Environment and Ecology 43 (4A) : 1171—1180, October—December 2025
Article DOI: https://doi.org/10.60151/envec/WKXQ6654
ISSN: 0970-0420 (Print), ISSN: 3049-3625 (Online)

Comparative Study of Morphometric Correlations in Green Rocket Shrimp, *Caridina hodgarti* (Kemp 1913) Concerning Sex Differences

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Received 4 October 2025, Accepted 2 December 2025, Published on 23 December 2025

ABSTRACT

The present investigation was undertaken to compare the morphometric correlations between major body components of male and female *Caridina hodgarti* (Kemp 1913), commonly known as the Green Rocket Shrimp, a freshwater atyid of ecological and aquacultural significance in India. Four morphometric traits—Total Length (TL), Carapace Length (CL), Abdominal Length (AL) and Rostrum Length (RL)—were measured from field-collected specimens and analyzed through linear regression models to evaluate inter-trait relationships and sex-linked growth variations. In males, weak to moderate positive correlations were recorded between TL and CL (R^2 = 0.1007), TL and AL (R^2 = 0.3666) and TL and RL (R^2 = 0.2001), while RL and CL also showed a moderate relationship (R^2 = 0.2175). A negative correlation between AL and CL (R^2 = 0.2274) indicated possible segmental trade-offs. In contrast, females exhibited stronger and more consistent proportional growth, especially between TL and AL (R^2 = 0.7008) and TL and RL (R^2 = 0.3229), whereas CL–AL (R^2 = 0.001) and RL–CL (R^2 = 0.0048) relationships were negligible. The results reveal marked sexual dimorphism in growth allometry, with females showing stable and reproductive-oriented body proportions, while males exhibited greater variability and segmental differentiation. This morphometric characterization provides useful baseline information for taxonomic identification, broodstock evaluation, population structure analysis and conservation management of freshwater atyid shrimps.

Keywords *Caridina hodgarti,* Morphometric analysis, Sexual dimorphism, Regression, Freshwater atyid shrimp.

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INTRODUCTION

Morphometric analysis, the quantitative assessment of organismal shape and size, is a cornerstone of fisheries biology, taxonomy, aquaculture, and ecological research. In decapod crustaceans such as shrimps and prawns, morphometric traits provide crucial insights into growth dynamics, sexual dimorphism, reproductive biology, and ecological adaptations (Costa *et al.* 2004, Anger and Moreira 1998). Standard morphometric parameters—including total length (TL), carapace length (CL), abdominal length (AL), and rostrum length (RL)—are widely employed to evaluate inter- and intra-specific variability, assess allometric growth, and monitor population structure in both natural and cultured stocks (Hartnoll 1978, Jayachandran 2001, Soundarapandian and Ananthan 2008, Mahapatra *et al.* 1997).

The Green Rocket shrimp, *Caridina hodgarti* (Kemp 1913), a freshwater shrimp species of the family Atyidae, is endemic to the Indian subcontinent and primarily inhabits hill streams, rivers, and lentic water bodies in northeastern India, particularly in the Eastern Himalayan foothills. This species has been reported in various habitats across Assam, West Bengal, Arunachal Pradesh, and parts of Bangladesh (Cai and Ng 2009, Kemp 1913, Raghunathan and Valarmathi 2007). Furthermore, the species has gained interest in the Indian ornamental shrimp trade due to its small size, transparency, and adaptability to captive environments.

Despite its ecological value and potential for ornamental aquaculture, detailed studies on the morphometric characterization of *C. hodgarti,* particularly regarding sex-based differences, remain scarce. Sexual dimorphism is a widespread phenomenon in crustaceans and often reflects evolutionary divergence in reproductive roles, mating behavior, or ecological niches (Sganga *et al.* 2016). Typically, females possess longer and broader abdomens to facilitate egg incubation and protection, while males may exhibit hypertrophied chelae, elongated rostrums, or specialized appendages used in agonistic or reproductive interactions (Jayachandran 2001). Such dimorphism is often expressed through allometric growth and can be reliably assessed through morphometric regressions.

In India, morphometric research has predominantly focused on palaemonid and penaeid prawns such as *Macrobrachium rosenbergii, Macrobrachium malcolmsonii* and *Peneaus monodon* all of which are economically significant (Mercy *et al.* 2007, Mahapatra *et al.* 1997). Comparatively, atyid shrimps like *Caridina* species remain understudied, with limited literature on their biometric growth patterns and population dynamics. However, their sensitivity to water quality and microhabitat changes makes them valuable candidates for bioassessment and ecological monitoring. In this context, *Caridina hodgarti* is an ideal model for studying morphometric and sexual dimorphism in a lesser-known but ecologically as well as economically relevant taxon.

The present study aims to conduct a comparative morphometric assessment of male and female *Caridina hodgarti* using linear regression models to examine correlations between TL, CL, AL, and RL. By exploring the strength and direction of these associations, this research seeks to identify sexually dimorphic trends, assess the degree of proportional growth, and understand the morpho-functional adaptations within and across sexes. Such studies offer baseline data for species-specific growth monitoring, taxonomic clarification, selective breeding practices, and conservation strategies—particularly in the face of increasing threats to freshwater biodiversity due to habitat degradation, pollution, and climate change.

Furthermore, this study contributes to bridging the knowledge gap between classical morphological taxonomy and modern aquacultural science by emphasising the functional significance of morphometric traits. With the growing interest in sustainable management and documentation of native aquatic biodiversity, detailed morphometric analyses of indigenous species like *Caridina hodgarti* are of both scientific and practical importance.

MATERIALS AND METHODS

Study area and sample collection

Specimens of Green Rocket shrimp were collected from freshwater streams and lentic water bodies in the Eastern Himalayan foothill regions of West Bengal and Assam, India, during March 2024–May 2025. The collection was carried out by local fishermen who transported the live specimens to Kolkata.

The study was conducted in the Fish Breeding Training Center, located in Kolkata 700152 (22.46°N, 88.41°E). The collected shrimps were carefully trans-

Fig. 1. Male *Caridina hodgarti.*

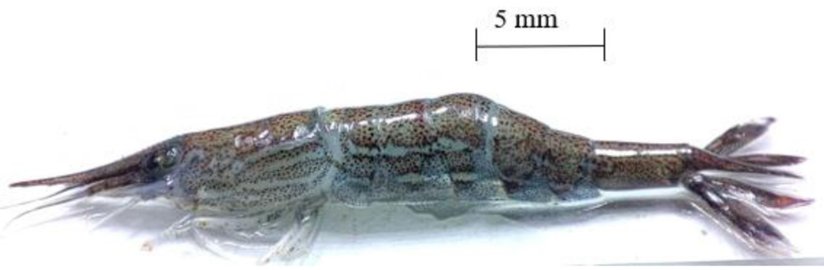

Fig. 2. Female *Caridina hodgarti.*

ferred into oxygenated containers and transported live to the laboratory. Upon arrival, the specimens were acclimatized in aerated freshwater tanks and subsequently anaesthetised using a clove oil solution (30 ppm) for morphometric analysis.

A total of 80 healthy adult specimens were selected for the study, comprising 30 males (Fig. 1) and 50 females (Fig. 2).

Morphometric measurements

The following morphometric parameters were recorded for each specimen using a digital vernier calliper with 0.01 mm precision:

Total length (TL): Measured from the tip of the rostrum to the end of the telson.

***Carapace length (CL)*:** Distance from the eye socket to the posterior margin of the carapace.

***Abdominal length (AL)*:** Length from the posterior margin of the carapace to the end of the telson (excluding the rostrum).

***Rostrum length (RL)*:** Measured from the tip of the rostrum to the orbital margin of the eye.

Each parameter was measured three times, and the mean value was used for statistical analysis to ensure accuracy and reduce observer error.

Sex determination

Sex was determined based on secondary sexual characteristics, such as the presence of the appendix masculine on the inner side of the males second pleopod, whereas females lacked this structure and generally exhibited a broader abdomen, often used for carrying eggs in ovigerous individuals. Additionally, rostral

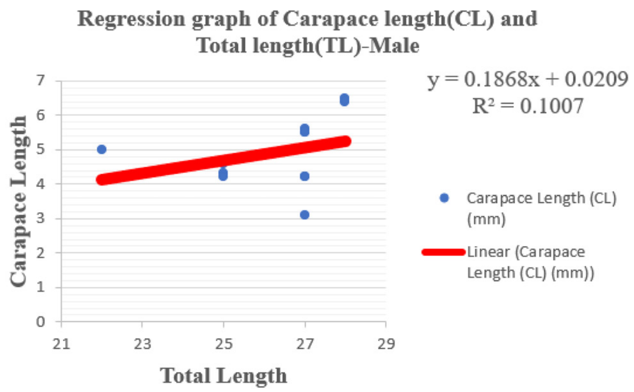

Fig. 3A. Regression graph of carapace length (CL) and total length (TL)-male.

morphology was considered for sex identification, with females exhibiting a pointed and sharp rostrum, while males displayed a blunt-ended rostrum.

Statistical analysis

The morphometric data were subjected to linear regression analysis using Microsoft Excel (Version 2019) and IBM SPSS Statistics (Version 25.0) to assess the relationships between various trait combinations for each sex. The regression models were evaluated using the equation: $Y = aX + b$

Where Y is the dependent variable (e.g., CL, AL, RL), X is the independent variable (typically TL or another morphometric trait), a is the slope, and b is the intercept.

The coefficient of determination (R^2) was used to interpret the strength of the relationship between the variables. A higher R^2 value indicates a stronger linear relationship. Separate regression equations were generated for males and females to facilitate comparison of sex-specific growth patterns.

Ethical considerations

All procedures involving live animals were carried out following ethical guidelines prescribed by the Institutional Animal Ethics Committee (IAEC) and adhered to CPCSEA norms (2020). No endangered or protected species were used in this study.

RESULTS

Carapace length–total length relationship

The regression graph (Fig. 3A) shows the relationship

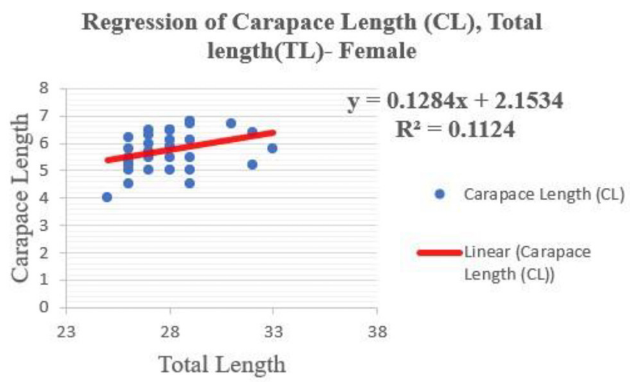

Fig. 3B. Regression graph of carapace length (CL) and total length (TL)-female.

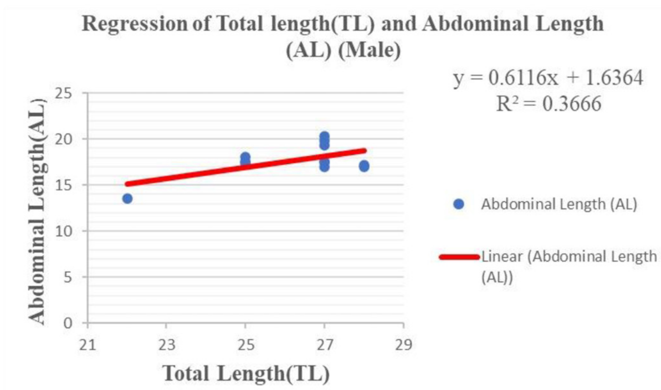

Fig. 4A. Regression of total length (TL) and abdominal length (AL) -male.

between carapace length (CL) and total length (TL) in male *Caridina hodgarti.* The linear equation, CL = 0.1868 × TL + 0.0209 (R^2 = 0.1007), indicates a weak positive correlation, with TL explaining only 10.07% of CL variation. This suggests high morphological variability among males, possibly due to biological or environmental factors.

The slope (b = 0.1868) is positive but <1, showing that CL increases with TL at a slower rate, reflecting negative allometric growth. Thus, males grow proportionally longer compared to carapace size. Despite the low R^2, the regression relationship is statistically significant ($p < 0.05$).

The regression analysis between carapace length (CL) and total length (TL) in female *Caridina hodgarti* gave the equation CL = 0.1284 × TL + 2.1534 (R^2 = 0.1124), indicating a weak positive correlation, with TL explaining only 11.24% of CL variation (Fig. 3B). Compared to males, females show a slightly stronger relationship, suggesting more consistent growth patterns, though overall variability remains high. The slope (0.1284) is positive but not statistically significant at the 5% level t (28) = 1.88, $p \approx 0.07$), being only marginally significant at the 10% level. Thus, the relationship between CL and TL in females is weak and only borderline significant.

Abdominal length-total length relationship

The regression analysis of total length (TL) and abdominal length (AL) in male *Caridina hodgarti* yielded the equation AL = 0.6116 × TL + 1.6364 (R^2 = 0.3666), showing a moderate positive correlation with TL explaining 36.66% of AL variation (Fig. 4A). This relationship is statistically significant t (28) = 4.03, $p < 0.001$, $F_{(1,28)} = 16.21$, and the 95% CI for

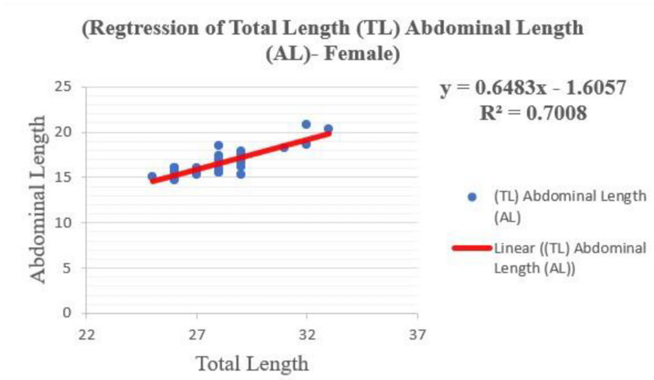

Fig. 4B. Regression of total length (TL) and abdominal length (AL) -female.

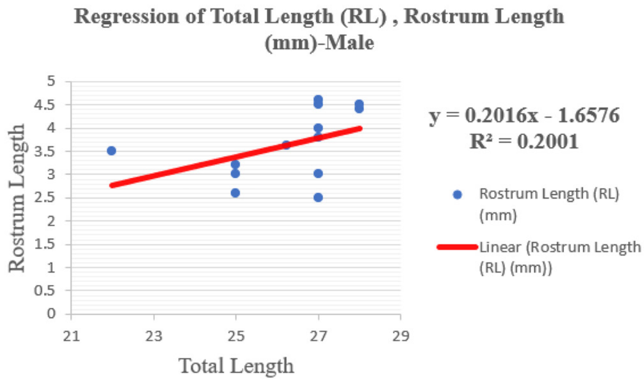

Fig. 5A. Regression of rostrum length (RL), total length (TL) -male.

the slope (0.300–0.923) confirms a reliably positive association. On average, AL increases by 0.61 units for every 1-unit increase in TL, suggesting abdominal growth is more proportionally aligned with body size than carapace growth, likely reflecting functional roles in locomotion or reproduction.

The regression analysis between total length (TL) and abdominal length (AL) in female *Caridina hodgarti* yielded AL = 0.6483 × TL – 1.6057 (R^2 = 0.7008), indicating a strong positive correlation with 70.1% of AL variation explained by TL (Fig. 4B). The slope (0.6483, SE = 0.0801) is highly significant t (28) = 8.09, F (1,28) = 65.55, $p < 0.0001$, with a 95% CI (0.484–0.812) confirming a robust positive association. On average, AL increases by 0.65 units for every unit rise in TL, reflecting consistent proportional growth in females, likely linked to reproductive adaptations such as egg carrying. Compared to males (R^2 = 0.3666), females show stronger abdominal-body size alignment, underscoring sexual dimorphism in abdominal development.

Rostrum length—total length relationship (Male and Female)

The regression between total length (TL) and rostrum length (RL) in male *Caridina hodgarti* is described by RL = 0.2016 × TL – 1.6576 (R^2 = 0.2001), indicating a weak to moderate positive correlation, with TL explaining 20% of RL variation (Fig. 5A). The slope (0.2016) is statistically significant t (28) = 2.65, F (1,28) = 7.02, p = 0.013), showing that rostrum length increases with body size but remains largely influ-

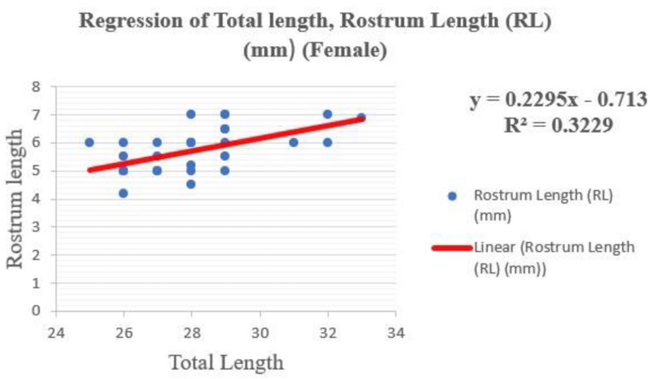

Fig. 5B. Regression of rostrum length (RL), total length (TL) -female.

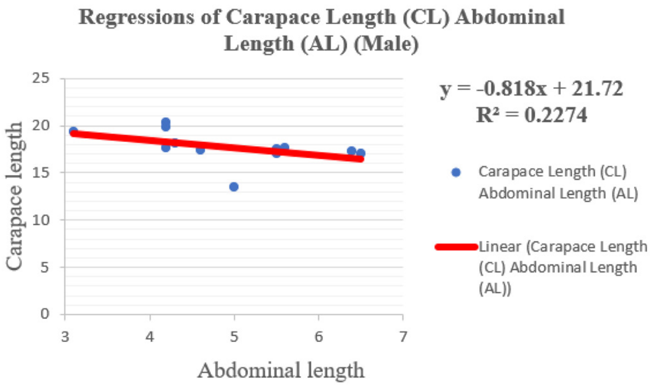

Fig. 6A. Regressions of carapace length (CL) and abdominal length (AL) -male.

enced by other biological or ecological factors. This suggests that rostrum growth in males is only partially body-size dependent, warranting further comparison with females to evaluate sex-linked differences.

The regression between total length (TL) and rostrum length (RL) in female *Caridina hodgarti* is described by RL = 0.2295 × TL – 0.713 (R^2 = 0.3229), indicating a moderate positive correlation with 32.29% of RL variation explained by TL (Fig. 5B). The slope is significant (b = 0.2295), t (28) = 3.65, F (1,28) = 13.35, p ≈ 0.001, and the 95% CI (0.101–0.358) confirms a robust positive association. On average, RL increases by 0.23 units per 1-unit rise in TL, suggesting a more consistent and predictable rostrum–body size relationship in females than in males (R^2 = 0.2001), likely reflecting sex-linked functional or adaptive roles.

Carapace length- abdominal length relationship

The regression between abdominal length (AL) and carapace length (CL) in male *Caridina hodgarti* is given by CL = –0.818 × AL + 21.72 (R^2 = 0.2274), showing a moderate negative correlation with AL explaining 22.74% of CL variation (Fig. 6A). The slope is significant (b = –0.818), t (28) = 2.87, F (1,28) = 8.24, p ≈ 0.0077), with a 95% CI (–1.402 to –0.234) confirming that CL decreases as AL increases. On average, CL declines by 0.82 units for each unit rise in AL, suggesting a trade-off in body proportions that may reflect male-specific morpho-functional adaptations.

The regression between carapace length (CL) and abdominal length (AL) in female *Caridina hodgarti* yielded AL = –0.0635 × CL + 16.965 (R^2 = 0.001),

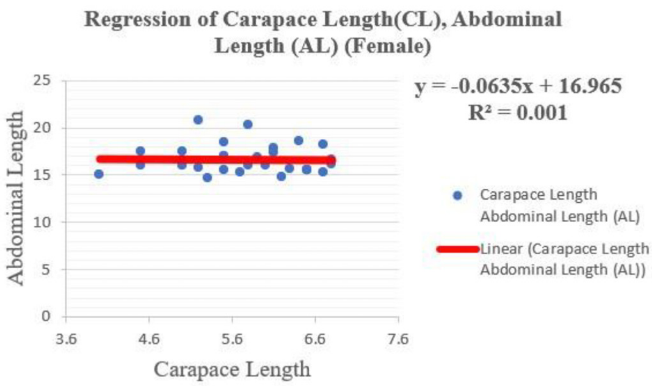

Fig. 6B. Regressions of carapace length (CL) and abdominal length (AL) -female.

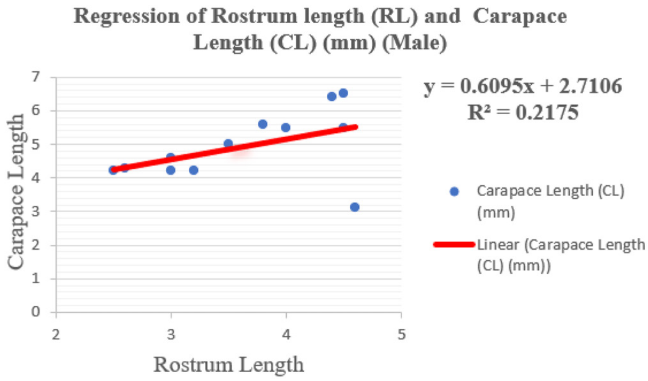

Fig. 7A. Regression of rostrum length (RL) and carapace length (CL) (mm) -male.

indicating an extremely weak and non-significant correlation (Fig. 6B). The slope (b = –0.0635, t (28) = –0.17, p ≈ 0.87) with 95% CI (–0.840 to 0.713) confirms no meaningful relationship, as CL explains only 0.1% of AL variation. Unlike males, females show independence between these traits, suggesting abdominal length is influenced by other biological or reproductive factors.

Rostrum length- carapace length relationship

The regression between rostrum length (RL) and carapace length (CL) in male *Caridina hodgarti* is given by CL = 0.6095 × RL + 2.7106 (R^2 = 0.2175), indicating a weak to moderate positive correlation with RL explaining 21.75% of CL variation (Fig. 7A). The slope is significant (b = 0.6095, SE = 0.2185, t (28) = 2.79, F (1,28) = 7.78, p ≈ 0.0094), with 95% CI (0.162–1.057) confirming a reliable positive association. On average, CL increases by 0.61 units per unit rise in RL, though much variability remains unexplained, suggesting additional biological or ecological factors influence carapace growth.

The regression between rostrum length (RL) and carapace length (CL) in female *Caridina hodgarti* is given by CL = –0.0639 × RL + 6.113 (R^2 = 0.0048), showing an extremely weak and non-significant negative correlation (Fig. 7B). The slope (b = –0.0639, SE = 0.174, t (28) = –0.37, p ≈ 0.71; F (1,28) = 0.135) is negligible, and the 95% CI (–0.420 to 0.292) includes zero, confirming no relationship. With only 0.48% of CL variation explained by RL, these traits appear virtually independent in females, contrasting with the moderate positive correlation seen in males and suggesting sex-specific growth patterns.

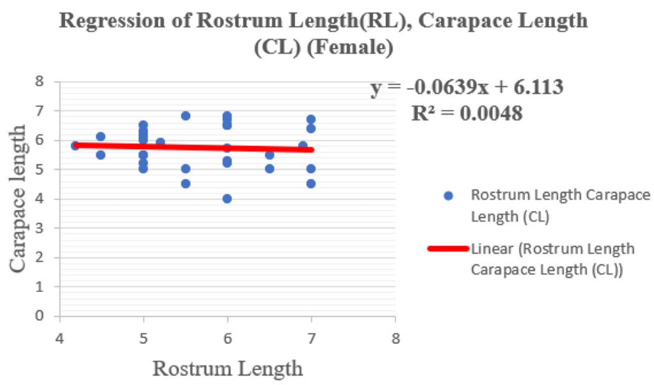

Fig. 7B. Regression of rostrum length (RL) and carapace Length (CL) (mm) -female.

DISCUSSION

The sex-specific morphometric patterns observed in *Caridina hodgarti* conform to established principles of relative growth and sexual dimorphism in decapods, where different tagmata scale allometrically according to function and maturation demands (Hartnoll 1978, Anger and Moreira 1998). Weak TL–CL coupling in both sexes suggests limited dependence of carapace expansion on overall size, consistent with early stabilization of cephalothoracic structures relative to abdominal components during growth and with reports of variable carapace allometry across carideans and other crustaceans (Hartnoll 1978).

The strong female TL–AL relationship versus the moderate male TL–AL association indicates proportionate and predictable abdominal scaling in females, matching the brood-carrying role and fecundity-linked abdominal enlargement documented in carideans and palaemonids (Anger and Moreira 1998; Jayachandran 2001). Correspondingly, the male negative CL–AL association signals a trade-off between protective and locomotive/reproductive regions, echoing functional allocation patterns described in decapod growth studies (Hartnoll 1978; Soundarapandian and Ananthan 2008).

Rostrum scaling differed by sex: females showed a more consistent TL–RL coupling than males, aligning with functional roles of the rostrum in feeding and environmental interaction recognized within *Caridina* systematics and natural history syntheses (Cai and Ng 2009, Chace 1997). In contrast, the near-independence of RL–CL and CL–AL in females highlights morphological modularity that preserves abdominal capacity for incubation while decoupling cephalothorasic proportions, a pattern compatible with reproductive specialization in atyids (Anger and Moreira 1998, Sganga *et al.* 2016).

Practically, these regressions provide baselines for stock characterization, broodstock selection, and ornamental culture of *C. hodgarti,* where female TL–AL predictability may serve as a condition and reproductive readiness indicator, while male trade-offs caution against single-trait selection. Taxonomically, the sex-specific regression signatures complement classical rostral and carapace characters used in *Caridina* identification and population assessment, reinforcing integrative morphometric approaches in Indian freshwater shrimp research (Raghunathan and Valarmathi 2007, Daphine *et al.* 2018).

These results highlight the functional and ecological basis of sexual dimorphism in *C. hodgarti,* showing that morphometric traits are not merely size-related but are also functionally specialized according to sex. Females exhibit a more conserved and reproductive-focused growth pattern, while males show segmental plasticity tailored to behavioural and ecological demands.

CONCLUSION

The present study clearly demonstrates that *Caridina hodgarti* exhibits distinct sex-based morphometric patterns reflecting functional and reproductive differentiation. Females showed a strong and consistent relationship between total and abdominal length, indicating proportionate growth associated with brood development and reproductive adaptation. Males displayed more variable morphometric associations, including a negative carapace–abdominal relationship, signifying a trade-off between protective and locomotive body regions.

Such variations confirm that morphometric traits in *C. hodgarti* are not only size-dependent but also reflect sex-specific adaptive strategies. The regression models obtained in this study serve as reliable indicators of growth patterns and can be utilized for species diagnosis, stock assessment, and aquaculture management. These results also provide essential baseline information for future ecological and evolutionary studies on atyid shrimps inhabiting Indian freshwater ecosystems.

ACKNOWLEDGMENT

The authors are deeply indebted to the Head, Department of Fisheries Sciences, Vidyasagar University, Midnapore, for providing the facilities necessary to carry out this research work.

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