



# Effect of Stocking Density on Growth, Survival and Economic Return during Nursery Rearing of Rohu, *Labeo rohita* (Hamilton) Larvae in Hapa Production Systems Installed in Community Village Ponds

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## Abstract

A detailed study on nursery raising of rohu, *Labeo rohita* larvae in community village ponds in hapa production system was attempted at six different sites of Gujarat, India. Rohu larvae were stocked at six densities; 100, 250, 500, 750, 1000, and 1500 larvae/m<sup>3</sup> in hapas (3 × 2 × 1 m) installed in the village ponds. Growth performance and survival were evaluated over a rearing period of four weeks. The growth performance and survival were significantly highest in stocking density of 100 larvae/m<sup>3</sup>, while the lowest survival was recorded in stocking density of 1500 larvae/m<sup>3</sup>. The rohu larvae stocked in hapa with density of 750 larvae/m<sup>3</sup> reported the highest yield, followed by 500 larvae/m<sup>3</sup>. Evaluation of economic returns indicated that the rohu stocked in hapa with 750 larvae/m<sup>3</sup> obtained better benefit cost ratio (1.4) and thus stocking density of 750 larvae/m<sup>3</sup> can be considered as optimal for rearing of rohu larvae under hapa production systems in village ponds. This study will benefit the aquaculture farmers for cost-effective raising of fish seed in village ponds.

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## Introduction

Aquaculture is a fast-growing industry that helps support livelihoods in rural areas of economically developing countries (Edwards, 2000, Troell et al., 2023). Fish production has increased from 95.79 lakh tonnes to 197.75 lakh tonnes during 2013-25 in India (Press Information Bureau, 2026). Community ponds and tanks are usually referred to as village ponds, form a vital water resource for aquaculture in India. These are mainly used by village dwellers for domestic purpose and rain water harvest. Gujarat, situated along the Western India has village ponds (6860) covering an area of 0.22 lakh ha. These water bodies hold significant potential and need to be utilized sustainably (Ail et al., 2019; Chaudhari et al., 2023). The inland fish production of the state during 2021-22 was 1.86 lakh MT (Department of Fisheries, 2023) and the fish production from ponds and tanks was 5404 MT, which was 2.91% of the total inland fish production from the state during 2021-22 (Commissioner of Fisheries, 2024). As per the State Government village-pond fisheries policy, these community water bodies are leased by local government bodies for a period of 10 years to the interested fish farmers. (Ail et al., 2021; Chaudhari et al., 2023). Farmers stock advanced fingerlings in ponds mainly relying on primary productivity for

growth, since these ponds are large to manage properly. Availability of quality fish seed for stocking was found to be the major constraint among the fish farmers of Gujarat (Ail et al., 2019). Lack of nurseries has been a major hurdle for producing fry in such regions and farmers depend on external suppliers located at far off places. Accordingly, in order to minimise the cost on procuring high priced fry and mortality due to prolonged distance transportation stress, scientific raising of rohu larvae to fry in hapas were attempted. Carp aquaculture has top priority in Indian context and availability of seed for grow-out needs paramount importance (Ayyappan & Jena, 2003; Biswas, Jena, Singh, Patmajhi, & Muduli, 2006). The study attempts to find the optimum stocking density in hapa production system which would act as one of the key practical knowledge bases for the farming community to improve the fish seed production practices and increase the economic benefits. Hence, the study was undertaken to assess the growth performance, survival pattern, and economic return while rearing rohu larvae at different stocking densities and under different environmental conditions of village ponds using multi-location trials.

## Materials and Methods

The study was carried out in districts of Anand and Kheda of the state of Gujarat, India at six locations, during pre-monsoon season (March-June) based on the fertility status of the ponds. Village ponds having nearly similar nutrient status were selected for setting up the experiment. Soil pH, organic carbon (%), nitrogen, and phosphorus content of all the ponds selected for the study, were tested for similarity. Soil pH was measured using pH meter (Eutech, Cyber Scan, Singapore). Organic carbon (OC) content in soil was determined by oxidation of OC by sulfuric acid potassium dichromate mixture, and the excessive dichromate was back-titrated against standard ferrous ammonium sulfate solution using diphenylamine indicator (Prescott, Taylor, & Marshall, 1934). Soil nitrogen content and phosphorus content were estimated as per Munsiri, Boyd, and Hajek (1995). After the selection of sites, the selected ponds were prepared during the pre-monsoon season for initiating the experiment. The dykes of ponds of these sites were cleaned properly, followed by weeding, and repeated netting was done for physical removal of cultured and weed fishes, which was then followed by liming and

fertilization depending on the soil pH and nutrient status as followed in the grow-out ponds for rearing of Indian major carps (Jena & Das, 2006). The hapas were installed as per experimental design.

Post preparation of ponds, during monsoon season the larvae of *L. rohita* were procured from the local fish hatchery of Gujarat state government in India located at Lingda, District Anand, Gujarat and were stocked at six different densities of 100, 250, 500, 750, 1000, and 1500 larvae/m<sup>3</sup> in triplicates in each hapa (3m length x 2m width x 1m height, 635 micron mesh size) fixed at six selected sites at different locations in village ponds (0.5-1.0 ha area) and were indicated as T1, T2, T3, T4, T5, and T6, respectively. The average initial length and weight of the larvae were 6.2 ± 0.2 mm and 1.6 ± 0.2 mg, respectively. The weight of the larvae was recorded using electronic weighing balance (Sartorius, Germany) by using a tared 100 mL beaker filled with water to minimize handling stress. The length of the spawn was measured by placing it on laminated, wet graph paper (Bairwa, Swain, Prusty, Das, & Ail, 2021). The experiment of nursery raising in hapa installed in selected village ponds was undertaken for four weeks. During the experiment, feed ingredient mixture of groundnut oil cake (GNOC) and rice bran at a ratio of 1:1 was fed four times the initial yield for initial 5 days and eight times during subsequent days as per Jena, Mukhopadhyay, Sarkar, Aravindakshan, and Muduli (1996).

Water quality parameters such as water temperature, total hardness, total dissolved solids, alkalinity, salinity, transparency, conductivity and pH were recorded on weekly basis till completion of the experiment based on standard procedures (APHA, 2005). Similarly, during the experiment, the soil quality parameters such as soil pH by pH meter (Eutech, CyberScan, Singapore) and organic carbon content of soil as per Prescott et al. (1934), were also recorded. Transparency was measured using a Secchi disk.

During the experiment, periodical monitoring of growth and survival parameters, including length (cm), length gain (%), weight (g), weight gain (%), survival rate (%), specific growth rate (SGR) was recorded (sample size was uniformly 20 individuals) on weekly basis till completion of experiment as per the following formulae (Ferozekhan et al., 2020).

$$\text{Length Gain (\%)} = \%LG = [(L_f - L_i) / L_i] \times 100$$

Weight Gain (%) = %WG =  $[(W_f - W_i) / W_i] \times 100$

Survival rate (%) = %S =  $(N_f/N_i) \times 100$

Specific Growth Rate = SGR =  $100 (\ln W_2 - \ln W_1) / t$

Where,  $L_f$  is the final length of the fish,  $L_i$  is the initial length of fish,  $W_f$  is the final weight of the fish and  $W_i$  is the initial weight of fish,  $N_f$  is the final number of fish available at the end of experiment,  $N_i$  is the initial number of fish stocked at the beginning of experiment,  $\ln W_2$  is the natural logarithm of the final weight,  $\ln W_1$  is the natural logarithm of the initial weight,  $t$  is the time (days) between  $\ln W_2$  and  $\ln W_1$ . The total yield per unit volume ( $\text{g}/\text{m}^3$ ) of rohu fry from each treatment of the selected sites was also recorded at the end of experiment.

Economic analysis was carried out using two best stocking density based on yield and survival to get the final conclusion. Gross benefit and net benefit were computed based on the number of fry (fish larvae) survived. Benefit cost ratio was computed by dividing gross income by total expenses.

All the values are expressed as the mean  $\pm$  standard error of the mean (SEM). The data were subjected to one way analysis of variance using SPSS software package version (17.0) to determine significant differences ( $p < 0.05$ ) between stocking densities. Second order regression was used to determine the relationship between yield ( $\text{g}/\text{m}^3$ ) and stocking density. Simple linear regression was used to draw relationship between survival and stocking density.

## Results and Discussion

The experiment was undertaken at six different sites (Table 1). Analysis of the initial soil quality parameters of selected ponds such as pH, organic carbon content, nitrogen content and phosphorus content at different sites showed no variation in the mean values. The initial organic carbon content of

sediment of selected ponds was within 1.51% to 1.53%, and the initial nitrogen content of the sediment of the selected ponds was between 51.78 to 52.19 mg/100g of pond soil. Similarly, the initial phosphorus content of soil of selected ponds was within a level of 6.08 to 6.72 mg phosphorus/100g soil sample.

The soil and water quality parameters of selected culture ponds from different sites were recorded at weekly intervals (Table 2). The sediment organic carbon content ranged from 1.42% to 1.98% at different locations during the experiment, whereas, the soil pH remained alkaline (7.9–8.2) throughout the experiment. Air temperature during the experiment at different locations ranged from 29.0 to 31.5 °C, whereas the water temperature was within 27.5–29.5 °C. The various water quality parameters, including pH, TDS, conductivity, and total hardness, were found to be within acceptable limits. Secchi disk transparency measurements revealed desirable range at all the locations, which varied within 24 to 34 cm (Table 1).

The final length of the fry stocked at lowest density (4.08–5.25 cm; 100 larvae/ $\text{m}^3$ ) was highest among all the treatments as 250 larvae/ $\text{m}^3$  (3.72–4.02 cm), 500 larvae/ $\text{m}^3$  (3.41–3.88 cm), 750 larvae/ $\text{m}^3$  (2.77–3.56 cm), 1000 larvae/ $\text{m}^3$  (2.32–3.11 cm), and 1500 larvae/ $\text{m}^3$  (2.16–2.55 cm) mentioned in Table 3. However, the group of fish stocked at the highest density (1500 larvae/ $\text{m}^3$ ) exhibited the lowest final length (2.16–2.55 cm). The length gain (%) of *L. rohita* fry raised in hapa production system during the experimental period was also significantly ( $p < 0.5$ ) highest in the group of seed stocked at low density, i.e., 580.56–775.00% at 100 larvae/ $\text{m}^3$  (Table 4). However, the length gain (%) decreased with increasing of stocking density in hapa. The maximum average final body weight (0.46–0.69 g) and ( $p < 0.05$ ) maximum weight gain 28947.92–43156.04% was recorded in hapa stocked with 100 larvae/ $\text{m}^3$  (Table

Table 1. Initial soil quality parameters of different sites selected for the experiment

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Soil pH	8.1	8.1	8.1	8.2	7.9	8.0
Initial Organic Carbon content (%) of soil	1.52	1.51	1.53	1.51	1.52	1.53
Initial Nitrogen content (mg N 100g of soil <sup>-1</sup> )	52.13	51.82	51.96	52.19	51.78	52.15
Initial Phosphorus content (mg P 100g of soil <sup>-1</sup> )	6.11	6.53	6.72	6.29	6.08	6.64

Table 2. Water and soil quality parameters during the experimental period at different sites

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Air Temperature (°C)	29.0-30.0	29.0-30.5	30.0-30.5	29.0-30.5	30.0-31.5	30.5-31.5
Water Temperature (°C)	27.5-29.0	28.0-29.0	29.0-29.5	28.0-29.5	29.0-29.5	29.0-30.0
pH	7.62-7.82	7.58-7.86	7.04-8.85	7.88-8.86	8.2-8.8	7.8-8.4
Total Hardness (mg L <sup>-1</sup> )	100-102	99-102	98-100	108-124	412-430	232-266
Total Dissolved Solids (g L <sup>-1</sup> )	0.15-0.16	0.15-0.16	0.33-0.35	0.20-0.21	0.85-0.89	0.62-0.63
Conductivity (S m <sup>-1</sup> )	0.23-0.26	0.24-0.25	0.51-0.54	0.29-0.36	1.24-1.37	0.96-0.97
Salinity (‰)	1.60-1.71	1.59-1.73	0.38-0.41	0.22-0.25	0.98-1.02	0.72-0.73
Transparency (cm)	24-26	24-25	28-34	25-29	26-34	25-34
pH (soil)	7.82-8.22	8.12-8.43	8.24-8.59	8.0-8.6	7.53-7.84	7.78-8.34
Organic Carbon % (soil)	1.46-1.57	1.52-1.64	1.48-1.67	1.51-1.62	1.54-1.83	1.55-1.89

Table 3. Final Length (cm) of rohu, *L. rohita* fry at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	5.25 ± 0.03 <sup>f</sup>	5.03 ± 0.14 <sup>f</sup>	4.44 ± 0.08 <sup>fe</sup>	4.08 ± 0.02 <sup>f</sup>	4.24 ± 0.03 <sup>f</sup>	4.11 ± 0.04 <sup>f</sup>
T2-250	3.97 ± 0.15 <sup>ed</sup>	4.02 ± 0.09 <sup>ed</sup>	3.94 ± 0.06 <sup>ef</sup>	3.72 ± 0.04 <sup>ed</sup>	3.89 ± 0.03 <sup>e</sup>	3.79 ± 0.02 <sup>e</sup>
T3-500	3.79 ± 0.13 <sup>de</sup>	3.88 ± 0.09 <sup>de</sup>	3.58 ± 0.05 <sup>d</sup>	3.64 ± 0.03 <sup>de</sup>	3.64 ± 0.02 <sup>d</sup>	3.41 ± 0.03 <sup>d</sup>
T4-750	3.35 ± 0.09 <sup>c</sup>	3.56 ± 0.06 <sup>c</sup>	2.77 ± 0.05 <sup>c</sup>	3.40 ± 0.01 <sup>c</sup>	3.15 ± 0.04 <sup>c</sup>	3.29 ± 0.02 <sup>c</sup>
T5-1000	2.85 ± 0.07 <sup>b</sup>	3.11 ± 0.06 <sup>b</sup>	2.32 ± 0.02 <sup>b</sup>	2.62 ± 0.02 <sup>b</sup>	2.64 ± 0.02 <sup>b</sup>	2.66 ± 0.03 <sup>b</sup>
T6-1500	2.48 ± 0.04 <sup>a</sup>	2.16 ± 0.03 <sup>a</sup>	2.25 ± 0.01 <sup>a</sup>	2.53 ± 0.01 <sup>a</sup>	2.55 ± 0.01 <sup>a</sup>	2.23 ± 0.02 <sup>a</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

5 and 6). Lowest average final body weight (0.14–0.16g) and weight gain (8345.83–10033.33%) was observed in hapa stocked at 1500 larvae/m<sup>3</sup>. Weight gain (%) among different groups of fish fry reared were significantly different from each other with an increasing trend of weight gain with decrease in stocking densities as 250 larvae/m<sup>3</sup> (25637.50–33965.42%), 500 larvae/m<sup>3</sup> (22547.92–28891.46%), 750 larvae/m<sup>3</sup> (17083.33–23055.83%), and 1000 larvae/m<sup>3</sup> (9894.79–13095.42%).

The average specific growth rate (SGR) of *L. rohita* fry reared at lower densities were significantly ( $p < 0.05$ ) higher than those reared at higher densities (Table 7). Significantly ( $p < 0.05$ ) high SGR (7.70–8.01) was recorded in hapa stocked with 100 larvae/m<sup>3</sup> and the lowest SGR (5.67–6.26) was observed in hapa stocked with 1500 larvae/m<sup>3</sup>. The average survival rate of rohu fry stocked with 250, 500, 750,

and 1000 larvae/m<sup>3</sup> densities were significantly different from each other (Table 8) at all the sites (50.43–55.71%, 47.49–50.37%, 42.84–46.83%, 33.84–38.66%, respectively). Significantly ( $p < 0.05$ ) high survival (53.23–59.66%) was observed in T1 treatment (100 larvae/m<sup>3</sup>) and significantly ( $p < 0.05$ ) lowest survival (29.17–35.83%) was recorded in T6 (1500 larvae/m<sup>3</sup>). The survival (%) of rohu fry reared in T1 was almost double that of the survival (%) of rohu fry reared in T6. Likewise, a negative linear regression ( $r^2 = 0.9239$ ) was observed with increased stocking density on survival of the fry (Fig. 1).

The average yield (88.35–120.85 g/m<sup>3</sup>) of *L. rohita* fry raised in the hapa production system was significantly ( $p < 0.05$ ) highest in the group of fish stocked at a density of 750 larvae/m<sup>3</sup> at all the sites except the 3<sup>rd</sup> (116.51 g/m<sup>3</sup>) and 5<sup>th</sup> (110.98 g/m<sup>3</sup>) site, wherein the fry of *L. rohita* reared at a stocking

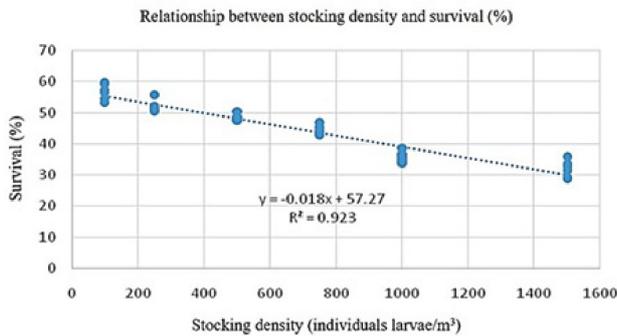


Fig. 1. Relationship between stocking density and survival of rohu fry during the experiment

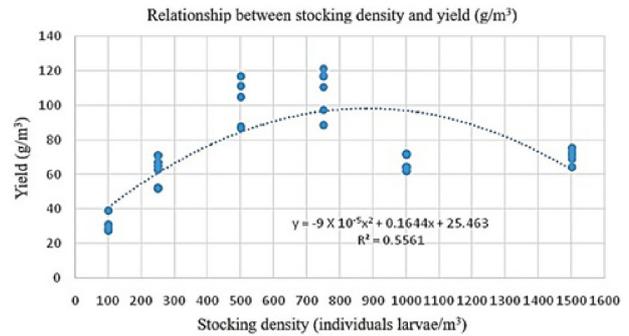


Fig. 2. Relationship between stocking density and yield of fry during the experiment

density of 500 larvae/m<sup>3</sup> were non-significantly ( $p > 0.05$ ) highest from the treatment T4 at their respective sites (Table 9). The study of relationship between stocking density and yield revealed a parabolic curve, wherein, the yield increased from the density of 100 larvae/m<sup>3</sup> (27.48–38.99 g/m<sup>3</sup>) up to a density of 750 larvae/m<sup>3</sup> after which the yield decreases (Fig. 2).

Cost and benefit analysis was undertaken to draw a conclusion about which stocking density was best amongst T3 and T4 (Table 10). The net benefit of producing *L. rohita* fry from larvae stocked at the density of 750 numbers/m<sup>3</sup> (T4) in hapa was highest. Even, the benefit-cost ratio was higher in T4 (1.40) than that in T3 (1.10).

The study was undertaken at multi-locations having similar soil fertility levels in terms of its major nutrient contents, such as organic carbon content, nitrogen content, and phosphorus content. Although potassium is a major nutrient required for crops, it is available in adequate quantities in ponds

required for aquaculture (Viriyatum & Boyd, 2011). All the ponds at the selected sites were moderately productive as they contained the medium range of organic carbon content, nitrogen content, and phosphorus content in the soil (Central Inland Fisheries Research Institute, 1985; Jena & Das, 2006). The observed range of water temperature (27.5– 30.0 °C), pH (7.04–8.86), water hardness (98–430 mg/L), TDS (0.15–0.89 g/L), EC (0.23–1.37 mS), and salinity (0.22–1.73 ‰) during the experiment in the selected ponds at different sites were within the desirable range for carp production in tropical countries (Swingle, 1967; Boyd, 1990; Mohanty, 1995; Singh, 1996; Boyd & Tucker, 1998; Jena, 1998). No marked difference in the water qualities at different sites were discernible in the present study, which can be attributable to the similar level of soil characteristics in terms of their fertility status of the selected sites and input management for nursery raising of rohu larvae to fry in hapa production systems.

The rate of growth slowed down as stocking densities of rohu larvae was increased in hapas at

Table 4. Length gain (%) of rohu, *L. rohita* fry at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	775.00 ± 14.27 <sup>f</sup>	738.33 ± 21.05 <sup>f</sup>	639.44 ± 2.42 <sup>f</sup>	580.56 ± 6.76 <sup>f</sup>	606.67 ± 15.67 <sup>f</sup>	585.56 ± 28.11 <sup>f</sup>
T2-250	562.22 ± 15.13 <sup>e</sup>	570.00 ± 22.00 <sup>e</sup>	556.11 ± 0.55 <sup>e</sup>	520.56 ± 6.83 <sup>de</sup>	548.89 ± 18.21 <sup>e</sup>	531.11 ± 24.59 <sup>e</sup>
T3-500	531.11 ± 14.40 <sup>d</sup>	546.67 ± 25.46 <sup>d</sup>	496.67 ± 0.96 <sup>d</sup>	506.11 ± 3.64 <sup>de</sup>	506.11 ± 19.53 <sup>d</sup>	468.33 ± 23.88 <sup>d</sup>
T4-750	458.33 ± 9.77 <sup>c</sup>	493.89 ± 31.88 <sup>c</sup>	362.22 ± 3.09 <sup>c</sup>	466.11 ± 1.47 <sup>c</sup>	424.44 ± 23.18 <sup>c</sup>	448.89 ± 19.72 <sup>c</sup>
T5-1000	375.56 ± 9.42 <sup>b</sup>	418.89 ± 31.09 <sup>b</sup>	287.22 ± 2.00 <sup>b</sup>	336.11 ± 2.78 <sup>ab</sup>	340.00 ± 22.09 <sup>b</sup>	342.78 ± 42.52 <sup>b</sup>
T6-1500	313.89 ± 19.44 <sup>a</sup>	259.44 ± 25.74 <sup>a</sup>	274.44 ± 2.42 <sup>a</sup>	322.22 ± 1.11 <sup>ab</sup>	325.00 ± 17.17 <sup>a</sup>	271.11 ± 34.91 <sup>a</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

all of the selected sites. Significantly highest weight gain (%), length gain (%), SGR and survival (%) was noticed in the group of rohu seed stocked at lowest density of 100 larvae/m<sup>3</sup>. Low stocking density should have helped the rohu larvae have more space for movement and feed efficiency has a good correlation with space (Slembrouck, Baras, Subagja, Hung, & Legendre, 2009; Rafaey et al., 2018). Less stress was also reported at low stocking densities (Liu et al., 2019; Zahedi, Akbarzadeh, Mehrzad, Noori, & Harsij, 2019). Higher feed utilization and low stress level might have resulted in higher weight gains and higher survival (%) at lower stocking densities (Chowdhury, Saha, Islam, & Das, 2002; Rahman, Islam, Halder, & Tanaka, 2006).

The present study showed significantly better yields at higher stocking densities up to the treatment T4 after which it has decreased, but the growth rate of rohu fry decreased significantly at all the selected sites with increasing stocking densities. Highest growth rate and lowest yield was found in T1, which

is obvious due to the lower numbers stocked. T4 revealed highest yield following T3, in spite of having higher stocking densities. Similar observations of higher yields at higher stocking densities and higher growth rates at lower stocking densities were observed by previous researchers (Chowdhury et al., 2002; Rahman et al., 2006; Chowdhury, Roy, & Chowdhury, 2020). However, treatments with 1000 larvae/m<sup>3</sup> and 1500 larvae/m<sup>3</sup> had significantly ( $p < 0.05$ ) lower yield which could be due to low survival rates. Fry size and survival are two important criteria to evaluate the performance of nursery rearing practice (Sahu, Jena, & Das, 2007). Carp nursery rearing is mainly recommended for a period of 15–20 days from larvae to fry with stocking density of 3–5 million/ha in earthen ponds and 10–20 million/ha in ferro-cement tanks (Ayyappan & Jena, 2001). Survival of 45–59% was achieved with a yield of 900–1200 fry/m<sup>2</sup> when rohu larvae was grown at high stocking density, 2000 larvae/m<sup>3</sup> in concrete tanks with supplementary daily feeding (Das, Jena, Patro, & Mahanta, 2016).

Table 5. Final body weight (g) of rohu, *L. rohita* fry at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	0.49 ± 0.01 <sup>f</sup>	0.46 ± 0.00 <sup>f</sup>	0.69 ± 0.01 <sup>fe</sup>	0.51 ± 0.01 <sup>f</sup>	0.59 ± 0.01 <sup>f</sup>	0.53 ± 0.01 <sup>f</sup>
T2-250	0.40 ± 0.00 <sup>e</sup>	0.41 ± 0.00 <sup>e</sup>	0.55 ± 0.00 <sup>ef</sup>	0.48 ± 0.00 <sup>e</sup>	0.51 ± 0.01 <sup>e</sup>	0.49 ± 0.00 <sup>e</sup>
T3-500	0.36 ± 0.00 <sup>d</sup>	0.36 ± 0.00 <sup>d</sup>	0.49 ± 0.00 <sup>d</sup>	0.46 ± 0.00 <sup>d</sup>	0.46 ± 0.00 <sup>d</sup>	0.43 ± 0.01 <sup>d</sup>
T4-750	0.27 ± 0.00 <sup>c</sup>	0.28 ± 0.00 <sup>c</sup>	0.33 ± 0.00 <sup>c</sup>	0.37 ± 0.00 <sup>c</sup>	0.33 ± 0.01 <sup>c</sup>	0.36 ± 0.00 <sup>c</sup>
T5-1000	0.19 ± 0.00 <sup>b</sup>	0.20 ± 0.00 <sup>b</sup>	0.16 ± 0.00 <sup>b</sup>	0.18 ± 0.00 <sup>b</sup>	0.21 ± 0.00 <sup>b</sup>	0.18 ± 0.00 <sup>b</sup>
T6-1500	0.16 ± 0.00 <sup>a</sup>	0.15 ± 0.00 <sup>a</sup>	0.14 ± 0.00 <sup>a</sup>	0.15 ± 0.00 <sup>a</sup>	0.16 ± 0.00 <sup>a</sup>	0.14 ± 0.00 <sup>a</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

Table 6. Weight gain (%) of rohu, *L. rohita* fry at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	30358.33 ± 95.24 <sup>f</sup>	28947.92 ± 166.15 <sup>f</sup>	43156.04 ± 128.81 <sup>f</sup>	32038.96 ± 19.37 <sup>f</sup>	36495.46 ± 459.13 <sup>f</sup>	33099.38 ± 531.78 <sup>f</sup>
T2-250	25145.83 ± 379.37 <sup>e</sup>	25637.50 ± 236.16 <sup>e</sup>	33965.42 ± 106.08 <sup>e</sup>	29998.75 ± 938.75 <sup>e</sup>	31538.35 ± 234.65 <sup>e</sup>	30276.46 ± 367.31 <sup>e</sup>
T3-500	22547.92 ± 224.47 <sup>d</sup>	22706.25 ± 316.23 <sup>d</sup>	30215.00 ± 34.56 <sup>d</sup>	28846.04 ± 170.62 <sup>d</sup>	28739.79 ± 281.18 <sup>d</sup>	26891.46 ± 197.18 <sup>d</sup>
T4-750	17083.33 ± 295.29 <sup>c</sup>	17706.25 ± 148.05 <sup>c</sup>	20605.17 ± 140.47 <sup>c</sup>	23055.83 ± 61.56 <sup>c</sup>	20661.04 ± 231.56 <sup>c</sup>	22363.33 ± 201.23 <sup>c</sup>
T5-1000	11508.33 ± 480.70 <sup>b</sup>	12291.67 ± 248.69 <sup>b</sup>	9894.79 ± 49.78 <sup>b</sup>	10847.92 ± 89.06 <sup>b</sup>	13095.42 ± 176.18 <sup>b</sup>	11263.75 ± 270.11 <sup>b</sup>
T6-1500	10033.33 ± 266.47 <sup>a</sup>	9422.92 ± 77.95 <sup>a</sup>	8345.83 ± 15.93 <sup>a</sup>	9285.42 ± 133.43 <sup>a</sup>	9862.71 ± 198.23 <sup>a</sup>	8412.08 ± 166.89 <sup>a</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

Maximum survival of 67.8% were obtained for rohu stocked at density of 2.5 million/ha in 0.04 ha earthen nursery pond (Jena, Aravindakshan, & Singh, 1998). The present investigation indicates that hapa enclosure-based nursery rearing of rohu larvae

in earthen village ponds achieved comparable survival rates (40–46%) at a stocking density of 750 larvae/m<sup>3</sup>. However, the availability of dedicated earthen nursery ponds or concrete tanks for larval rearing is becoming increasingly constrained in

Table 7. SGR of Rohu, *L. rohita* fry at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	7.76 ± 0.04 <sup>f</sup>	7.70 ± 0.13 <sup>f</sup>	7.75 ± 0.00 <sup>f</sup>	7.83 ± 0.00 <sup>f</sup>	8.01 ± 0.05 <sup>f</sup>	7.88 ± 0.15 <sup>f</sup>
T2-250	7.51 ± 0.02 <sup>e</sup>	7.53 ± 0.15 <sup>e</sup>	7.45 ± 0.00 <sup>e</sup>	7.75 ± 0.02 <sup>e</sup>	7.81 ± 0.03 <sup>e</sup>	7.76 ± 0.11 <sup>e</sup>
T3-500	7.37 ± 0.05 <sup>d</sup>	7.37 ± 0.12 <sup>d</sup>	7.30 ± 0.00 <sup>d</sup>	7.69 ± 0.00 <sup>d</sup>	7.69 ± 0.04 <sup>d</sup>	7.60 ± 0.10 <sup>d</sup>
T4-750	6.99 ± 0.03 <sup>c</sup>	7.04 ± 0.11 <sup>c</sup>	6.81 ± 0.01 <sup>c</sup>	7.39 ± 0.00 <sup>c</sup>	7.24 ± 0.05 <sup>c</sup>	7.35 ± 0.14 <sup>c</sup>
T5-1000	6.46 ± 0.01 <sup>b</sup>	6.54 ± 0.10 <sup>b</sup>	5.88 ± 0.01 <sup>b</sup>	6.37 ± 0.01 <sup>b</sup>	6.63 ± 0.02 <sup>b</sup>	6.42 ± 0.12 <sup>b</sup>
T6-1500	6.26 ± 0.05 <sup>a</sup>	6.19 ± 0.14 <sup>a</sup>	5.67 ± 0.00 <sup>a</sup>	6.16 ± 0.01 <sup>a</sup>	6.24 ± 0.01 <sup>a</sup>	6.03 ± 0.15 <sup>a</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

Table 8. Survival (%) of rohu, *L. rohita* fry at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	57.29 ± 0.04 <sup>f</sup>	59.13 ± 0.10 <sup>f</sup>	56.33 ± 0.27 <sup>f</sup>	59.66 ± 0.43 <sup>f</sup>	53.23 ± 0.36 <sup>f</sup>	54.33 ± 0.59 <sup>f</sup>
T2-250	51.71 ± 0.19 <sup>e</sup>	50.43 ± 0.66 <sup>e</sup>	52.13 ± 0.53 <sup>e</sup>	55.71 ± 0.49 <sup>e</sup>	51.19 ± 0.98 <sup>e</sup>	51.53 ± 0.43 <sup>e</sup>
T3-500	48.37 ± 0.27 <sup>d</sup>	47.49 ± 0.43 <sup>d</sup>	48.04 ± 0.84 <sup>d</sup>	50.37 ± 0.32 <sup>d</sup>	48.10 ± 0.87 <sup>d</sup>	48.43 ± 0.77 <sup>d</sup>
T4-750	42.84 ± 0.13 <sup>c</sup>	45.44 ± 0.53 <sup>c</sup>	46.83 ± 0.04 <sup>c</sup>	43.49 ± 0.27 <sup>c</sup>	44.27 ± 0.55 <sup>c</sup>	43.41 ± 0.63 <sup>c</sup>
T5-1000	34.48 ± 0.49 <sup>b</sup>	36.27 ± 0.49 <sup>b</sup>	38.66 ± 0.33 <sup>b</sup>	36.66 ± 0.88 <sup>b</sup>	33.84 ± 0.91 <sup>b</sup>	35.37 ± 0.88 <sup>b</sup>
T6-1500	29.17 ± 0.43 <sup>a</sup>	32.76 ± 0.04 <sup>a</sup>	35.83 ± 0.13 <sup>a</sup>	33.53 ± 0.99 <sup>a</sup>	28.77 ± 0.65 <sup>a</sup>	31.46 ± 0.69 <sup>a</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

Table 9. Average yield (g/m<sup>3</sup>) of rohu, *L. rohita* at different stocking densities

Stocking Density	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
T1-100	27.92 ± 0.31 <sup>a</sup>	27.48 ± 0.15 <sup>a</sup>	38.99 ± 0.23 <sup>a</sup>	30.68 ± 0.17 <sup>a</sup>	31.17 ± 0.02 <sup>a</sup>	28.86 ± 0.12 <sup>a</sup>
T2-250	52.23 ± 0.05 <sup>b</sup>	51.92 ± 0.11 <sup>b</sup>	71.03 ± 0.09 <sup>c</sup>	67.05 ± 0.11 <sup>c</sup>	64.79 ± 0.05 <sup>b</sup>	62.59 ± 0.13 <sup>b</sup>
T3-500	87.65 ± 0.02 <sup>e</sup>	86.66 ± 0.10 <sup>c</sup>	116.51 ± 0.06 <sup>d</sup>	116.64 ± 0.08 <sup>d</sup>	110.98 ± 0.03 <sup>e</sup>	104.56 ± 0.14 <sup>d</sup>
T4-750	88.35 ± 0.01 <sup>e</sup>	97.11 ± 0.14 <sup>f</sup>	116.35 ± 0.09 <sup>d</sup>	120.85 ± 0.12 <sup>e</sup>	110.29 ± 0.04 <sup>e</sup>	116.91 ± 0.11 <sup>e</sup>
T5-1000	64.05 ± 0.04 <sup>c</sup>	71.92 ± 0.13 <sup>d</sup>	61.82 ± 0.07 <sup>b</sup>	64.22 ± 0.11 <sup>b</sup>	71.43 ± 0.02 <sup>d</sup>	64.31 ± 0.14 <sup>c</sup>
T6-1500	70.94 ± 0.01 <sup>d</sup>	74.89 ± 0.12 <sup>c</sup>	72.63 ± 0.03 <sup>c</sup>	75.52 ± 0.12 <sup>c</sup>	68.80 ± 0.04 <sup>c</sup>	64.17 ± 0.10 <sup>c</sup>

The data are expressed as the mean ± SEM (standard error of the mean) (n = 3, replicate hapa). Values in the same line with different superscripts are significantly different ( $p < 0.05$ ).

Table 10. Costs and benefits for larvae to fry rearing of rohu, *L. rohita* in hapa at different stocking densities

Items	Treatments			
	T3			T4
Stocking density	500 individuals' larvae/m <sup>3</sup>		750 individuals' larvae/m <sup>3</sup>	
A. Capital cost				
Hapa –size 3m x 2m x 1m @ Rs. 900/-	100 individuals	90,000/-	100 individuals	90,000/-
B. Variable cost (For 3 cycles in a year)				
Pond lease value		5,000/-		5,000/-
Bamboo poles for fixing hapa in pond		5,000/-		5,000/-
Larvae @ Rs. 800/lakh larvae	9 lakhs	7,200/-	13.5 lakhs	10,800/-
Supplementary feed @ Rs. 30/kg	90 kg	2,700/-	100 kg	3,000/-
Labour for management and harvesting		5,000/-		5,000/-
Miscellaneous		2,000/-		2,000/-
Sub - Total Variable Cost		26,900/-		30,800/-
Depreciation of capital cost @ 25%		22,500/-		22,500/-
Interest on fixed cost per annum 12%		10,800/-		10,800/-
C. Total Cost of Production		60,200/-		64,100/-
D. Gross Benefit				
Selling @ Rs. 15,000/lakh	4.4 lakh fry, Survival-48%	66,000/-	6 lakh fry Survival- 45%	90,000/-
Net Benefit (D-C)		5,800/-		25,900/-
Benefit cost ratio		1.10		1.40

Amount (Rs.) expressed in Indian Rupees

regions where land resources are largely diverted for agricultural and industrial purposes.

The total cost of production was lower in T3 (INR 60,200) than in T4 (INR 64,100). Higher cost of production with increased stocking density could be due to the increase in variable costs, mainly due to the higher initial seed costs for higher stocking densities and costs for increased supplementary feed requirements. But highest net benefit was obtained in T4 (INR 25,900) followed by T3 (INR 5,800) and Benefit Cost Ratio was also found better in T4 (1.40:1) than T3 (1.10:1). Although Treatments having stocking densities with 100 and 250 larvae/m<sup>3</sup> have higher length, weight, growth rate, survival and less days to achieve fry stage, they have lesser net benefit and B:C ratio. Thus, the study clearly indicated that other production and financial indicators like overall yield, net benefit and benefit: cost ratio are stocking density-dependent. Other authors reported good profitability through rearing of fish species at different stocking densities in

earthen ponds (Abou, Oké, & Odountan, 2016; Shoko, Limbu, Mrosso, Mkenda, & Mgaya, 2016), and under such circumstances, the adoption of hapa-based nursery rearing in existing village ponds represents a viable and efficient alternative for ensuring adequate seed production for sustainable fish culture. Profits in seed rearing practices are higher and many farmers are ready to invest in such operations (Biswas et al., 2006). The results of the present study indicates that the rohu stocked in hapa with 750 larvae/m<sup>3</sup> obtained good growth rate and survival with higher net production. Thus, it can be stated that stocking density with 750 larvae/m<sup>3</sup> can be optimal for rearing of rohu larvae under hapa production system in village ponds.

The study highlighted the impact of stocking density on growth performance, survival, overall yield and economic return of nursery rearing of *L. rohita* larvae to fry in hapa production systems installed in community ponds located in the rural areas of the state of Gujarat wherein Indian major

carps are the dominating group of food fish species in entire aquaculture production sector. Stocking density significantly impacted the production and financial parameters like overall yield, net benefit and benefit-cost ratio while undertaking nursery raising of rohu in hapa production systems, with the highest stocking density up to treatment T4 realising the highest profits within a single production season. Thus, the study had clearly indicated the upper limit of stocking density for nursery raising of rohu fry to obtain maximum overall yield along with maximum net benefits. The study recommends a stocking density of *L. rohita* larvae at 750 larvae/m<sup>3</sup> for achieving high fry production with higher net benefits under hapa production systems installed in village ponds. The findings of the study are useful for the rural farmers for nursery raising of Indian major carps on their existing grow out farm ponds in rural areas through ease in installation of hapa production systems. The results are based on the given conditions indicated in the culture systems and these results should be strengthened by conducting a broader study that examines multiple weather variables, pond productivity factors, overall seed health, seed quality, and an economic evaluation, in order to better disentangle the wider impacts of stocking density in carp nursery seed production programmes.

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### References

- Abou, Y., Oké, V., & Odountan, H. O. (2016). Effects of stocking density on growth, production and farming portability of African catfish, *Clarias gariepinus* (Burchell, 1822) fed chicken viscera-diet in earthen ponds. *International Journal of Biosciences*, 6(6), 404–414. <http://dx.doi.org/10.12692/ijb/9.6.404-8>
- Ail, S. K. S., Misra, C. K., Chaudhari, A. K., Landge, A., Dube, K., Nayak, B. B., & Shenoy, L. (2019). Comparative analysis of fish culture methods in village ponds of Gujarat. *Fishery Technology*, 56(4), 254–260.
- Ail, S. K. S., Devadas, D., Sudhan, C., Misra, C. K., Chaudhari, A. K., Landge, A., Dube, K., Nayak, B. B., & Shenoy, L. (2021). Plankton diversity and dominance in three undrainable village pond aquaculture systems. *Proceedings of the National Academy of Sciences, India Section: B Biological Science*, 91(2), 391–396. <https://doi.org/10.1007/s40011-021-01224-3>
- American Public Health Association. (2005). *Standard methods for the examination of water and wastewater* (19th ed.).
- Ayyappan, S., & Jena, J. K. (2001). Sustainable freshwater aquaculture in India. In T. J. Pandian (Ed.), *Sustainable Indian fisheries* (pp. 88–133). National Academy of Agricultural Science.
- Ayyappan, S., & Jena, J. K. (2003). Indian fisheries and aquaculture: Present status and future prospects. In *Fish for all: National launch* [Souvenir] (pp. 12–24).
- Bairwa, M. K., Swain, S. K., Prusty, S., Das, A., & Ail, S. K. S. (2021). Effect of tank colour on growth performance and survival during larval rearing of Koi carp (*Cyprinus carpio*). *Fishery Technology*, 58(2), 77–82.
- Biswas, G., Jena, J. K., Singh, S. K., Patmajhi, P., & Muduli, H. K. (2006). Effect of feeding frequency on growth, survival and feed utilization in mrigal, *Cirrhinus mrigala*, and rohu, *Labeo rohita*, during nursery rearing. *Aquaculture*, 254(1-4), 211–218. <https://doi.org/10.1016/j.aquaculture.2005.08.001>
- Boyd, C. E. (1990). *Water quality in ponds for aquaculture*. Alabama Agricultural Experiment Station, Auburn University.
- Boyd, C. E., & Tucker, C. S. (1998). *Pond aquaculture water quality management*. Kluwer, Academic Publishers.
- Central Inland Fisheries Research Institute. (1985). *Carp culture: Package of practices for increasing production* [Aquaculture Extension manual No. 2]. Central Inland Fisheries Research Institute.
- Chaudhari, A. K., Ail, S. K. S., Misra, C. K., De, H. K., Rathod, R., Bhatt, J. H., & Swain, S. K. (2023). Status of freshwater aquaculture in Gujarat: A trend analysis and potential. *International Journal of Bio-resource and Stress Management*, 14(1), 59–67. <https://doi.org/10.23910/1.2023.3284a>
- Chowdhury, M. A., Roy, N. C., & Chowdhury, A. (2020). Growth, yield and returns of striped catfish (*Pangasianodon hypophthalmus*) at different stocking densities under floodplain cage culture system. *Egyptian Journal of Aquatic Research*, 46, 91–95. <https://doi.org/10.1016/j.ejar.2019.11.010>
- Chowdhury, R. H., Saha, S. B., Islam, M. N. & Das, N. G. (2002). Production of Thai catfish (*Pangasius sutchii* Fowler), in the coastal impoundments of Cox's Bazar at different stocking densities. *Journal of Aquaculture in the Tropics*, 17(3), 231–240.
- Commissioner of Fisheries. (2024). *Fisheries statistics of Gujarat state 2022-23 & 2023-24*. Commissioner of

- Fisheries, Government of Gujarat. <https://cof.gujarat.gov.in/Index>
- Das, P. C., Jena, J., Patro, B., & Mahanta, D. (2016). High density rearing of rohu, *Labeo rohita* (Hamilton) from spawn to fry in concrete tanks: Effect of daily feed ration and soil base on fry growth and survival. *Aquaculture Research*, 47(12), 3973–3979. <https://doi.org/10.1111/are.12847>
- Department of Fisheries. (2023). *Handbook on fisheries statistics 2022*. Department of Fisheries, Government of India.
- Edwards, P. (2000). *Aquaculture, poverty impacts and livelihoods*. Overseas Development Institute.
- Ferosekhan, S., Sahoo, S. K., Radhakrishnan, K., Velmurugan, P., Shamna, N., Giri, S. S., & Pillai, B. R. (2020). Influence of rearing tank colour on Asian catfish, magur (*Clarias magur*) and pangas (*Pangasius pangasius*) larval growth and survival. *Aquaculture*, 521, Article 735080. <https://doi.org/10.1016/j.aquaculture.2020.735080>
- Jena, J. K. (1998). *Input management in carp culture for optimisation of production levels* [Ph. D. Thesis, Orissa University of Agriculture and Technology].
- Jena, J. K., Aravindakshan, P. K., & Singh, W. J. (1998). Nursery rearing of Indian major carp fry under different stocking densities. *Indian Journal of Fisheries*, 45(2), 163–168.
- Jena, J. K., & Das, P. C. (2006). Carp culture. In S. A. Verma, A. T. Kumar, & S. Pradhan (Eds.), *Handbook of fisheries and aquaculture* (pp. 265–282). Indian Council of Agricultural Research.
- Jena, J. K., Mukhopadhyay, P. K., Sarkar, S., Aravindakshan, P. K., & Muduli, H. K. (1996). Evaluation of a formulated diet for nursery rearing Indian major carp under field condition. *Journal of Aquaculture in the Tropics*, 11, 299–305.
- Liu, Y., Liu, H., Wu, W., Yin, J., Mou, Z., & Hao, F. (2019). Effect of stocking density on growth performance and metabolism of juvenile Lenok (*Brachymystax lenok*). *Aquaculture*, 504, 107–113. <https://doi.org/10.1016/j.aquaculture.2019.01.058>
- Mohanty, U. K. (1995). *Comparative evaluation of growth and survival of Indian major carp fry in aerated vis-à-vis non-aerated ponds under different stocking densities* [Master's Thesis, Orissa University of Agriculture and Technology].
- Munsiri, P., Boyd, C. E. & Hajek, B. F. (1995). Physical and chemical characteristics of bottom soil process in ponds at Au-burn, Alabama, USA and a proposed method for describing pond soil horizons. *Journal of the World Aquaculture Society*, 26(4), 346–377. <https://doi.org/10.1111/j.1749-7345.1995.tb00831.x>
- Prescott, J. A., Taylor, J. K., & Marshall, T. J. (1934). The relationship between the mechanical composition of the soil and the estimate of texture in the field. In *Transactions of the First Commission of the International Society of Soil Science* (pp. 143–153). Thomas Murby & Co.
- Press Information Bureau. (2026, January 12). *Fish production has increased to 197.75 lakh tonnes in FY 2024-25 from 95.79 lakh tonnes fish production in FY 2013-14 increasing a significant 106%*. <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2213532&reg=3&lang=1>
- Rafaey, M. M., Li, D., Tian, X., Zhang, Z., Zhang, X., Li, L., & Tang, R. (2018). High stocking density alters growth performance, blood biochemistry, intestinal histology and muscle quality of channel catfish (*Ictalurus punctatus*). *Aquaculture*, 492, 73–81. <https://doi.org/10.1016/j.aquaculture.2018.04.003>
- Rahman, M. M., Islam, M. S., Halder, G. C., & Tanaka, M. (2006). Cage culture of sutchi catfish, *Pangasius sutchi* (Fowler, 1937): Effects of stocking density on growth, survival, yield and farm profitability. *Aquaculture Research*, 37(1), 33–39. <https://doi.org/10.1111/j.1365-2109.2005.01390.x>
- Sahu, P. K., Jena, J. K., & Das, P. C. (2007). Nursery rearing of kalbasu, *Labeo calbasu* (Hamilton), at different stocking densities in outdoor concrete tanks. *Aquaculture Research*, 38(2), 188–192. <https://doi.org/10.1111/j.1365-2109.2006.01648.x>
- Shoko, A. P., Limbu, S. M., Mrosso, H. D. J., Mkenda, A. F., & Mgaya, Y. D. (2016). Effect of stocking density on growth, production and economic benefits of mixed sex Nile tilapia (*Oreochromis niloticus*) and African sharptooth catfish (*Clarias gariepinus*) in polyculture and monoculture. *Aquaculture Research*, 47(1), 36–50. <https://doi.org/10.1111/are.12463>
- Singh, W. J. (1996). Comparative evaluation of growth and survival of Indian major carp fry reared in nursery ponds under different stocking densities [Master's Thesis, Orissa University of Agriculture and Technology].
- Slembrouck, J., Baras, E., Subagja, J., Hung, L. T., & Legendre, M. (2009). Survival, growth and food conversion of cultured larvae of *Pangasianodon hypophthalmus*, depending on feeding level, prey density and fish density. *Aquaculture*, 294(1–2), 52–59. <https://doi.org/10.1016/j.aquaculture.2009.04.038>
- Swingle, H. S. (1967). *Standardisation of chemical analysis for water and pond muds* (FAO Fisheries Report No. 44, pp. 397–421). Food and Agriculture Organization of the United Nations.
- Troell, M., Costa-Pierce, B., Stead, S., Cottrell, R. S., Brugere, C., Farmery, A. K., Little, D. C., Strand, A., Pullin, R., Soto, D., Beveridge, M., Salie, K., Dresdner,

- J., Moraes-Valenti, P., Blanchard, J., James, P., Yossa, R., Allison, E., Devaney, C., & Barg, U. (2023). Perspectives on Aquaculture's contribution to the sustainable development goals for improved human and planetary health. *Journal of World Aquaculture Society*, 54(2), 251–342. <https://doi.org/10.1111/jwas.12946>
- Viriyatum, R., & Boyd, C. E. (2011). Re-evaluation of potassium fertilisation of bluegill, *Lepomis macrochirus* ponds. *Journal of the World Aquaculture Society*, 42(3), 332–338. <https://doi.org/10.1111/j.1749-7345.2011.00471.x>
- Zahedi, S., Akbarzadeh, A., Mehrzad, J., Noori, A., & Harsij, M. (2019). Effect of stocking density on growth performance, plasma biochemistry and muscle gene expression in rainbow trout (*Onchorhynchus mykiss*). *Aquaculture*, 498, 271–278. <https://doi.org/10.1016/j.aquaculture.2018.07.044>