

Evaluation of growth performance and stock variance of common carp, *Cyprinus carpio* in inland saline aquaculture system

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Abstract

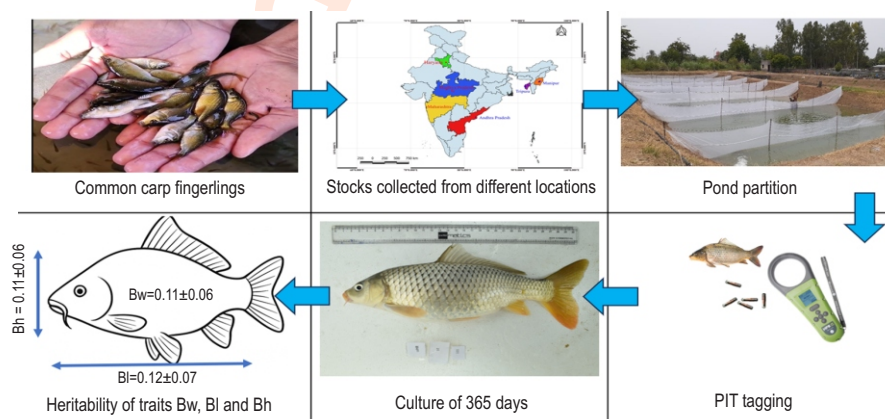
Aim: This study examined the growth performance of six geographical stocks of common carp, *Cyprinus carpio* a species that tolerates salinity up to 10 ppt, in saline water systems.

Methodology: Two growth experiments were conducted under low salinity (S1: 2-4 ppt) and high salinity (S2: 8-10 ppt) levels. In the first experiment (1-225 days), six stocks (MH, MN, TR, MP, HR, AP) were housed separately, and traits like body weight, length, and height were recorded. In the second experiment (225-365 days), fish were tagged and communally reared, with males and females kept separately.

Results: Significant variations in Body weight (Bw), Body length (Bl), and Body height (Bh) were observed among the stocks in the first experiment, with the MH stock performing best. In the second experiment, the least squares means of Bw was 354.59±10.04 g in S1 and 335.99±10.12 g in S2. The effect of Bw at tagging, salinity and sex by salinity interaction had a significant effect on Bw and Bh. Females in the S1 group exhibited the highest growth metrics (376.19±10.39 g, 21.39±0.43 cm, and 8.23±0.10 cm for Bw, Bl and Bh, respectively). Heritability estimates for growth traits (Bw: 0.11 ± 0.06; Bl: 0.12 ± 0.07; Bh: 0.11 ± 0.06) indicated moderate genetic variability, supporting the potential for a selective breeding program to develop fast growing common carp for inland saline aquaculture.

Interpretation: The study demonstrates the potential of selective breeding in common carp to culture in saline environment, offering a sustainable solution for utilizing degraded saline soils.

Key words: Common carp, Growth performance, Inland saline aquaculture, Salinity tolerance



Introduction

Currently India holds second position for fish production in the world. To meet the growing demand of fish, it is essential to utilize untapped resources with significant potential for aquaculture. This maybe in terms of diversification of culture species, use of unused land like salt affected area, wetland, etc. At present in India, 6.73 million hectares of land across 16 states in India are affected by salinity (ICAR-CSSRI, 2023). It has been suggested that every year nearly 10% additional area is getting salinized, and by the year 2050, around 50% of the total arable land would be affected by soil salinization (Kumar et al., 2020). Extraction of saline ground water is not preferable for irrigation but at the same time it provides considerable opportunity for utilization in aquaculture initiatives. Utilizing inland saline water bodies for aquaculture can significantly contribute to fish production and help address the growing demand for aquatic resources. Inland saline water differs from marine or brackish water, particularly due to low potassium concentration (Boyd et al., 2002; Roy et al., 2010). Therefore, selecting appropriate aquaculture species based on their salinity tolerance is critical.

Freshwater species like carps have been tested for ISW, offering a familiar choice for inland farmers. Brackish water species, including mullets and pearl spot, show moderate tolerance. Marine and high-salinity species such as milkfish (*Chanos chanos*), seabass (*Lates calcarifer*), rainbow trout (*Oncorhynchus mykiss*), and the shrimp *Litopenaeus vannamei* have also been successfully cultured in inland saline waters (Ansal et al., 2016; Bais, 2018; Partridge et al., 2006). Currently, the farmers are successfully culturing *L. vannamei* in ISW in different parts of the world. A major pitfall of culturing brackish or marine fish species in saline affected area is that they are cold intolerant and are unable to survive in extreme winter seasons. In addition, they require various ion amendments, which increases the production cost and water treatment problems post-culture season. Unavailability of seeds of brackish water species in Northern India is another issue that needs attention as transportation of seeds from other coastal regions adds additional cost to the farmers, except for high market price fetched species like shrimp (Ansal et al., 2016). On the other hand, freshwater species like common carp are salinity and cold tolerant offer a better alternative.

Common carp (*Cyprinus carpio*) is one of the most cultured fish species in the world (Kaur, et al., 2019; Yaqoob, 2021). As one of the dominant cyprinid species, it is cultured in over 100 countries worldwide and is the third major species produced in the world after grass carp and silver carp, accounting to 8 percent of total aquaculture production (FAOs, 2022). In India, common carp is cultured across the country and accounts for a significant fraction of carp seeds produced by state hatcheries. It is preferred due to high growth rate, sturdiness, easy breeding, and salinity and cold tolerant. Previous studies have reported that common carp can tolerate upto 10 ppt saline condition without showing mortality (Mangat et al., 2014 and

Singh et al., 2018). Genetic improvement programs are currently being undertaken in several species for enhancing their performance in saline water environments. The Sukamandi strain, a hybrid tilapia, shows stable growth at salinity level 30–58 ppt with a high survival rate of 82.7%, significantly outperforming Nile tilapia, which shows only 41.07% survival under similar high-salinity conditions (Setyawan and Robisalmi, 2014). Selective breeding of striped catfish (*Pangasianodon hypophthalmus*) for better performance in brackish water (10 ppt salinity) showed 18.0% improvement in growth and 11.4% increase in survival rate just after one generation of selection (Minh et al., 2022). In India, work is initiated to develop a faster-growing strain of common carp for low-salinity aquaculture, focusing on body weight at harvest as the key selection trait. Our previous study reported genetic diversity of six assembled stocks, which were further used for the formation of base population (Lalramnunsanga et al., 2024). The present study aimed to evaluate the growth performance of six geographical stocks of common carp under two salinity regimes (S1: 2–4 ppt and S2: 8–10 ppt) in an inland saline aquaculture system, for 365 days (one year production cycle) to identify high-performing stocks and generate baseline information for developing genetically superior, salinity-tolerant lines through selective breeding.

Materials and Methods

Study site: The experiment was performed at ICAR-Central Institute of Fisheries Education Rohtak Centre, Haryana during 2021–2022.

Study population: The population consisted of fingerlings assembled from six geographical regions of India, viz., Maharashtra, Manipur, Tripura, Madhya Pradesh, Haryana and Andhra Pradesh. The genetic diversity of stocks has been reported in our previous study by Lalramnunsanga et al. (2024). Each geographical population was assembled from various hatcheries. The assembled fish were transported to ICAR-CIFE, Rohtak Centre, Haryana. Two growth trial experiments were performed across two salinity levels viz., Low Saline (S1): 2-4 ppt and High Saline (S2): 8-10 ppt.

Preparation of experimental ponds: Two earthen ponds measuring 1000 m² (50m x 20m) were selected for the experiment. Each pond had six temporary compartment partitions (pen-like structures) of equal dimensions (8m x 20 m). The partition was done by fixing HDPE Monofilament fabric of 0.6 mm mesh size (LxH: 24x2.5 m²) (Fig. 1). The partition allowed the flow of water, and the fish stock remained isolated from other stocks in each compartment. This ensured that all fish stocks were exposed to same water quality and management, minimizing environmental variation. Each geographical stock was allocated to each of the six partitions in each pond, respectively. Each pond represented a particular level of salinity viz., Pond 1 – S1 and Pond 2 – S2. The ponds were prepared prior stocking, following best management practices (Jhingran, 1991). The pond bottom was plowed for about 1 foot; the dried cow dung



Fig. 1: Layout of the experimental ponds partitioned into six equal sections for rearing six stocks of common carp.

was applied @ 10,000 kg ha⁻¹ prior filling with water. Diammonium phosphate and urea were applied @ of 17.5 kg ha⁻¹ and 22 kg ha⁻¹, respectively, for the optimum growth of phyto and zooplanktons. After 15 days of fertilization, the fish were stocked for growth trials.

Source of inland saline groundwater and management:

Inland saline groundwater was extracted from two borewells located on the farm—one supplying freshwater and the other supplying saline water (8–10 ppt) and was delivered to the respective ponds. The saline water was directly fed to S2 salinity pond, whereas S1 salinity was obtained by intermixing 8 ppt water with freshwater (supplied from another borewell). About 30 percent of water was exchanged every week from each pond and refilled with the required salinity water. About 1.2–1.5 m of water depth was maintained in each pond. The hapas that partitioned the pond into various pen like structures were cleaned every week to allow optimum flow of water across. The physico-chemical parameters of water, viz., temperature, pH, dissolved oxygen, salinity, total hardness, alkalinity, calcium, and magnesium content, were recorded and quantified weekly. The fish were fed with a commercially available floating diet. Initially, for 3 months, the fish were fed with carp floating feed (size: 2mm, crude protein: 32 %, crude fat: 4 %) and later fed with the floating feed of size: 3mm, crude protein: 30 %, and crude fat: 4%. The fish were fed twice daily by the broadcasting method @ of 2% body weight. Regular sampling was performed to adjust the feeding ration.

Estimation of water quality parameters: The salinity of pond water was estimated by Multi-water parameter testing device (TOADKK sensor module WMS-24-1-10). Water parameters like, salinity, DO, total alkalinity, total hardness, calcium, magnesium,

pH, and temperature, were recorded daily. Dissolved oxygen, hardness, alkalinity, calcium, and magnesium content in water were estimated by the standard methods (APHA, 2023).

Growth evaluation:

Two growth experiments were conducted. The first experiment was of 225 days duration from August 2021 to February 2022. Six geographical stocks of common carp were exclusively stocked (density 10,000 ha⁻¹) in each hapa compartment in each pond, with specified salinity level. Body weight, Body length and Body height were recorded at 1, 30, 90, 120, 150, and 225 days pond age. Sampling was conducted monthly, except during peak winter period. To avoid stress-induced mortality, common during colder months due to physical handling and netting, sampling was deliberately avoided during this time. The body weight was recorded to the nearest 0.001kg using a portable weighing balance, while the Body length and Body height were recorded with a measuring scale to the nearest 0.01 cm. Prior recording, the fish were anaesthetised with 250 mg l⁻¹ of ms-222. Partial sampling was performed at 30, 90, 120, and 150 days of pond age, whereas complete sampling was performed at 1 and 225 days of pond age. At 225 days, the sex of the fish was recorded on the Basis of the release of milt, rough pectoral fins and operculum while the females were identified on the basis of the release of eggs on the application of pressure on the abdomen. The sex identification was possible as the 225 days of pond age coincided with the spawning season of common carp in North India (February, temperatures range 20–25°C).

The second growth trial was conducted in the same two ponds but with a single hapa partition. All the tagged fish stocks belonging to the same sex were now communally reared (the partition was performed sex-wise compartment in each pond). At

225 days of pond age, the harvested fish from each stock were tagged using PIT tags. The traits viz., Bw, Bl, Bh, and Sex were recorded for each fish. The growth trial growth 140 days (mean pond surface water temperature 21 to -34°C). The final harvesting was performed at 365 days of pond age, and all growth traits were recorded.

Statistical analyses: Statistical analysis was performed using SAS for Academics software. The data was initially tested for normality, invoking PROC UNIVARIATE. The exploratory analysis was performed invoking various procedures in SAS, viz., Frequency, means, univariate and sgplot. The effect of stock, salinity, and their interaction on Body weight at various pond ages was performed using the linear model (equation 1) in SAS, invoking PROC GLM. The ANOVA for Body length and Body height was also performed for the above using Eq. 1, except there was no covariate in the analysis. The pairwise comparison of means was performed by Tukey–Kramer Test at a significance level $\alpha < 0.01$.

$$Y_{ijk} = \mu + Bl + S_i + Sa_j + S_i * Sa_j + e_{ijk} \quad (\text{Eq. 1})$$

where, Y_{ijk} is the Body weight of k^{th} fish belonging to i^{th} stock reared in j^{th} salinity; μ is the common mean; Bl is the Body length as covariate; S_i is the effect of stock ($i = \text{MH, MN, TR, MP, HR and AP}$); Sa_j is the effect of salinity ($j = \text{salinity S1 and S2}$); $S_i * Sa_j$ is the interaction effect of stock by salinity; e_{ijk} is the residual.

The effect of stock was considered as a random effect (genetic effect) and the stock variance was estimated using the following mixed model (Eq. 2) by invoking PROC MIXED. The pairwise comparison of means was performed using the Tukey–Kramer test and a significance level was set at $\alpha < 0.01$.

$$Y_{ijk} = \mu + Bw_0 + S_i + Sa_j + Sb_k + Sa_j * Sb_k + e_{ijk} \quad (\text{Eq. 2})$$

where, Y_{ijk} is the growth related record of fish; μ is the common mean; Bw_0 is the Body weight at tagging; S_i is the random effect of stock (MH, MN, TR, MP, HR and AP); Sa_j is the fixed effect of j^{th} salinity (S1, S2); Sb_k is the fixed effect of sex (male, female); $Sa_j * Sb_k$ is the interaction effect of salinity and sex; e_{ijk} is the residual variance.

The broad sense heritability and its standard error were estimated by the Eq. 3 and 4.

$$H^2 = \frac{Vg}{Vp} \quad (\text{Eq. 3})$$

where, Vg is the Genetic variance; Vp is the Phenotypic variance; Standard error of H^2 was estimated by Dickerson and Delta method (Lynch and Walsh, 1988).

$$\text{Var} \left(\frac{x}{y} \right) \approx \left[\frac{\text{var}(X)}{E(X)^2} + \frac{\text{var}(Y)}{E(Y)^2} - \frac{2\text{cov}(X,Y)}{E(X)E(Y)} \right] \quad (\text{Eq. 4})$$

$$\text{Standard error} = \sqrt{\text{Var} \frac{x}{y}}$$

where, $\text{Var}(X)$ is the stock variance; $\text{Var}(Y)$ is the total variance; $\text{Cov}(X,Y)$ is the covariance between stock and total; $E(X)$ is the expectation of stock variance; $E(Y)$ is the expectation of total variance, respectively.

Results and Discussion

Water quality parameters like salinity, dissolved oxygen Total alkalinity, Total hardness, Calcium, Magnesium, pH, and Temperature are given in Table 1. Salinity was maintained at 2- 4 ppt in S1 pond and 8-10 ppt in S2 pond throughout the experiment. Total hardness in S1 ranged between 480-1080 (mg l^{-1}) and 2170-2420 (mg l^{-1}) in S2. The mean surface water temperature during the first growth trial was 16°C (range 10-22°C) and during second growth trial it was 27.5°C (range 21–34°C). Descriptive statistics for the first growth trial (1-225 pond age) viz., number, mean and Coefficient of Variation is given in Table 2. The mean Bw, Bl, and Bh at stocking were 13.40 g, 7.45 cm and 2.69 cm, respectively. At 225 days pond age the mean Bw, Bl and Bh was 159.59 g, 16.60 cm and 6.07cm, respectively. At stocking, there were 1800 fish, and at 225 days pond age, 1468 fish were recovered. The CV for Bw, Bl, and Bh at stocking was 54.09, 16.33 and 17.33%; however, at 225 days pond age, the CV for Bw, Bl and Bh reduced to 32.64, 10.64 and 13.03% respectively. Among traits, the Bw had higher CV compared to Bl and Bh at stocking as well as at 225 pond age.

The least squares means for Bw, Bl and Bh across various pond ages, stock wise, salinity wise and their interaction is provided in Table 3 (a,b). LS-means are the adjusted averages that help remove bias in unbalanced data, such as biological datasets where sample sizes often vary. At stocking (Pond age 1), no significant difference was observed in LS means Bw across stock (14.06 – 14.81 g), except for Tripura (12.54 g) and Haryana (10.61 g) stocks. However, at Pond age 225, the Maharashtra stock had significantly the highest Bw (189.31 g) followed by Madhya Pradesh and Manipur stocks, whereas the Tripura stock had the lowest Bw (136.02 g) (Fig. 2). At stocking, no significant difference in LS means Bl across all stocks (mean Bl: 7.02 – 7.98 cm) was recorded. However, at Pond age 225, the stock had significantly the highest Bl (17.16 cm) whereas the Haryana stock had significantly the lowest Bl (16.10 cm) respectively. At stocking, the Andhra Pradesh and Manipur stocks had significantly the highest Bh (2.92 and 2.93cm) compared to other stocks. However, at 225 days Pond age, the Maharashtra stock had significantly the highest LS means Bh (6.73 cm) followed by Manipur and Madhya Pradesh (6.37 cm and 6.32 cm), respectively.

Across salinity levels, no significant differences were recorded in LS means for Bw, Bl and Bh at stocking. However, at 225 days of Pond age, the LS mean Bw at S1 was significantly higher (165.71 g) than at S2 (154.93 g) (Fig. 3). Similarly, Bl was significantly higher at S1 (16.81 cm) in comparison to S2. No significant differences in Bh were observed between the two salinity levels. The effect of Bl and stock was significant on Bw at all Pond ages (Table 4 a,b). However, the effect of salinity on Bw was significant only at 45, 75, 105, and 225 days of Pond age. The

Table 1: Water quality parameters in low saline and high saline ponds

Parameters		Low saline pond (S1)	High saline pond (S2)
pH		7.75-8.85	7.75-8.85
Salinity (ppt)		2-4 ppt	8-10 ppt
Dissolved oxygen (mg l ⁻¹)		2-8	2-8
Total Alkalinity (mg l ⁻¹)		206-260	210-276
Total Hardness (mg l ⁻¹)		480-1080	2170-2420
Calcium (mg l ⁻¹)		66-132	232-300
Magnesium (mg l ⁻¹)		153-189	342-442
Temperature (°C)	Growth trial-1	10-22	10-22
	Growth trial-2	21-34	21-34

Table 2: Descriptive statistics for first growth trial (1-225 Pond age)

	Number	Body weight (g)		Body length (cm)		Body height (cm)	
		Mean	CV(%)	Mean	CV(%)	Mean	CV(%)
At Stocking	1800	13.40	54.09	7.45	16.33	2.69	17.33
At 225 days Pond age	1468	159.59	32.64	16.60	10.64	6.07	13.03

CV (%): Coefficient of Variation

stock by salinity interaction effect on Bw was significant at 45 and 225 days of Pond age. The stock had a significant effect on BI at all Pond ages. The effect of salinity and stock by salinity interactions on BI was significant only for 105 and 225 days of Pond age. The stock, salinity, and stock by salinity interaction had a significant effect on Bh at 225 days of Pond age. Basavaraju *et al.* (2002), studied the growth performance of different common carp stocks of Karnataka. They found the Amur carp from Hungary performed better than the stocks collected from Vietnam and local hatcheries. In the present study, the Maharashtra stock exhibited the highest growth performance in terms of body weight and body height. The observed variation in performance among stocks, with significant differences in mean growth traits, reflects underlying genetic diversity and suggests the presence of useful alleles for selective breeding (Notter, 1999).

In the present study, survival at 225 days was 81%, which was higher than the 70% survival reported by Singh *et al.* (2023) after 120 days of culture at 8 ppt salinity. Similarly, in a recent study, Nagaraja *et al.* (2025) reported up to 93% survival rate after 200 days of culture at 6.7 ppt salinity. In the present study, a significant difference was observed in Bw across (approximately 9 g). Emeish (2019) reported that common carp can grow in salinities up to 6 ppt after one month of culture without adverse effects. Boeuf and Payan (2001) also reported that moderate salinity enhances fish growth by optimizing osmotic balance, thereby reducing energy costs. An increase in growth rate of fresh water fishes was reported by increasing the salinity level upto certain level in common carp at 2ppt (Boeuf and Payan, 2001), Grass carp at 2ppt (Konstantinov, 1993), *Oreochromis niloticus* at

8 ppt (Likongwe *et al.*, 1996), respectively.

Descriptive statistics for second growth trial (225-365 Pond age) are presented in Table 5. About 1468 tagged fish were stocked and at 365 days of Pond age, 1132 tagged fish were recovered. At stocking, the mean Bw, BI and Bh was 159.59 g, 16.60 cm and 6.07 cm. At 365 days Pond age, the mean Bw, BI and Bh was 347 g, 21.18 cm and 7.89 cm, respectively. The CV (%) for Bw, BI and Bh at stocking was 32.64, 10.73 and 13.04. At harvest, the CV for Bw, BI, and Bh was 33.79, 11.07 and 12.88. Among the traits, Bw exhibited a higher CV (%) compared to BI and Bh, both at stocking and 365 days of Pond age, respectively. The LS means for Bw, BI and Bh, sex-wise, salinity-wise, and their interaction for the second growth trial are presented in Table 6. In terms of salinity, fish reared in S1 (low salinity) had significantly higher LS means for body weight (354.59 g) and body height (7.94 cm) compared to those in S2 salinity levels (Fig. 4). However, the body length did not differ significantly between salinity levels. Regarding sex, males showed significantly higher LS means for BI (21.30 cm) compared to females, while no significant differences were observed in Bw and Bh between sexes. Notably, females reared in S1 Pond exhibited the highest values for all traits (Bw: 376.19 g, BI: 21.39 cm and Bh: 8.23 cm (Fig. 5). The results obtained from Type 3 fixed effects (Table 7) indicate that the effect of Body weight at tagging, salinity and sex by salinity interaction had a significant effect on Body weight and Body height whereas only salinity had no significant effect on Body length.

In the current study, at 365 days of Pond age, salinity

Table 3: Least square means of growth parameters (1-225 Pond age)

Stocks	1 day			45 day			75 day			105 day		
	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)
Andhra Pradesh	14.06±0.14 ^a	7.98±0.07 ^a	2.92±0.03 ^a	61.04±0.88 ^{bc}	12.52±0.15 ^a	4.47±0.06 ^{ab}	90.75±1.17 ^{bc}	14.04±0.16 ^a	4.86±0.06 ^b	138.62±1.20 ^{bc}	15.66±0.11 ^{bc}	5.90±0.05 ^{bc}
Haryana	10.61±0.13 ^c	7.54±0.07 ^{bc}	2.54±0.03 ^b	60.39±0.87 ^c	12.21±0.15 ^a	4.33±0.06 ^{ab}	91.87±1.18 ^{bc}	13.86±0.16 ^a	4.94±0.06 ^b	135.63±1.21 ^{cd}	15.38±0.12 ^c	5.69±0.05 ^c
Manipur	14.36±0.15 ^{ab}	7.91±0.07 ^{ab}	2.93±0.03 ^a	66.46±0.89 ^a	12.98±0.15 ^a	4.67±0.06 ^a	95.23±1.20 ^{ab}	14.87±0.17 ^a	5.44±0.06 ^a	143.66±1.20 ^b	16.37±0.11 ^{ab}	6.36±0.04 ^a
Maharashtra	14.38±0.14 ^a	7.02±0.07 ^d	2.60±0.03 ^b	68.99±0.88 ^a	12.33±0.15 ^a	4.60±0.06 ^{ab}	102.16±1.19 ^a	13.99±0.17 ^a	5.23±0.06 ^{ab}	153.64±1.21 ^a	15.85±0.12 ^{abc}	6.39±0.05 ^a
Madhya Pradesh	14.81±0.15 ^a	7.02±0.07 ^d	2.57±0.03 ^b	68.67±0.88 ^a	12.52±0.15 ^a	4.68±0.06 ^a	102.54±1.16 ^a	13.97±0.16 ^a	5.17±0.06 ^{ab}	151.43±1.21 ^a	15.49±0.12 ^c	6.15±0.05 ^{ab}
Tripura	12.54±0.13 ^b	7.25±0.07 ^{cd}	2.60±0.03 ^b	58.71±0.88 ^c	12.67±0.15 ^a	4.27±0.06 ^c	86.48±1.16 ^c	14.60±0.16 ^a	4.90±0.06 ^b	128.35±1.28 ^d	16.44±0.12 ^a	5.86±0.05 ^{bc}
(S1)	13.42±0.08 ^a	7.49±0.04 ^a	2.69±0.01 ^a	66.03±0.51 ^a	12.55±0.09 ^a	4.49±0.03 ^a	96.50±0.67 ^a	14.35±0.09 ^a	5.15±0.03 ^a	145.79±0.70 ^a	15.98±0.07 ^a	6.17±0.03 ^a
(2-4ppt)												
(S2)	13.50±0.08 ^a	7.42±0.04 ^a	2.70±0.02 ^a	62.06±0.51 ^b	12.52±0.09 ^a	4.52±0.03 ^a	93.17±0.68 ^a	14.09±0.09 ^a	5.03±0.03 ^a	137.99±0.70 ^b	15.75±0.07 ^a	5.95±0.03 ^b
(8-10ppt)												
Stocks	165 day			195 day			225 day					
Stocks	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)
Andhra Pradesh	160.54±2.34 ^{bc}	17.30±0.21 ^a	6.85±0.09 ^{ab}	164.40±2.21 ^{bc}	16.59±0.16 ^a	6.15±0.06 ^{abc}	146.01±1.39 ^c	16.40±0.10 ^{bc}	5.74±0.04 ^c			
Haryana	159.29±2.43 ^{bc}	16.40±0.21 ^a	6.42±0.09 ^b	156.77±2.26 ^{cd}	16.49±0.17 ^a	6.03±0.06 ^{bc}	152.28±1.56 ^c	16.10±0.11 ^c	5.70±0.04 ^c			
Manipur	158.40±2.30 ^{bc}	17.59±0.20 ^a	6.95±0.09 ^{ab}	164.55±2.26 ^{bc}	17.12±0.17 ^a	6.41±0.06 ^{ab}	166.52±1.52 ^b	16.95±0.11 ^{ab}	6.37±0.04 ^b			
Maharashtra	176.20±2.33 ^a	17.33±0.21 ^a	7.17±0.09 ^a	182.13±2.27 ^a	16.78±0.17 ^a	6.51±0.07 ^a	189.31±1.52 ^a	16.58±0.11 ^{abc}	6.73±0.04 ^a			
Madhya Pradesh	171.10±2.41 ^{ab}	17.45±0.21 ^a	7.13±0.09 ^a	176.87±2.26 ^{ab}	17.01±0.17 ^a	6.51±0.06 ^a	171.78±1.63 ^b	16.43±0.12 ^{bc}	6.32±0.05 ^b			
Tripura	148.19±2.86 ^d	17.60±0.25 ^a	6.60±0.11 ^{ab}	147.97±2.26 ^d	17.33±0.17 ^a	5.95±0.06 ^c	154.93±0.88 ^d	17.16±0.11 ^a	5.68±0.04 ^c			
(S1) (2-4ppt)	161.24±1.38 ^a	17.48±0.12 ^a	6.91±0.05 ^a	165.09±1.30 ^a	17.00±0.10	6.35±0.04 ^a	136.02±1.58 ^d	16.81±0.06 ^a	6.02±0.02 ^a			
(S2) (8-10ppt)	163.33±1.45 ^a	17.08±0.13 ^a	6.79±0.05 ^a	165.81±1.30 ^a	16.78±0.10	6.16±0.04 ^a	165.71±0.89 ^b	16.40±0.06 ^b	6.16±0.03 ^a			

Bw- Body weight; Bl- Body length; Bh- Body height; a, b, c, d as superscript letters are significant different means

Table 4: Mean Sum of Squares for growth parameters

Culture age	1 day			45 day			75 day			105 day		
	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)
BI	5.55±0.05*			12.46±0.26*			16.47±0.32*			23.23±0.28*		
Stock	744.87*	50.69*	9.13*	1655.28*	5.83*	2.55*	3426.44*	13.98*	4.29*	20613.96*	44.99*	18.68*
Salinity	2.76	2.28	0.08	1901.22*	0.15	0.11	1354.63*	8.39	1.54	20809.61*	18.83*	17.11*
Stock*Salinity	3.12	2.58	0.49	188.96*	1.99	0.57	106.66	4.56	0.50	381.00	9.46*	1.66*
EMS	5.41	1.33	0.19	62.02	1.89	0.26	112.44	2.20	0.29	337.33	3.10	0.47
EMS(DF)	1698	1699	1699	471	472	472	481	482	482	1364	1365	1365
R ² (%)	89	10	12	84	4	11	85	8	15	84	6	15
	165 day			195 day			225 day					
Culture age	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)	Bw (g)	Bl (cm)	Bh (cm)
BI	25.97±0.51*			25.35±0.55*			24.82±0.36*			24.82±0.36*		
Stock	7457.57*	16.46*	7.08*	16133.17*	11.01*	6.31*	90777.47*	6.31*	6.31*	36.03*	36.03*	47.97*
Salinity	518.33	19.58	1.85	79.42	7.32	5.40*	41529.35*	5.40*	5.40*	60.24*	60.24*	6.78*
Stock*Salinity	69.14	13.48	3.30*	400.54	6.20	0.54	5923.86*	0.54	0.54	9.29*	9.29*	1.76*
EMS	479.45	3.76	0.67	520.88	2.85	0.42	563.81	0.42	0.42	2.94	2.94	0.45
EMS(DF)	483	484	484	605	606	606	1455	1455	1455	1456	1456	1456
R ² (%)	85	8	14	79	5	13	79	5	13	6	6	28

Bw- Body weight; Bl- Body length; Bh- Body height; EMS-Error means square; *Significant at P < 0.05

Table 5: Descriptive statistics for second growth trial (225-365 days)

Source/Variables	Body weight (g)			Body length (cm)		Body height (cm)	
	N	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)
At stocking	1468	159.59	32.64	16.60	10.73	6.07	13.04
At harvest	1132	347	33.79	21.18	11.07	7.89	12.88

CV: Co-efficient of Variation

Table 6: Least square means for growth parameters (225-365 days)

SV	Variables	Body weight (g)	Body length (cm)	Body height (cm)	
Sex	Female	341.48±10.12 ^a	21.01±0.20 ^a	7.91±0.09 ^a	
	Male	349.10±10.08 ^a	21.30±0.20 ^b	7.83±0.09 ^a	
Salinity	S1	354.59±10.04 ^a	21.11±0.20 ^a	7.94±0.09 ^a	
	S2	335.99±10.12 ^b	21.20±0.20 ^a	7.80±0.09 ^b	
Sex*Salinity	Female	S1	376.19±10.39 ^a	21.39±0.21 ^a	8.23±0.10 ^a
	Female	S2	306.77±10.66 ^b	20.63±0.21 ^b	7.58±0.10 ^b
	Male	S1	332.98±10.40 ^c	20.82±0.21 ^b	7.65±0.10 ^b
	Male	S2	365.21±10.50 ^a	21.77±0.21 ^c	8.02±0.10 ^c

S1- Low salinity; S2- High salinity; a, b, c as superscript letters are significant different means

Table 7: Fixed effects at 365 days Pond age

Source/Variable	Num Degree of freedom	Den Degree of freedom	F value		
			Body weight	Body length	Body height
Initial body weight	1	1122	1928.67*	2188.49*	1130*
Sex	1	1122	3.32	12.27*	3.30
Salinity	1	1122	21.56*	1.44	11.97*
Sex*Salinity	1	1122	160.75*	114.38*	170.52*

*Significant at P <0.05

Table 8: Genetic Variance at 365 Pond age

	Genetic variance	Phenotypic variance	Heritability
Body weight	561.82	5000.99	0.11±0.06
Body length	0.24	2.02	0.12±0.07
Body height	0.05	0.48	0.11±0.06

significantly influenced the body weight. The least square mean body weight was 354.59 g in S1 and 335.99 g in S2 salinity levels. Emeish *et al.* (2019) studied the adaptability of common carp to different salinity levels and reported that growth and survival remained stable up to 6 ppt, while further increase (≥ 8 ppt) caused a significant decline in body weight and feed conversion efficiency. Similarly, Ahmed and Jaffar (2022) observed that juvenile common carp exhibited reduced growth rate, weight gain, and feed intake as salinity increased, although survival remained high even at elevated salinity levels of 9–12 ppt. In

another study, *Cyprinus carpio haematopterus* reared in inland saline water showed the highest weight gain and specific growth rate at 0–5 ppt salinity, with growth decreasing beyond this level (Singh *et al.*, 2020). In the present study, the fish were stocked in August and experienced three winter months with temperatures ranging 10–22°C. The low temperature during winter significantly retarded the growth in common carp during the first growth trial as compared to the second growth trial. Dawood *et al.* (2022) evaluated common carp exposed to salinity levels of 0–20 ppt followed by a heat stress of 32°C. They reported reduced weight

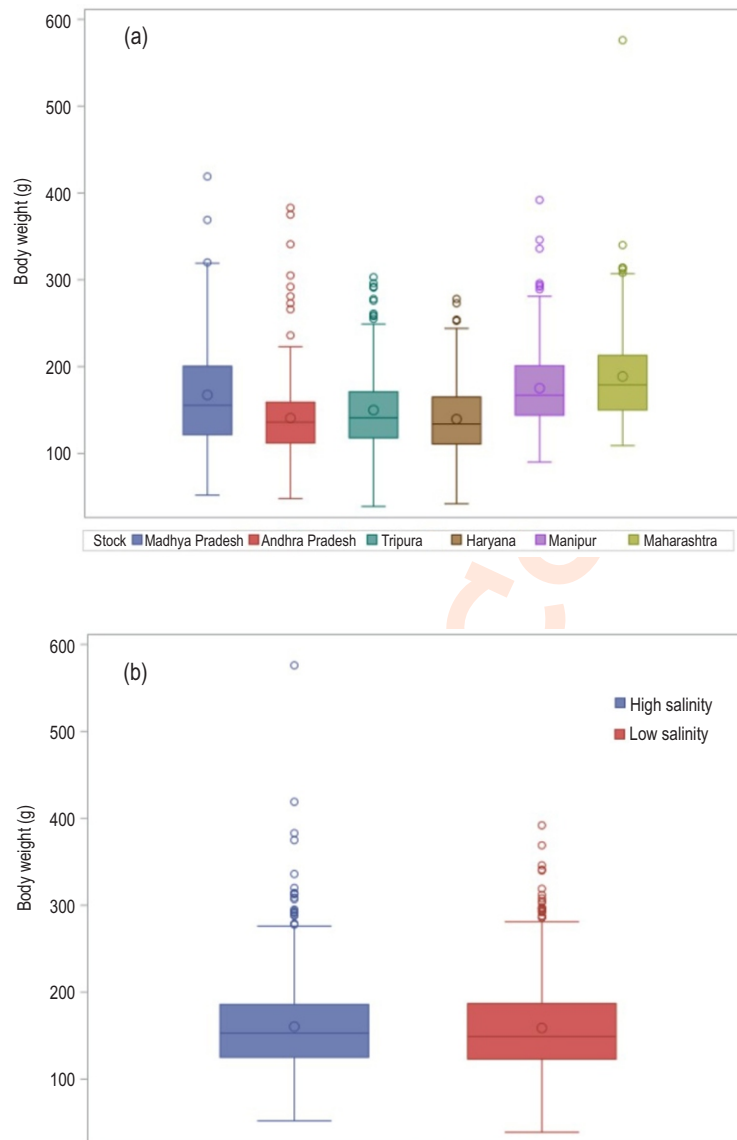


Fig. 2: Distribution of Body weight (a) stock-wise and (b) salinity wise at 225 days Pond age

gain, feed efficiency, and immune enzyme activity, along with elevated oxidative stress at 15–20 ppt salinity and under thermal challenge.

The coefficient of variation for body weight was approximately 33%, which is comparable to 28% reported by Lalramnunsanga *et al.* (2024), however, notably lower than 70% reported by Dong *et al.* (2015) for fish of similar size. At 365 days of Pond age, 77.09% of the tagged fish were recovered which was lower than the recovery observed in the first experimental trial. The reduced survival may be attributed to higher water temperature (34°C) combined with salinity stress, which likely impacted fish survival in comparison to the initial trial. Females in S1 (low salinity)

group exhibited significantly higher body weight, body length and body height, which may be attributed to early maturation and higher gonadosomatic index (Wagaw *et al.*, 2024).

In common carp, the females are generally heavier than males, a difference often linked to greater body size to accommodate the gonadal mass in females (Barakov *et al.*, 2024). The estimates of Genetic variance, Environmental variance and Phenotypic variance and broad sense heritability along with their standard errors for growth-related traits at 365 days pond age are presented in Table 8. The broad sense heritability, along with SE for Bw, BI and Bh was 0.11, 0.12 and 0.11, respectively. The growth-related traits in the present study

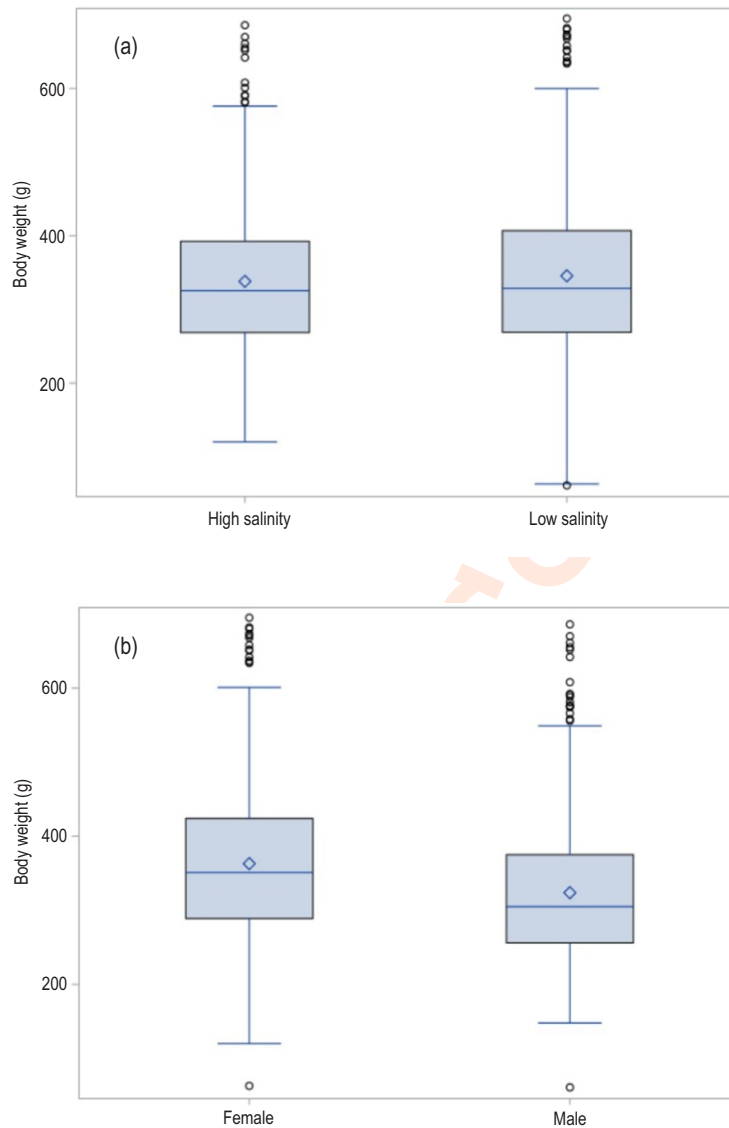


Fig. 3: Distribution of Body weight (a) salinity wise and (b) sex wise at 365 days Pond age.

had low to medium heritability, which indicated a substantial genetic variance in growth-related traits. Similar reports on estimates of heritability in common carp has been reported earlier. The heritability of growth and stress-related traits in *Cyprinus carpio* has been reported as low to moderate. In *C. carpio* var. Quanzhounensis, family-based selection over two generations produced modest improvement, with heritabilities of 0.132 for body mass and 0.122 for body length (Xuesong *et al.*, 2022). Similarly, Dong *et al.* (2015) reported that a selection program targeting improvement of harvest body weight in common carp yielded a moderate heritability estimate for body weight (0.17 ± 0.05). Minh *et al.* (2022) reported heritability of 0.29 for body weight in the second generation on selective breeding for salinity tolerance up to 15 ppt in *Pangasianodon hypophthalmus*.

The present study revealed significant variation in growth performance among six geographical stocks of common carp cultured under two salinity regimes in inland saline water. Stocks maintained at low salinity (2–4 ppt) showed superior growth and survival. The growth traits in the present study exhibited low to medium heritability, providing essential baseline information for selective breeding towards genetic improvement of common carp for inland saline aquaculture.

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