text{CP})$

Survival rate, $\text{SR (\%)} = 100 \times N_f / N_i$

Net production (kg cage) = $[(N_f \times W_f) - (N_i \times W_i)] / 1000$

Net production (kg m^3) = net production per cage / cage working volume

Specific growth rate is computed on the natural-logarithm basis, which is the convention in the aquaculture nutrition literature and is required for comparison with published values. Reporting of the experimental unit, the feed basis used for FCR and the analysed composition of each diet follows the recommendations of Turchini and Hardy [21] for applied feeding trials.

2.7. Chemical analysis

Samples of the edible portion (muscle) were taken at the start and at the end of the trial. Diets were sampled for moisture, crude protein, crude lipid, crude fibre and ash. All determinations followed AOAC [22] standard procedures. Dry matter was determined by drying in an electric oven at 105°C to constant weight. Crude protein was determined by the micro-Kjeldahl method, total nitrogen being multiplied by 6.25. Crude lipid was determined in a Soxhlet apparatus with petroleum ether over 16 h, the solvent then evaporated at 105°C for 30 min and the flask reweighed after cooling. Crude fibre was determined by successive digestion in 1.25% H_2SO_4 and 1.25% NaOH for 30 min each, the undigested residue being taken as crude fibre. Ash was determined by ignition in a muffle furnace at 600°C for 6 h to constant weight.

2.8. Economic analysis

Costs per cubic metre of cage volume were compiled for each treatment from fingerling purchase, feed, labour, veterinary treatments, transport and depreciation of the cage structures. Gross revenue was calculated from net production and the farm-gate price obtained for each treatment, and net income by difference. All monetary values are in Iraqi dinars (IQD) at 2025 prices.

2.9. Statistical analysis

Data were analysed as a completely randomised design (CRD) using the Statistical Analysis System (SAS) [23]. Treatment means were separated by Duncan's multiple range test [24] at $P \leq 0.05$. The experimental unit was the cage and the number of replicates was three per treatment ($n = 3$), giving 12 error degrees of freedom for the six-treatment comparison. Results are presented as mean $\pm$ Standard deviation of the three replicate cages; means within a row bearing different superscript letters differ significantly at $P \leq 0.05$.

Table 1: Ingredient composition of the two experimental diets (% of formulation)

Ingredient	Diet 1 (16% CP)	Diet 2 (25% CP)
Fish protein concentrate	5	10
Soybean meal	10	30
Barley	20	20
Wheat bran	20	10
Rice polish (sahala)	20	20
Wheat flour	25	10
Total	100	100

Both diets were pelleted at 3-5 mm diameter.

Table 2: Analysed proximate composition and calculated gross energy of the two experimental diets

Component	Diet 1 (16% CP)	Diet 2 (25% CP)
Moisture (%)	4.36	4.38
Ash (%)	4.81	4.80
Crude lipid (%)	7.20	7.10
Crude protein (%)	16.73	25.16
Crude fibre (%)	7.44	7.41
Carbohydrate (%)	59.46	51.15
Gross energy ($\text{kcal } 100 \text{ g}^{-1}$)	423.855	432.827

Analysed by AOAC [22] procedures. Gross energy calculated as crude protein $\times 5.56$ + carbohydrate $\times 4.45$ + crude lipid $\times 9.2$ [20]. The two diets differ in gross energy by 2.1%, i.e. they are near-isoenergetic, while crude protein differs by 50.4% in relative terms.

3. Results

3.1. Water quality

Monthly water quality is summarised in Table 3. Temperature rose from 18.5 ± 0.08 °C in April to 28.55 ± 1.80 °C in July. pH varied narrowly, between 7.4 and 7.9.

Salinity ranged from 0.323 to 0.333 g L and dissolved oxygen from 7.75 to 8.15 mg L. Secchi transparency was highest in April (70 ± 0.90 cm) and lowest in May (51 ± 1.31 cm).

Table 3: Physicochemical characteristics of Euphrates River water at the cage site, Al-Hamiya, April-July 2025 (mean $\pm$ SD)

Month	Temperature (°C)	pH	Salinity (g L ⁻¹)	Dissolved oxygen (mg L ⁻¹)	Transparency (cm)
April	18.50 ± 0.08	7.8 ± 0.08	0.326 ± 0.008	8.15 ± 0.21	70.0 ± 0.90
May	24.40 ± 0.60	7.4 ± 0.00	0.323 ± 0.050	7.85 ± 0.07	51.0 ± 1.31
June	28.50 ± 0.90	7.7 ± 0.05	0.331 ± 0.010	7.90 ± 0.00	53.5 ± 2.13
July	28.55 ± 1.80	7.9 ± 0.00	0.333 ± 0.010	7.75 ± 0.07	53.5 ± 7.71

Values are monthly means $\pm$ standard deviation.

3.2. Survival

Mortality was low and confined to the first two fortnightly periods (Figure 1, Table 4). On the 16% CP diet it was 0.35%, 0.79% and 1.24% at 70, 90 and 120 fish m³ in the first period, and 0.48%, 0.38% and 0.68% in the second. The corresponding values on the 25% CP diet were 0.57%, 0.62% and 1.17%, then 0.70%, 0.51% and 0.57%. Nothing

died in any treatment after 1 May. Cumulative survival ranged from 98.08% at 120 fish m³ on the 16% CP diet to 99.17% at 70 fish m³ on the same diet, and in both diets the highest cumulative mortality fell at the highest density (1.92% and 1.74% at 120 fish m³). In every treatment the peak came in the first fortnight after stocking.

Table 4: Period-wise mortality and cumulative survival of common carp reared in Euphrates River cages at three stocking densities and two dietary protein levels

Treatment	Mortality, 1-15 Apr (%)	Mortality, 15 Apr-1 May (%)	Cumulative mortality (%)	Survival (%)
D70/P16	0.35	0.48	0.83	99.17
D70/P25	0.57	0.70	1.27	98.73
D90/P16	0.79	0.38	1.17	98.83
D90/P25	0.62	0.51	1.13	98.87
D120/P16	1.24	0.68	1.92	98.08
D120/P25	1.17	0.57	1.74	98.26

D = stocking density (fish m⁻³); P = dietary crude protein (%). Values are means of three replicate cages (n = 3). No mortality was recorded after 1 May in any treatment.

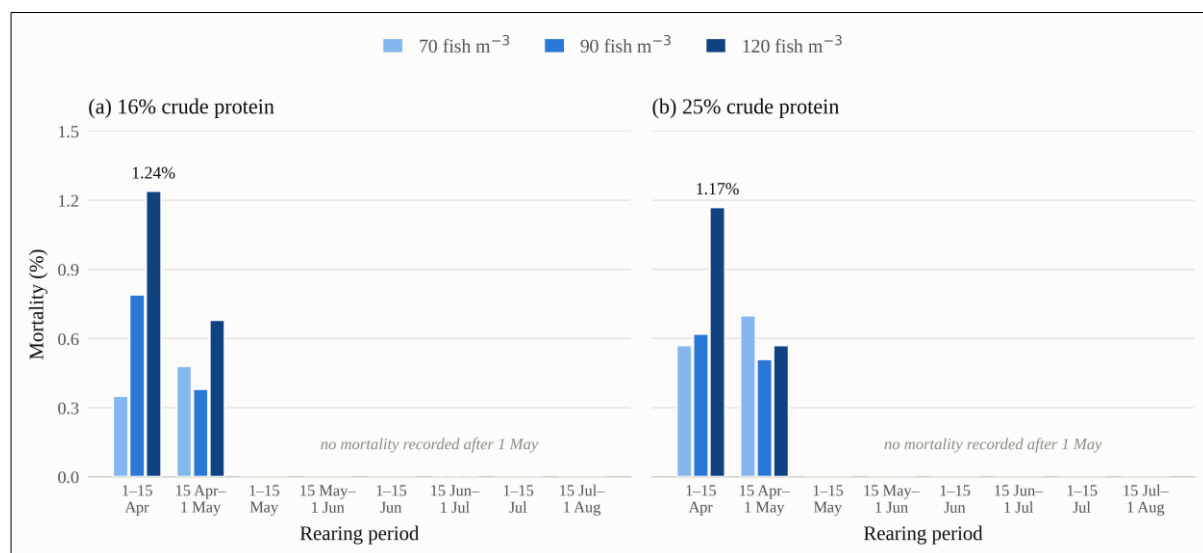


Fig 1: Period mortality of common carp reared in Euphrates River cages at three stocking densities on (a) a 16% crude protein diet and (b) a 25% crude protein diet. Bars are means of three replicate cages. Mortality occurred only in the first two fortnightly periods; no mortality was recorded in any treatment after 1 May. The highest mortality in both diets occurred at 120 fish m³ during the first fortnight after stocking, consistent with acclimation stress rather than a density effect operating throughout the trial.

3.3. Growth performance and feed utilisation

Initial mean weight did not differ among treatments ($P > 0.05$), averaging 100.2-100.3 g (Table 5). Every growth criterion differed significantly at harvest ($P \leq 0.05$). Final mean weight was highest at 70 fish m³ on the 25% CP diet (1043.5 ± 0.71 g), then 90 fish m³ on the same diet

(993.5 ± 13.43 g). The 70 fish m³ / 16% CP combination (953.5 ± 14.85 g) did not differ from 90 fish m³ / 16% CP (924.0 ± 7.07 g). Lowest was 120 fish m³ on the 16% CP diet (861.5 ± 10.61 g). Total and daily weight gain and relative growth rate all followed the same ordering.

Specific growth rate ranged from 1.79% day⁻¹ (120 fish m⁻³, 16% CP) to 1.95% day⁻¹ (70 fish m⁻³, 25% CP), the latter being significantly superior to all other treatments. Feed conversion ratio was best at 70 fish m⁻³ with 25% CP (2.26±0.01), which differed significantly from all other combinations; FCR at 70/16, 90/25 and 120/25 did not differ from one another (2.31), while the poorest values occurred at 90 and 120 fish m⁻³ on the 16% CP diet (2.355 and 2.36). Feed conversion efficiency mirrored this pattern exactly, ranging from 42.3% to 44.2%.

Protein efficiency ratio ranked the treatments in reverse. All three densities on the 16% CP diet (2.523-2.579) were significantly superior to all three on the 25% CP diet (1.703-1.756), with no significant difference among densities within a diet. Net production per cage and per cubic metre also reversed the individual-growth ranking, rising consistently with stocking density: from 1067.04 kg cage (59.28 kg m⁻³) at 70 fish m⁻³ on the 16% CP diet to 1728.99 kg cage (96.06 kg m⁻³) at 120 fish m⁻³ on the 25% CP diet. Every treatment differed significantly from every other.

Table 5: Growth, feed utilisation and net production of common carp reared for 120 days in Euphrates River cages at three stocking densities and two dietary protein levels (mean ± SD)

Parameter	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
Initial weight (g)	100.2 ^a ±2.4	100.2 ^a ±2.3	100.3 ^a ±1.4	100.3 ^a ±0.5	100.2 ^a ±4.2	100.2 ^a ±2.3
Final weight (g)	953.50 ^c ±14.85	1043.50 ^a ±0.71	924.00 ^c ±7.07	993.50 ^b ±13.43	861.50 ^c ±10.61	916.00 ^d ±21.21
Total weight gain (g fish)	855.00 ^c ±21.21	941.50 ^a ±6.36	822.00 ^c ±5.66	891.00 ^b ±14.14	760.00 ^c ±11.31	816.50 ^d ±19.09
Daily weight gain (g fish day)	7.12 ^c ±0.18	7.84 ^a ±0.06	6.84 ^d ±0.05	7.42 ^b ±0.11	6.33 ^c ±0.10	6.93 ^{dc} ±0.04
Relative growth rate (%)	855.00 ^c ±21.21	941.50 ^a ±6.36	822.00 ^{dc} ±5.66	891.00 ^b ±14.14	760.00 ^c ±11.31	816.50 ^d ±19.09
SGR (% day, ln basis)	1.877 ^c ±0.010	1.953 ^a ±0.000	1.850 ^c ±0.000	1.911 ^b ±0.010	1.793 ^d ±0.000	1.844 ^c ±0.010
Feed conversion ratio	2.310 ^b ±0.030	2.260 ^a ±0.010	2.355 ^{cb} ±0.050	2.310 ^b ±0.020	2.360 ^c ±0.010	2.310 ^b ±0.010
Feed conversion efficiency (%)	43.2 ^b	44.2 ^a	42.4 ^{cb}	43.2 ^b	42.3 ^c	43.2 ^b
Protein efficiency ratio	2.579 ^a ±0.050	1.756 ^b ±0.020	2.533 ^a ±0.080	1.715 ^b ±0.020	2.523 ^a ±0.020	1.703 ^b ±0.020
Net production (kg cage)	1067.04 ^f ±27.18	1167.93 ^c ±3.78	1313.73 ^d ±3.24	1424.88 ^c ±20.34	1605.69 ^b ±22.50	1728.99 ^a ±42.66
Net production (kg m ⁻³)	59.280 ^f ±1.510	64.885 ^c ±0.210	72.985 ^d ±0.180	79.160 ^c ±1.130	89.205 ^b ±1.250	96.055 ^a ±2.370

D = stocking density (fish m⁻³); P = dietary crude protein (%). Values are means±SD of three replicate cages (n = 3); the cage is the experimental unit. Means in the same row bearing different superscript letters differ significantly (P ≤ 0.05, Duncan). Net production is total biomass gain, i.e. (N_f × W_f) - (N_i × W_i). Cage working volume = 18 m³.

3.4. Temporal pattern of growth and feed utilization

Cumulative specific growth rate increased steadily as the river warmed (Table 6). No significant differences among treatments were detected on the first three sampling dates (15 April, 1 May, 15 May). Differences emerged from 1 June onward and persisted to harvest, with 70 fish m⁻³ on the 25% CP diet retaining the highest cumulative SGR at every subsequent date. Cumulative feed conversion ratio improved sharply over the same interval, falling from 3.16-5.50 in mid-April to 1.83-1.99 by 1 July before rising slightly to 2.26-2.36 at harvest as fish approached market size (Table 7). Cumulative protein efficiency ratio peaked on 1 July in every treatment and declined thereafter (Table 8), and cumulative net production per cubic metre diverged progressively between densities from 1 June onward (Table 9).

Feed conversion ratio computed within each fortnight, rather than cumulatively, resolves this pattern more sharply (Figure 2). In every treatment of both diets, period FCR followed the same trajectory: poor during the two cold-water fortnights of April (3.18-6.81), improving abruptly as the river warmed through May, reaching a minimum in the first fortnight of June (1.15-1.37), and then deteriorating steadily through July to 2.98-3.16 by harvest. The rank order of densities was preserved through most of the trajectory, with 120 fish m⁻³ giving the poorest period FCR from April through to the end of May; from mid-June onward the three densities converged, and in the final fortnight the ranking reversed, the 120 fish m⁻³ treatment recording the best period FCR on both diets (2.975 and 2.995 against 3.10 and 3.03-3.16 at the lower densities).

Table 6: Cumulative specific growth rate (% day, natural-logarithm basis) of common carp at successive sampling dates

Date	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
15 Apr	0.910 ^a	0.990 ^a	1.220 ^a	1.220 ^a	0.840 ^a	0.910 ^a
1 May	1.059 ^a	1.255 ^a	1.186 ^a	1.382 ^a	0.956 ^a	1.025 ^a
15 May	1.347 ^a	1.439 ^a	1.347 ^a	1.439 ^a	1.105 ^a	1.186 ^a
1 Jun	1.462 ^{ab}	1.589 ^a	1.416 ^b	1.508 ^{ab}	1.197 ^c	1.255 ^c
15 Jun	1.796 ^{bc}	1.888 ^a	1.761 ^c	1.854 ^{ab}	1.658 ^d	1.715 ^{dc}
1 Jul	1.923 ^{ab}	1.992 ^a	1.877 ^{ab}	1.865 ^{ab}	1.785 ^b	1.865 ^{ab}
15 Jul	1.900 ^b	1.980 ^a	1.865 ^c	1.923 ^b	1.808 ^d	1.854 ^c
1 Aug	1.854 ^c	1.934 ^a	1.842 ^c	1.900 ^b	1.773 ^d	1.831 ^c

D = stocking density (fish m⁻³); P = dietary crude protein (%); n = 3 cages per treatment. Means in the same row bearing different superscript letters differ significantly (P ≤ 0.05, Duncan).

Table 7: Cumulative feed conversion ratio of common carp at successive sampling dates

Date	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
15 Apr	4.400	3.850	3.450	3.160	5.150	5.500
1 May	4.005	3.270	3.670	3.195	4.660	4.170
15 May	2.850	2.650	2.950	2.750	3.600	3.400
1 Jun	2.540	2.615	2.795	2.605	3.325	3.160

15 Jun	1.950	1.860	2.030	1.930	2.110	2.005
1 Jul	1.865	1.830	1.955	1.880	1.985	1.910
15 Jul	2.060	2.020	2.110	2.050	2.160	2.085
1 Aug	2.310	2.260	2.355	2.310	2.360	2.310

D = stocking density (fish m⁻³); P = dietary crude protein (%). Superscript letters omitted; see text for significance at each date.

Table 8: Cumulative protein efficiency ratio of common carp at successive sampling dates.

Date	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
15 Apr	1.379	1.024	1.856	1.247	1.161	0.860
1 May	1.587	1.214	1.733	1.361	1.278	0.963
15 May	2.069	1.473	2.000	1.438	1.636	1.147
1 Jun	2.351	1.689	2.135	1.558	1.795	1.256
15 Jun	3.057	2.132	2.938	2.058	2.826	1.977
1 Jul	3.194	2.168	3.050	2.107	2.997	2.028
15 Jul	2.891	1.925	2.827	1.924	2.757	1.875
1 Aug	2.579	1.756	2.533	1.715	2.523	1.703

D = stocking density (fish m⁻³); P = dietary crude protein (%).

Table 9: Cumulative net production (kg m³) at successive sampling dates

Date	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
15 Apr	1.080	1.215	1.885	1.900	1.570	1.700
1 May	2.710	3.145	3.935	4.605	3.705	4.250
15 May	5.840	6.385	7.490	8.250	7.710	8.275
1 Jun	10.070	11.215	11.985	13.460	12.535	13.460
15 Jun	20.205	22.195	24.925	27.385	29.305	31.620
1 Jul	32.970	35.660	40.085	43.840	48.190	51.840
15 Jul	45.640	49.565	56.180	61.010	67.255	72.765
1 Aug	59.280	64.885	72.985	79.160	89.205	96.055

D = stocking density (fish m⁻³); P = dietary crude protein (%). Net production is cumulative biomass gain per cubic metre of cage volume

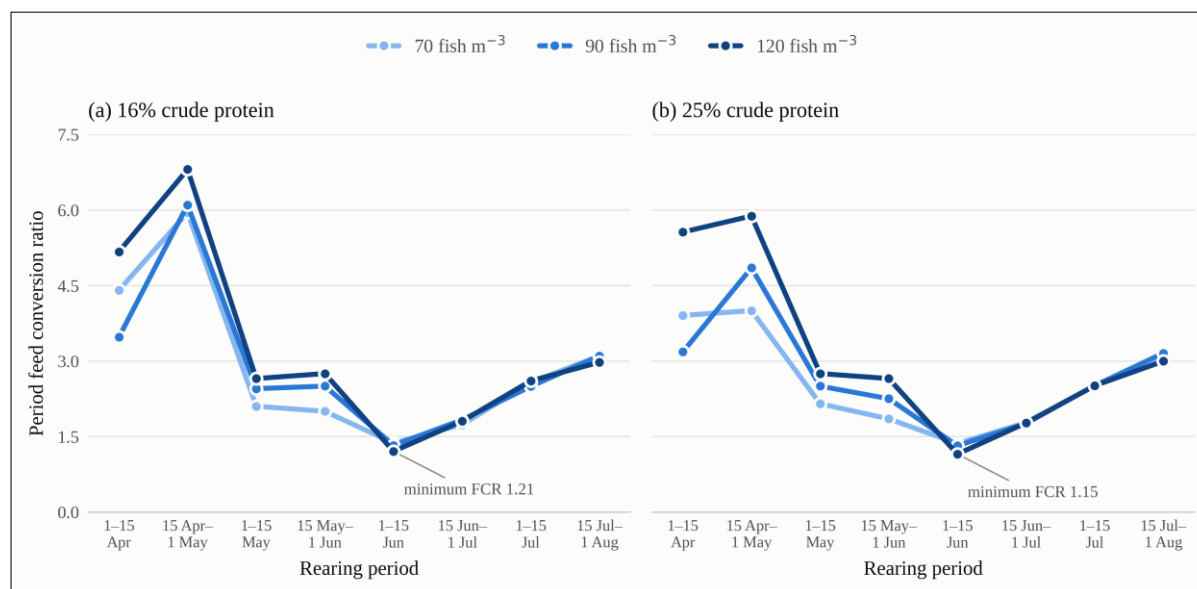


Fig 2: Period (within-fortnight) feed conversion ratio of common carp reared in Euphrates River cages at three stocking densities on (a) a 16% crude protein diet and (b) a 25% crude protein diet. Points are means of three replicate cages. Feed conversion was poorest during the cold-water fortnights of April, reached a minimum in the first fortnight of June as water temperature approached 28.5 °C, and deteriorated again through July as the fish approached market size. Density ranking was preserved from April to late May and reversed in the final fortnight.

3.5. Muscle proximate composition

Muscle composition at harvest is given in Table 10. Crude protein rose from 12.535±0.148% at stocking to 15.31-15.50% ($P \leq 0.05$) and ash fell from 7.310±0.169% to 5.27-5.37%. Moisture (74.20-74.35%) and crude lipid (4.33-

4.43%) did not differ from initial values. No composition variable differed among the six treatments, so neither stocking density nor dietary protein level altered muscle composition within the range tested.

Table 10: Proximate composition (%) of the edible muscle of common carp at stocking and after 120 days of cage rearing (mean $\pm$ SD)

Component	Initial	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
Moisture	75.14 ^a $\pm$ 0.08	74.20 ^a $\pm$ 0.14	74.23 ^a $\pm$ 0.21	74.35 ^a $\pm$ 1.13	74.35 ^a $\pm$ 1.14	74.34 ^a $\pm$ 1.32	74.34 ^a $\pm$ 1.21
Ash	7.31 ^a $\pm$ 0.17	5.51 ^b $\pm$ 0.03	5.52 ^b $\pm$ 0.04	5.27 ^b $\pm$ 0.01	5.28 ^b $\pm$ 0.12	5.29 ^b $\pm$ 0.62	5.37 ^b $\pm$ 0.23
Crude lipid	4.62 ^a $\pm$ 0.06	4.40 ^a $\pm$ 0.08	4.43 ^a $\pm$ 0.06	4.38 ^a $\pm$ 0.03	4.37 ^a $\pm$ 0.32	4.34 ^a $\pm$ 0.41	4.33 ^a $\pm$ 0.11
Crude protein	12.54 ^b $\pm$ 0.15	15.41 ^a $\pm$ 0.13	15.31 ^a $\pm$ 0.12	15.48 ^a $\pm$ 0.00	15.49 ^a $\pm$ 0.89	15.50 ^a $\pm$ 0.22	15.44 ^a $\pm$ 0.37

Values are means $\pm$ SD of three replicate cages (n = 3). Means in the same row bearing different superscript letters differ significantly (P $\leq$ 0.05, Duncan).

3.6. Economic analysis

Costs, revenues and net income per cubic metre are presented in Table 11. Feed was the largest single cost item in every treatment, ranging from 103.8 thousand IQD m³ (70 fish m³, 16% CP) to 192.0 thousand IQD m³ (120 fish m³, 25% CP) and representing 58-64% of total cost. Fingerlings were the second largest item (42-72 thousand IQD m³, 20-27% of total cost), followed by labour (15.6 thousand IQD m³ in all treatments), depreciation (12.12), transport (4.84-8.28) and veterinary treatments (0.718-1.21). Total cost rose with stocking density and with dietary protein, from 179.12 to 301.68 thousand IQD m³. Gross revenue rose more steeply, from 331.12 to 532.09 thousand IQD m³, so that net

income per cubic metre increased monotonically with density, from 152.12 thousand IQD m³ at 70 fish m³ on the 16% CP diet to 230.40 thousand IQD m³ at 120 fish m³ on the 25% CP diet.

Per kilogram of fish produced, the picture inverts (Table 12). Unit production cost was lowest at 120 fish m³ on the 16% CP diet (2649 IQD kg) and highest at 90 fish m³ on the 25% CP diet (2830 IQD kg). Farm-gate price also fell slightly at the highest density, so net margin per kilogram was greatest at 90 fish m³ on the 16% CP diet (2336 IQD kg) and smallest at 120 fish m³ on the 25% CP diet (2121 IQD kg) the treatment that nevertheless returned the most income per cage.

Table 11: Costs, gross revenue and net income per cubic metre of cage volume (thousand IQD m³, 2025 prices)

Item	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
Fingerlings	42.0	42.0	54.0	54.0	72.0	72.0
Feed	103.8	127.0	130.0	159.0	159.5	192.0
Labour	15.6	15.6	15.6	15.6	15.6	15.6
Veterinary treatments	0.718	0.718	0.906	0.906	1.210	1.210
Transport	4.84	4.84	6.21	6.21	8.28	8.28
Depreciation	12.12	12.12	12.12	12.12	12.12	12.12
Total cost	179.12	202.56	219.03	247.81	268.84	301.68
Gross revenue	331.12	367.50	411.09	442.18	487.03	532.09
Net income	152.12	164.93	192.06	194.37	218.18	230.40

D = stocking density (fish m³); P = dietary crude protein (%). IQD = Iraqi dinar; values at 2025 prices.

Table 12: Unit production cost, farm-gate price and net margin per kilogram of common carp (IQD kg, 2025 prices)

Item	D70/P16	D70/P25	D90/P16	D90/P25	D120/P16	D120/P25
Total production cost	2704	2811	2664	2830	2649	2779
Farm-gate price	5000	5100	5000	5000	4800	4900
Net margin	2296	2289	2336	2170	2151	2121

D = stocking density (fish m³); P = dietary crude protein (%).

4. Discussion

Density and protein pull individual performance and volumetric output in opposite directions, and no single treatment wins on both. Growth, feed conversion and feed conversion efficiency were best at the lowest density on the higher-protein diet. Net production per cage and per cubic metre — and with it net income per cage — were greatest at the highest density on the same diet. A recommendation is therefore incomplete unless it states which of the two the producer is maximising.

That growth falls as density rises is not new. Every cage study cited above reports it, and attributes it to competition for feed, crowding stress and localised water-quality decline. Ramteke *et al.* [5] recorded a 37% loss of final weight and a rise in FCR from 1.86 to 2.35 in Amur carp between 10 and 30 fish m⁻³, with elevated cortisol and glucose and suppressed immune markers. Wu *et al.* [25] found the same coupling of crowding with impaired antioxidant capacity and immunity in grass carp, and Li *et al.* [26] traced chronic high-density stress in rainbow trout as far as lipid metabolism. Li *et al.* [6] reported significantly

higher FCR alongside depressed dissolved oxygen and elevated nitrite nitrogen in gibel carp, and Debnath [7] the same direction in common carp cages at 20-80 fish m³. The present results differ in magnitude, not direction. Our densities (70-120 fish m³) sit well above all of those ranges, and above the 60-70 fish m³ that Salman *et al.* [4] describe as prevailing Iraqi practice — yet the penalty was small. Final weight fell 9.6% between 70 and 120 fish m³ on the 25% CP diet (1043.5 $\rightarrow$ 916.0 g) and FCR worsened by 2.2% (2.26 $\rightarrow$ 2.31), against a 37% weight penalty over a threefold density range in Ramteke *et al.* [5].

The explanation is hydrological rather than nutritional. Dissolved oxygen never fell below 7.75 mg L in any month, comfortably above the concentrations at which feeding behaviour and growth begin to suffer [27, 28]. More important, the current carries away the metabolic load that accumulates inside a static or semi-static culture unit — the same transfer that produces the downstream nutrient enrichment Komba *et al.* [17] document below cage installations. Shamsuddin *et al.* [18] likewise could not separate riverine tilapia cage sites statistically on water quality across a 120-day cycle. A lotic

cage externalises the water-quality penalty that normally caps stocking density, which is why densities above pond and reservoir norms were tolerable here. That is an advantage to the operator and a cost carried downstream.

Survival points the same way. Cumulative mortality stayed below 2% in every treatment, was highest at 120 fish m³ on both diets, and ceased entirely after the first month, peaking in the fortnight immediately after stocking (Figure 1). Timing like that belongs to acclimation, not to a density effect running through the trial: once the fish had settled, no further mortality occurred at any density, the highest included. Ramteke *et al.* [5] lost ten percentage points of survival across a comparable relative increase in density in reservoir cages. The gap between the two outcomes is hard to attribute to anything but flow.

Feed conversion computed within each fortnight, rather than cumulatively, sharpens the seasonal picture (Figure 2). Period FCR was worst in April at 18.5–24.4 °C. It fell to a minimum of 1.15–1.37 in the first half of June as the water reached 28.5 °C, then rose again through July with temperature still at its maximum. Temperature had stopped changing over those last six weeks, so it cannot account for the late deterioration; the remaining candidate is fish size, on which the cold-water penalty of April is superimposed at the start of the cycle. The productive window here therefore runs from mid-May to early July, and every fortnight beyond it buys biomass at a worse conversion. The three densities also converge from mid-June and reverse in the final fortnight, where 120 fish m³ gave the best period FCR on both diets — placing the density penalty early in the cycle, when the fish are small relative to the cage and competition for a fixed ration is sharpest, rather than late.

The protein response was positive but small: 6–9% more final weight and about 2% better FCR on the 25% CP diet at the same density. Fish of this size are past the point at which protein strongly limits growth. Jiang *et al.* [13] put the requirement of juvenile Yellow River carp of 51.6 g at 33.99–35.26% crude protein, and Ali and Rawal [12] derived a comparable figure for common carp fingerlings; the fish here entered the trial at 100 g and left it near 1 kg. Against that background, a growth response that flattens at a comparatively low dietary protein content is unsurprising.

Protein efficiency ratio makes the plateau explicit by inverting the ranking. PER was significantly higher on the 16% CP diet (2.523–2.579) than on the 25% CP diet (1.703–1.756) at every density, and did not differ among densities within a diet. Part of that follows arithmetically: PER varies inversely with the product of FCR and dietary protein content, so raising protein without a proportional gain in FCR must depress it. Biologically it means the extra protein of the 25% CP diet was used less efficiently, a fraction of it deaminated and catabolised for energy rather than retained. Two observations support this reading. Muscle protein at harvest (15.31–15.50%) did not differ among treatments, so the additional dietary protein did not reach the edible portion — the same decoupling Jiang *et al.* [13] saw above the requirement plateau, and consistent with flesh composition in carp tracking specific dietary components more closely than bulk crude protein [29]. And feed conversion efficiency spanned only 42.3–44.2% across all six treatments, a far narrower range than the 50% relative difference in analysed crude protein between the diets.

The economics reconcile the two rankings. Feed dominated cost in every treatment (58–64%), so the higher-protein diet

cost more; it also produced more biomass, and revenue rose faster than cost. Net income per cubic metre therefore climbed with both density and protein, reaching 230.40 thousand IQD m³ at 120 fish m³ with 25% CP. That matches Kebtieneh *et al.* [9], whose densest treatment was also the most profitable per unit area, and runs against Ramteke *et al.* [5], Debnath [7] and Li *et al.* [6], where the return to the producer was greatest at the lowest density. Which of the two patterns applies depends on what is scarce. Feed and fingerlings dominate operating cost in small-scale cage systems on Volta Lake [10] and in Lake Victoria [11]; where that holds, efficiency per fish decides. Where instead the cage is the fixed asset and river water is free, output per cubic metre decides, and dense stocking wins. A survival penalty can also tip the balance, as it did in the reservoir cages of Ramteke *et al.* [5] with ten points of mortality. Survival above 98% in every treatment here is what leaves the volumetric argument standing.

Per kilogram of fish, the ranking inverts again. The highest-density, high-protein treatment gave the smallest margin (2121 IQD kg): unit cost was higher, and the farm-gate price obtained at 120 fish m³ was 100–200 IQD kg below that at the lower densities. A producer with a fixed number of cages should therefore stock densely. One limited by working capital or feed supply, or selling into a market that pays a premium for large fish, should not.

How far these results travel is limited in several ways. The trial ran one season at one site, so the temperature trajectory (18.5 → 28.6 °C) is confounded with time; treatments are comparable with each other, but the absolute growth rates belong to a spring-summer Euphrates cycle. Total ammonia nitrogen and nitrite were not measured, which weakens any inference about the water-quality mechanism inside the cages — the variables that proved diagnostic for Li *et al.* [6]. The two diets were near-isoenergetic (423.9 vs 432.8 kcal 100 g, 2.1% apart) while differing by 50% in relative crude protein, so the contrast is a reasonably clean one; they nevertheless differ in ingredients as well as in protein, so what is reported is the effect of two practical formulations, not of dietary protein in isolation — a confounding that Turchini and Hardy [21] identify as recurrent in applied feeding trials. Replication was three cages per treatment, giving 12 error degrees of freedom: enough for the large contrasts reported here, not enough to resolve small ones, which is why the consistency of the rankings across every criterion and all eight sampling dates carries part of the evidential weight. Between-individual variability in harvest traits is substantial in this species [30], a further reason to treat the cage mean rather than the fish as the unit of inference. Finally, two protein levels establish a direction, not an optimum; a requirement estimate needs graded levels and regression, as in Ali and Rawal [12] and Jiang *et al.* [13], not mean separation.

5. Conclusion

Common carp grew well in Euphrates River cages at Babylon across 70–120 fish m³, reaching 861–1044 g from 100 g fingerlings in 120 days with cumulative survival above 98% in every treatment. Raising density depressed individual growth and feed conversion while raising net production and net income per unit of cage volume. Raising dietary crude protein from 16% to 25% improved growth and feed conversion modestly, cut protein efficiency ratio substantially, and left muscle composition unchanged.

Where cage volume is the binding constraint, 120 fish m³ on a 25% CP diet maximised volumetric yield (96.06 kg m³) and net income (230.40 thousand IQD m³). Where the aim is large individual fish, or the most efficient use of purchased protein, 70 fish m⁻³ on the 25% CP diet gave the best growth and feed conversion, and the 16% CP diet gave markedly better protein utilisation at every density. Tolerance of densities well above those reported for reservoir and recirculating systems appears specific to lotic cages, where flow externalises the metabolic load — a load that, as Komba *et al.* [17] show, is transferred downstream and belongs in any assessment of the sector's expansion. Graded, isoenergetic protein levels analysed by regression, monitoring of nitrogenous waste inside and below the cages, and repetition across seasons to separate temperature from time would each strengthen what can be concluded.

Declarations

Ethics approval: All ethical guidelines related to Fish and care issued by national and international organizations were implemented in this report

Conflict of interest: The authors declare that they have no conflict of interests.

Acknowledgements: The authors wish to extend their sincere appreciation to everyone who provided assistance and support throughout the course of this study.

References

- Food and Agriculture Organization of the United Nations. The state of world fisheries and aquaculture 2026. Rome: FAO; 2026. doi:10.4060/cd8357en.
- Al-Hilali H. Status, challenges, and prospects of aquaculture development in Iraq. Iraqi J Aquac. 2025;22^[1]:111-139. doi:10.58629/ijaq.v22i1.700.
- Al-Hilali HA, Lozovskiy AR. Common carp aquaculture *Cyprinus carpio* in Iraq: history, challenges, and opportunities. J Akuakultur Indones. 2026;25^[1]:26-42. doi:10.19027/jai.25.1.26-42.
- Salman NA, Saleh KI, Taher MM. Cage culture in Iraq, current status and potential: a review. Basrah J Agric Sci. 2022;35^[2]:362-372. doi:10.37077/25200860.2022.35.2.27.
- Ramteke MH, Swain HS, Das BK, Kumar V, Behera BK, Krishnani KK, *et al.* Density-dependent effects on growth performance, feed utilisation, integrated health biomarkers, and economic efficiency of Amur carp, *Cyprinus carpio haematopterus* (Linnaeus, 1758) in inland cages for sustainable production. Front Sustain Food Syst. 2026;9:1701262. doi:10.3389/fsufs.2025.1701262.
- Li H, Liu J, Gu X, Li L, Yu L, Tang R, *et al.* Effect of stocking density on growth performance of juvenile gibel carp (*Carassius gibelio*) and economic profit of land-based recirculating aquaculture system. Water. 2024;16^[17]:2367. doi:10.3390/w16172367.
- Debnath C. Effect of stocking density on growth, production, ecosystem dynamics, and economic viability of common carp (*Cyprinus carpio*) cage culture in a forest water body of Northeast India. Aquac Int. 2025;33^[4]:245. doi:10.1007/s10499-025-01931-y.
- Aura CM, Awandu H, Mziri V, Awuor FJ, Nyamweya CS, Musa S. Optimizing stocking density for enhanced fish yield in lacustrine cage aquaculture. Sci Afr. 2025;28. doi:10.1016/j.sciaf.2025.e02721.
- Kehtienh N, Geremew A, Yalew A, Abdissa B, Tilahun G. Optimizing Nile tilapia stocking density for enhanced water use efficiency and profitability in fish-cabbage integrated farming systems in Northwest Ethiopia. Aquac Int. 2025;33^[7]:672. doi:10.1007/s10499-025-02359-0.
- Magna EK, Mensah ET-D, Mabe FN, Johnson-Ashun M, Konadu LO, Appiah EK. Profitability analysis of small-scale cage aquaculture farms in the Volta Lake of Ghana. Aquac Res. 2023;2023:1314660. doi:10.1155/2023/1314660.
- Obiero K, Mboya JB, Ouko KO, Okech D. Economic feasibility of fish cage culture in Lake Victoria, Kenya. Aquac Fish Fish. 2022;2^[6]:484-492. doi:10.1002/aff2.75.
- Ali B, Rawal YK. Evaluation of optimum dietary protein requirement for maximum growth of common carp (*Cyprinus carpio*) fingerlings. Aquac Res. 2022;53^[17]:5915-5924. doi:10.1111/are.16059.
- Jiang X, Qu F, Ge Y, Li C, Shi X, Hu X, *et al.* Effects of dietary protein levels on the growth, physiological, and biochemical indices of juvenile Yellow River carp (*Cyprinus carpio*). Animals. 2025;15^[12]:1800. doi:10.3390/ani15121800.
- Raghuvanan N, Varghese T, Jana P, Angela Brightly RJ, Sethupathy MA, Sudarshan S, *et al.* Current status and global research trend patterns of insect meal in aquaculture from a scientometric perspective [2013-2022]. Aquac Nutr. 2024;2024:5466604. doi:10.1155/2024/5466604.
- Mahmud MN, Ritu FY, Ansary AA, Haque MM. Exploring protein-based fishmeal alternatives for aquaculture feeds in Bangladesh. Aquac Nutr. 2025;2025:3198303. doi:10.1155/anu/3198303.
- Ringø E. Spirulina (*Arthrospira*) as feed additive in finfish and shellfish aquaculture. Aquac Fish. 2025;10^[6]:931-944. doi:10.1016/j.aaf.2025.06.005.
- Komba RS, Mwita CJ, Kimaro EG. Cage-cultured Nile tilapia (*Oreochromis niloticus*) farming: a third generation of pollution in Lake Victoria, Tanzania. Aquac Fish Fish. 2025;5^[4]. doi:10.1002/aff2.70108.
- Shamsuddin M, Hossain MB, Rahman M, Kawla MS, Tazim MF, Albeshr MF, *et al.* Effects of stocking larger-sized fish on water quality, growth performance, and the economic yield of Nile tilapia (*Oreochromis niloticus* L.) in floating cages. Agriculture. 2022;12^[7]:942. doi:10.3390/agriculture12070942.
- Domínguez-May R, Poot-López GR, Hernández JM, Velázquez-Abunader I. Optimization of feed ration size in aquatic system according to the optimal control approach: implications of using the von Bertalanffy growth model. Aquac Res. 2024;2024:6512507. doi:10.1155/2024/6512507.
- New MB. Feed and feeding of fish and shrimp. Rome: FAO/UNDP; 1987.
- Turchini GM, Hardy RW. Research in aquaculture nutrition: what makes an experimental feeding trial successful? Rev Fish Sci Aquac. 2024;33^[3]:487-495. doi:10.1080/23308249.2024.2413672.
- Association of Official Analytical Chemists. Official methods of analysis of AOAC International. 17th ed.

- Gaithersburg (MD): Association of Official Analytical Chemists; 2000.
23. SAS Institute Inc. SAS/STAT user's guide. Version 9.1. Cary (NC): SAS Institute Inc.; 2004.
 24. Duncan DB. Multiple range and multiple F tests. *Biometrics*. 1955;11^[1]:1-42.
 25. Wu Z, Xu Q, Feng L, Wang J, Xu Y, Wu Y, *et al*. Effects of different stocking densities on growth performance, stress resistance, antioxidant capacity and immunity of grass carp. *Animals*. 2026;16^[5]:745. doi:10.3390/ani16050745.
 26. Li Z, Gao Q, Dong S, Dong K, Xu Y, Mei Y, *et al*. Effects of chronic stress from high stocking density in mariculture: evaluations of growth performance and lipid metabolism of rainbow trout (*Oncorhynchus mykiss*). *Biology*. 2024;13^[4]:263. doi:10.3390/biology13040263.
 27. Zhang K, Ye Z, Qi M, Cai W, Saraiva JL, Wen Y, *et al*. Water quality impact on fish behavior: a review from an aquaculture perspective. *Rev Aquac*. 2024;17^[1]. doi:10.1111/raq.12985.
 28. Yu M, Feng Y, Ouyang B, Wills PS, Tang Y. Dissolved oxygen in aquaculture ponds: causal factors, predictive modeling, and intelligent monitoring. *Aquac Eng*. 2026;112:102634. doi:10.1016/j.aquaeng.2025.102634.
 29. Zhang R, Li H, Wang X, Liu L, Zhu H. Potential benefits of glycine, proline and hydroxyproline on growth and flesh quality of mirror carp (*Cyprinus carpio* var. *specularis*). *Int J Mol Sci*. 2025;26^[18]:9011. doi:10.3390/ijms26189011.
 30. Nagaraja PS, Pathan MA, Raghul R, Susitharan V, Sanwal P, Krishnan S, *et al*. Variability in harvest growth traits and genetic parameters in common carp, *Cyprinus carpio* (Linnaeus, 1758), cultured in extracted inland saline groundwater. *Aquac Int*. 2026;34^[3]:89. doi:10.1007/s10499-026-02478-2.