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Nursery Rearing of Milkfish, *Chanos chanos* in Net Cages as a Viable Livelihood Activity by the Self-Help Group of Navsari district, Gujarat

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Abstract

Polyculture of shrimp (*Penaeus vannamei*) with milkfish (*Chanos chanos*) fingerlings is increasingly recognized as a sustainable and profitable method, particularly in coastal regions of Gujarat, India. In shrimp-milkfish polyculture, milkfish fingerlings are cultured with shrimp to maintain pond water quality. However, due to the non-availability of desired stockable-size fingerlings and high transportation costs, shrimp farmers depend on procuring small-sized milkfish seed from southern states of India. Considering the anticipated demand for stockable-size milkfish fingerlings for shrimp polyculture, and to promote milkfish nursery rearing as a livelihood activity, a study was conducted to evaluate production performance, economic and livelihood feasibility of milkfish fry (2.3 ± 0.1 cm g) reared at different stocking densities (250, 300, 350, 400, 450, 500 fry/m^3) in net cages (2 × 1 × 1 m) installed in ponds (2,500 m^3) for a period of 90 days, with participation of Self-Help Group (SHG) in Matwad village, Gujarat. The fish were fed with nursery feed (35.12% crude protein) twice daily (9:00 and 17:00 h) until apparent satiation, and the net cages were cleaned weekly by SHG members. The results indicated that a stocking density of 350 fry/m^3 yielded optimal growth (SGR 4.23 %/day; final weight 14.9 g) and survival (88.4%), making it the most economically viable option for commercial nursery operations (net profit ₹6,823 per net cage per cycle; BCR 1.59) compared to other tested densities. The SHG generated a revenue of ₹1.66 lakh in one cycle through the sale of fingerlings (₹13–18 per seed) to shrimp farmers. Overall, the model demonstrates that the milkfish fry nursery rearing (10000 nos) in net cages installed in small ponds (2,500 m^3) can generate a net profit of ₹86,901 with minimal labour requirement (2-3 h/day), making it a profitable livelihood activity for SHGs, particularly fisherwomen. This participatory "Technology Transfer Mode" by ICAR-CIBA offers a sustainable employment model for coastal SHGs, enhances shrimp farming sustainability through bioremediation, and helps bridge the demand-supply gap for milkfish fingerlings on the west coast of India.

Keywords: Milkfish, fry, stocking density, net cages, nursery, self-help group, benefit-cost ratio, sustainable aquaculture

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Introduction

Milkfish is one of the most sought-after species for aquaculture due to its fast growth, herbivorous feeding habit, euryhaline nature, disease tolerance and adaptability to captive environments, hardy nature, and high-quality flesh (Yusuf, Malik, Subachri, Ahyani, & Yusuf, 2014). Milkfish is commercially farmed in brackishwater ponds, marine and freshwater cages and pens, as well as hyper-saline ponds (Food and Agriculture Organization of the United Nations [FAO], 2009; Gopalakrishnan et al., 2016). In countries such as Taiwan, Indonesia, and Philippines, milkfish aquaculture constitutes a significant component of the economy (Jose & Divya, 2022). In Taiwan, milkfish is frequently integrated with shrimp farming to enhance profitability and utilize leftover feed and waste from shrimp ponds (Lalramchhani et al., 2019). This practice not only reduces the need for extra feed but also helps keeping the pond clean without slowing down milkfish growth, and acts as a safety net. In case of reduced milkfish production, farmers can rely on the relatively high market value of shrimp to compensate for losses and reduce overall business risk (Lu, Huang, Lee, & Huang, 2022).

Global milkfish production reached 1,196 thousand tonnes in 2022 (FAO, 2024). Farmed milkfish contributes about 1.9% of the total global production of major aquaculture species (FAO, 2022). Based on stocking density, feeding strategies, and water management practices, milkfish culture systems are classified as extensive, modified-extensive, semi-intensive, and intensive (Aqua Farm News, 1992; Fortes, 1996; Baliao, de los Santos, & Franco, 1999; Sumagaysay-Chavoso, 2003). In India milkfish farming is an age-old practice in the brackishwater regions of Kerala and Karnataka, traditionally dependent on availability of wild seed. Recently, ICAR-CIBA has developed comprehensive milkfish seed production technologies (Bera et al., 2019; Bera et al., 2021) and has popularized milkfish farming practices across different coastal states (Kumar & Mandal, 2022).

Integrating milkfish into shrimp farming systems offers both ecological and socio-economic benefits, particularly in coastal regions of India. One of the major advantages of incorporating milkfish into shrimp ponds is their role in bioremediation. Milkfish help reduce to organic load and manage ammonia buildup in the pond by feeding on naturally occurring algae, debris, and leftover shrimp feed (Lalramchhani et al., 2019). Consequently, polyculture of milkfish (*C. chanos*) with shrimp (*P. vannamei*) is increasingly recognized as a sustainable and profitable method, especially in areas like Gujarat, India (Hussain et al., 2022).

Stocking density is a vital factor in aquaculture as it directly impacts the development, survival, and overall well-being of fish under captive conditions. Determining the optimal stocking density is crucial in net cage-based systems, as it must align with the carrying capacity of the water body and the biological requirements of the cultured species (Asase, Nunoo, & Attipoe, 2016). Higher stocking densities can negatively affect water quality, as well as the growth and survival rate of fish (Tjoronge, 2005; Suriya, Shanmugasundaram, & Mayavu, 2016; Lalramchhani et al., 2019). Stocking densities in net cage culture vary widely among species, and limited research has been conducted to establish optimal densities for certain species such as milkfish.

Therefore, considering the anticipated demand for milkfish fingerlings particularly in Gujarat as well as to promote milkfish nursery rearing as a livelihood activity, the present study evaluates the effects of different stocking densities of milkfish fry during nursery rearing in the net cage system and assesses the techno-economic viability to support the livelihoods of small-scale farmers from self-help groups.

Materials and Methods

The experiment was conducted for 90 days of culture from June to August 2021 at the Brackishwater Aquaculture Research and Demonstration (BARD) farm of CIBA-NGRC, Matwad, Navsari, Gujarat, India (20°55′11.9″ N and 72°49′23.28″ E). The study was implemented in collaboration with a Self-Help Group (SHG) comprising six women and two men from Matwad village, while adhering to all protocols of the COVID-19 Pandemic. The experiment was carried out in a pump-fed brackishwater earthen pond with a water holding capacity of 2,500 m^3 and an average water depth of 1.5 m.

A total of 15,000 milkfish fry was procured from the ICAR-CIBA hatchery, Chennai, India, and acclimatized to the pond environmental conditions for two weeks. Prior to the start of the experiment, SHG members were trained in pond preparation, installation and maintenance of net cages, seed stocking, fish feeding, and water quality management. A total of 13,500 milkfish fry (average body weight 2.2 ± 0.1 g and average total length 2.3 ± 0.1 cm) were randomly allocated to six distinct experimental groups in triplicate viz., T1 (250 fry/m^3), T2 (300 fry/m^3), T3 (350 fry/m^3), T4 (400 fry/m^3), T5 (450 fry/m^3), and T6 (500 fry/m^3). The experiment was conducted using HDPE net cages of dimensions 2m × 1m × 1 m. A mesh size of 2 mm was used during the initial 30 days, followed by 5 mm and subsequently 10 mm mesh net cages up to 90 days of culture. All net cages were installed within a single pond, and three replicates for each treatment represented subsamples within the same water body. The fish were fed a CIBA formulated milkfish nursery feed (0.6 -1.2 mm) twice daily (9:00 and 17:00 h) until apparent satiation. The ingredients and proximate composition of the experimental feed are provided in Table 1. Net cages were cleaned weekly using soft hand brushes by the SHG members.

Table 1. Ingredient (%) and proximate composition (%) of the experiment feed fed to milkfish fry in the net cages

Ingredient/diets	**g/100g**
Fishmeal	5
Acetes	10
Dry Fish	20
Prawn head meal	5
Soybean meal	13
wheat	10
Rice	9
Maize	9
Groundnut cake	4
Rapeseed meal	3.95
Fish oil	2
Lecithin	1
Mineral Mixture	1.8
Vitamin Mixture	0.2
Binder	1
Rice bran	5
Vitamin C	0.05
Proximate composition of the experimental diet (%)	
Moisture	10.12
Crude Protein	35.21
Ether Extract	7.3
Crude Fiber	4.56
Total Ash	13.18
NFE	29.63

Growth performance of milkfish fry was assessed at 15-day intervals throughout the experimental period. From each net cage, 100 fry were randomly sampled using a nylon hand net, and individual body length and weight were measured using a digital balance (Hindustan scale company, HSCO, India). Survival percentage was recorded during each sampling and at the end of the experiment. Feed ration was adjusted every 15 days based on the biomass estimation. Growth parameters were calculated using standard formulae described by Houde (1981).

Weight gain (g) =
Final body weight (g) - Initial body weight (g)

Length gain (cm) =
Final body length (cm) - Initial body length (cm)

Specific growth rate (SGR) =

$$\frac{\text{[ln (Final body weight – ln (initial (initial body weight)]}}{\text{Day}} \text{x100}$$

$$\text{Survival} = \frac{\text{Total number of fish survived}}{\text{total number of fish stocked}} \text{ x 100}$$

Feed conversion ration (FCR) =

$$\frac{\text{Feed given to fish (dry weight in g)}}{\text{body weight of fish (wet weight in g)}}$$

Total biomass (kg) =

$$\frac{\text{Total number of fish x average weight of fish (g)}}{1000}$$

Water quality parameters of the experimental pond were monitored regularly to maintain optimal conditions for milkfish fry health and growth throughout the experiment. Total ammonia nitrogen concentration (mg/L) were measured weekly (Hanna ammonia meter HI97700, Romania), while pH, temperature (°C), salinity (ppt), and dissolved oxygen (mg/L) were recorded daily during early morning hours using a Eutech CyberScan Series 600 portable multi-parameter probe (PCD650, Singapore).

The collected data were analyzed using appropriate statistical methods. Growth and survival data were subjected to One-way ANOVA using SPSS 20 software to determine the significant difference among treatments. When significant differences among treatments were detected, mean values were compared using Tukey's post hoc test.

Results and Discussion

The pond water quality parameters recorded during the 90-day milkfish nursery rearing at different stocking densities are presented in Table 2. Pond water pH, temperature (°C), salinity (ppt), dissolved oxygen (mg/L) and total ammonia nitrogen (mg/L) ranged from 7.78 to 8.3, 28.6 to 31.2 °C, 32 to 18.2 ppt, 5.2 to 5.82 mg/L, and 0.005–0.031 mg/L, respectively. All parameters remained within the

Table 2. Water quality parameters of milkfish fry nursery rearing at different densities in net cages in pond for 90 days

Parameters	Initial	30 DOC	60 DOC	90 DOC
pH	8.3 ± 0.0	8.12 ± 0.1	7.96 ± 0.02	7.78 ± 0.03
Temperature (°C)	31.2 ± 0.0	30.3 ± 0.1	29.5 ± 0.1	28.6 ± 0.1
Salinity (ppt)	32 ± 0.0	28.5 ± 0.3	23.7 ± 0.4	18.2± 0.6
Dissolved oxygen (mg L^{-1})	5.92± 0.0	5.77 ± 0.04	5.44 ± 0.03	5.20 ± 0.03
Ammonia (mg L^{-1})	0.005± 0.0	0.011. ± 0.002	0.023 ± 0.002	0.031± 0.001

DOC-Days of culture.

ideal range required for optimal growth and efficient feed utilization of milkfish under pond culture conditions (Sumagaysay-Chavoso & San Diego-McGlone, 2003). Stocking density is a critical factor influencing the viability and productivity of culture systems. Therefore, implementation of an optimal density can enhance the economic viability of aquaculture systems by maximizing the efficient use of water and other resources within the rearing environment (Fairchild & Howell, 2001). In net cage-based nursery systems, stocking density exerts a considerable effect on growth rate, survival, health status, water quality, and overall production outcomes (Daudpota, Kalhoro, Shah, Kalhoro, & Abbas, 2014; Shajib et al., 2018; Aktar & Hossain, 2023). High stocking density stimulates the fish to produce an excessive amount of the stress hormone cortisol, which induces stress on fish. Excessively high-density levels often result in reduced individual growth rates and feed utilization in fish (De las Heras, Martos-Sitcha, Yúfera, Mancera, & Martínez-Rodríguez, 2015). As a result, it is imperative to ascertain the optimal stocking densities for each specific species and production phase, thereby facilitating effective management strategies and augmenting both production and profitability.

No significant differences ($p > 0.05$) were observed in the initial length of milkfish fry across treatments, which ranged from 2.2 ± 0.1 cm to 2.4 ± 0.1 cm. After 90 days of culture, the highest final length was recorded in T1 (11.8 ± 0.5 cm), followed by T2 (11.4 ± 0.3 cm), T3 (11.3 ± 0.6 cm), T4 (10.5 ± 0.3), T5 (9.9 ± 0.3), while the lowest length was observed in T6 (9.2 ± 0.4 cm). Significantly ($p < 0.05$) higher final length was observed in T1, T2, and T3 as compared to T4, T5, and T6. Similarly, no significant differences ($p > 0.05$) were observed in initial body weight of milkfish fry among treatments, which ranged from 0.37 ± 0.04 g to 0.47 ± 0.03 g. At the end of the experimental period, the highest growth in terms of weight (g) was recorded in T1 (15.9 ± 0.6 g), followed by T2 (15.3 ± 0.5 g), T3 (14.9 ± 0.5 g), T4 (13.7 ± 0.7 g), T5 (12.9 ± 0.8 g), and T6 (11.1 ± 0.8 g). In this study, fish reared at lower stocking densities (T1, T2, and T3) exhibited significantly ($p < 0.05$) higher weight compared to those stocked at higher densities (T4, T5, and T6) (Table 3). These results are consistent with the findings of Shinta (2022) that increased stocking density decreases the growth of the milkfish larvae. Alam, Amin, Das, Choudhury, and Haque (2009) also reported tilapia fry grew best at optimal densities (702 fry/m^3) in net cages of 1 m^3. Milkfish exhibit a schooling behaviour and occupy the water column, which can intensify competition for feed under high stocking density.

Specific growth rate (SGR) followed a similar trend, with the highest SGR recorded in T1 (4.30 ± 0.1 %/day), followed by T2 (4.26 ± 0.1 %/day), T3 (4.23 ± 0.1 %/day), T4 (3.76 ± 0.1 %/day), T5 (3.66 ± 0.1 %/day), and T6 (3.61 ± 0.1 %/day). Lower stocking densities (T1, T2 and T3) resulted in significantly higher SGR ($p < 0.05$) compared to higher densities (T4, T5, and T6). Similar decline in specific growth rate with increasing stocking density have been reported in milkfish (Ganesh, Rao, Prasad, Prasad, & Rao, 2022), Nile tilapia (Ndwiga, 2015; Asase et al., 2016), African mud catfish (Nwipie, Erondu, & Zabbey, 2015), Red tilapia (Daudpota et al., 2014), and common carp (Bostami, Akter, Banu, Hasan, & Sarker, 2020). These findings suggest that reduced densities result in less stress and competition, thereby enhancing individual growth.

In our study, T1 demonstrated effective feed utilization with lowest FCR of 1.78 compared to other densities. In contrast, the highest FCR of 2.70 was observed in T6, likely due to increased feed competition and stress-induced reduction in feeding activity at higher densities. However, no significant difference ($p > 0.05$) was observed in FCR among the lower densities (T1, T2, and T3), indicating a progressive increase in FCR with increasing stocking density. Similar results were reported by Ganesh et al. (2022), who investigated the impact of stocking two distinct size groups of milkfish (351.72 ± 1.05 g and 720.80 ± 1.25 g) on growth and efficiency of

Table 3. Growth performance, feed utilization, survival and biomass production of milkfish fry nursery rearing at different densities in net cages in pond for 90 days

Parameters/density	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Initial length (cm)*	2.2 ± 0.1^a	2.3 ± 0.1^a	2.2 ± 0.1^a	2.3 ± 0.1^a	2.4 ± 0.1^a	2.3 ± 0.1^a
Final length (cm)	11.8 ± 0.5^a	11.4 ± 0.3^a	11.3 ± 0.6^a	10.5 ± 0.3^b	9.9 ± 0.3^c	9.2 ± 0.4^d
Length gain (cm)	9.5 ± 0.3^a	9.2 ± 0.2^a	9.1 ± 0.4^a	8.2 ± 0.5^b	7.5 ± 0.4^c	6.9 ± 0.3^d
Initial weight (g)	0.38 ± 0.07^a	0.37 ± 0.04^a	0.37 ± 0.04^a	0.43 ± 0.06^a	0.47 ± 0.03^a	0.43 ± 0.05^a
Final weight (g)	15.9 ± 0.6^a	15.3 ± 0.5^a	14.9 ± 0.5^a	13.7 ± 0.7^b	12.9 ± 0.8^c	11.1 ± 0.8^d
Total weight gain (g)	15.4 ± 0.4^a	14.9 ± 0.5^a	14.5 ± 0.7^a	12.3 ± 0.3^b	12.5 ± 0.5^c	10.8 ± 0.7^d
SGR (%/day)	4.30 ± 0.1^a	4.26 ± 0.1^a	4.23 ± 0.1^a	3.76 ± 0.1^b	3.66 ± 0.1^b	3.61 ± 0.1^b
FCR	1.78 ± 0.02^a	1.86 ± 0.02^a	1.93 ± 0.05^a	2.28 ± 0.04^b	2.50 ± 0.02^c	2.70 ± 0.06^d
Survival (%)	89.6 ± 0.5^a	88.7 ± 0.9^a	88.4 ± 0.8^a	81.5 ± 1.1^b	76.0 ± 1.1^c	70.9 ± 1.1^d
Biomass (kg/net cages)	7.11 ± 0.1^a	8.14 ± 0.2^b	9.21 ± 0.1^c	8.97 ± 0.3^c	8.79 ± 0.2^{bc}	7.83 ± 0.1^{ab}

Growth parameters are expressed as mean ± SD of three replicates per treatment (n=3), and values with different superscript letters are significantly different ($p < 0.05$) among treatments and values with * are non-significantly ($p > 0.05$) different among treatments. SGR: Specific growth rate; FCR: Feed conversion ratio.

Table 4. Economics (₹) of milkfish fry nursery rearing at different densities in net cages in pond for 90 days

A	Cost (₹)/Treatments	T1	T2	T3	T4	T5	T6
B	Capital cost (net cages, bamboo)	425 ± 0	425 ± 0	425 ± 0	425 ± 0	425 ± 0	425 ± 0
C	Operational cost (seed, feed, rope, hand brush, bucket, etc)	2455 ± 4.4^a	2935 ± 14.8^b	3415 ± 10.9^c	3902 ± 17.2^d	4332 ± 30.7^e	4730 ± 9.9^e
D	Total expenditure (B+C)	2880 ± 4.4^a	3360 ± 14.8^b	3840 ± 10.9^c	4327 ± 17.2^d	4757 ± 30.7^e	5155 ± 9.9^e
E	12 % interest on total expenditure	346 ± 0.5^a	403 ± 1.8^b	461 ± 1.3^b	519 ± 2.1^d	571 ± 3.7^b	619 ± 1.2^b
F	Total cost for one cycle (D+E)	3225 ± 41.6^a	3763 ± 99.9^b	4301 ± 95.2^c	4846 ± 116.8^e	5328 ± 137.6^f	5773 ± 150.1^e
G	Total income from sale of fingerlings	8064 ± 41.6^a	9582 ± 99.9^b	11124 ± 95.2^c	8506 ± 116.8^{ae}	8862 ± 7.6^d	9204 ± 150.1^{be}
H	Net Profit (G-F)	4839 ± 45.0^a	5819 ± 83.3^b	6823 ± 83.1^c	3660 ± 103.2^d	3534 ± 106.5^d	3431 ± 141.6^d
I	Benefit cost ratio (H/F)	1.50 ± 0.02^a	1.55 ± 0.02^b	1.59 ± 0.01^b	0.76 ± 0.02^c	0.66 ± 0.02^d	0.59 ± 0.02^d

Economic indices of one milkfish nursery rearing unit in hapa in pond are expressed as mean ± SD of three replicates per treatment (n=3), and values with different superscript letters differ significantly ($p < 0.05$) among treatments feed utilization, and observed that as the stocking density increased, the feed conversion ratio (FCR) also increased, suggesting reduced feed efficiency at higher stocking levels.

Milkfish fingerlings exhibited favorable growth metrics and high survival rates at the ideal stocking densities (T1, T2, and T3), indicating that these stocking densities are suitable for nursery operations (Table 3). At the end of the study, the highest survival rates were observed in the lower-density treatments (T1, T2, and T3), which were significantly different ($p < 0.05$) from the higher-density treatments. T1 recorded the highest survival rate (89.6 ± 0.5%), followed by T2 (88.7 ± 0.9%) and T3 (88.4 ± 0.8%). A significant decline in survival was observed in T4 (81.5 ± 1.1%), T5 (76.0 ± 1.1%), and T6 (70.9 ± 1.1%). Among all treatments, T6 showed the lowest survival rate. Overall, survival exhibited a downward trend with increasing stocking density, indicating a density-dependent effect on stress tolerance capacity and overall health of the stocked milkfish fry. The present findings are similar to those of Ghosh et al. (2016) and Sukmawantara, Arthana, and Kartika (2021), who reported poor survival of milkfish and seabass fingerlings stocked at higher stocking densities in cage culture systems.

Greater biomass production was observed at higher stocking densities, even though individual growth and survival were lower. At harvest, the maximum biomass of milkfish fry (9.21 ± 0.1 kg) was obtained in T3, which was significantly higher ($p > 0.05$) than both the lower-density treatments (T1 and T2) and the higher-density treatments (T4, T5, and T6).

Fig. 1. Milkfish fry nursery rearing at different densities in net cages in pond at CIBA NGRC BARD Farm, Navsari, Gujarat

However, despite exhibiting the best growth and survival, T1 produced the lowest biomass (7.11 ± 0.1 kg). This indicates that stocking density has a greater impact on overall output than on individual performance. In aquaculture, higher stocking densities often result in greater total biomass output, even when individual growth rates and survival decline. Ezhilmathi et al. (2022) similarly reported that Asian seabass (*Lates calcarifer*) stocked at 70 fish/m^3 showed higher individual development and survival than fish stocked at 350 fish/m^3; however, total biomass was greater at the higher density due to the larger number of fish.

The total cost of raising milkfish fry in a nursery using net cages for one production cycle was ₹0.82 lakh, which included ₹0.08 lakh as capital cost, ₹0.65 lakh as operational cost, and ₹0.09 lakh as interest (12%) on total expenditure (Table 4). Through the sale of 10,270 fingerlings at ₹13-18 per fingerling, the SHG generated a total income of ₹1.66 lakh and a

Fig. 2. Milkfish fry growth sampling by women SHG members

Fig. 3. Partial income cheque distribution to the women SHG members

net profit of ₹0.84 lakh from one cycle. This suggests that the model is suitable as an additional income-generating activity, particularly SHGs comprising both men and women. The benefit-cost ratio (BCR), net profit, and production costs varied significantly ($p < 0.05$) among treatments. All treatments had the same capital cost (₹425 ± 0), indicating that the infrastructure arrangement was consistent and can be used for four cycles per year of milkfish farming in net cages in pond. However, as the stocking density increased, operational expenditures increased significantly ($p < 0.05$) from ₹2,455 ± 4.4 in T1 (250 fry/m^2) to ₹4,730 ± 9.9 in T6 (500 fry/m^2). T1 recorded the significantly lowest ($p < 0.05$) total cost per cycle (₹3,225 ± 41.6), while T6 had the highest (₹5,773 ± 150.1). T3 generated significantly higher income (₹11124 ± 95.2; $p < 0.05$) than T2 (₹9,582 ± 99.9), T6 (₹9,204 ± 150.1), T5 (₹8,862 ± 137.6), T4 (₹8,506 ± 116.8), and T1 (₹8,064 ± 41.6). Similarly, T3 recorded highest net profit (₹6823 ± 83.1), which was significantly higher ($p < 0.05$) than T2 (₹5,819 ± 83.3), T1 (₹4,839 ± 45.0), T4 (₹3,660 ± 103.2), T5 (₹3,534 ± 106.5), and T6 (₹3,431 ± 141.6).

Interestingly, despite producing higher biomass, T4, T5, and T6 generated lower profits compared to T1, T2, and T3. The most cost-effective stocking density is one that yields maximum biomass per unit area along with the highest BCR and net revenue. In this study, the BCR was significantly higher ($p < 0.05$) in T3 (1.59 ± 0.01) compared to T2 (1.55 ± 0.02), T1 (1.50 ± 0.02), T4 (0.76 ± 0.02), T5 (0.66 ± 0.02), and T6 (0.59 ± 0.02). The higherr BCR values observed in T1, T2, and T3 indicate optimal economic efficiency at moderate densities, whereas T4, T5, and T6 recorded substantially lower BCRs, suggesting reduced profitability at higher stocking densities due to increased operational costs and diminished returns. A BCR ≥ 1 at T1, T2, and T3 indicates that milkfish fry nursery rearing livelihood model is an economically viable production system. Similar to this study, Bostami et al. (2020) also found that the BCR was significantly higher at moderate density of 400/m^3 (1.97 ± 0.004) in common carp (*Cyprinus carpio* var. spicularis) nursery rearing compared to higher densities of 600/m^3 (1.81 ± 0.003) and 800/m^3 (1.72 ± 0.005). Collectively, these findings indicate that although biomass production increases with density, economic efficiency and profitability are maximized at moderate stocking levels for all species.

In the present study, SHG members generated ₹1.66 lakh by working 2-3 hours daily through the sale of milkfish fingerlings to shrimp farmers which provided supplementary income. The findings align with Kumaran et al. (2022), who suggested that spending 2 hours daily on seabass nursery rearing provided considerable earnings for coastal fisher families, with active participation of fisher women. By increasing productivity, reducing risk, encouraging diversification, and facilitating local-level value addition, this strategy helps achieve the objective of doubling farmers' income, as outlined in the Doubling Farmers' Income Report published by the Ministry of Agriculture (2018). Additionally, the study resulted in availability of disease-free milkfish fingerlings of desired size for shrimp farmers within a short period. Such co-culture systems offer SHGs a practical means to enhance returns per unit area, ensure a steady income throughout the year, and strengthen their ability to withstand environmental changes.

The pilot study concludes that a stocking density of 350 fry/m^3 performed best under the tested conditions and is the ideal stocking density for nursery rearing in net cages, yielding optimal growth, survival, production, and economic returns. The model demonstrates that with a net profit of ₹86,901 from a total income of ₹1.66 lakh and minimal labor (2-3 h/day), the milkfish fry (10,000 fry) nursery rearing in net cages (2 m^3) in small pond for a period of 90 days is a profitable livelihood activity for self-help groups (SHGs), especially fisherwomen. This participatory "Technology Transfer Mode" by ICAR-CIBA provides a sustainable employment framework for coastal self-help groups, improves the sustainability of shrimp farming via bioremediation, and aids in addressing the demand-supply disparity for milkfish fingerlings along India's west coast. Overall, the study concludes that up to four cycles of milkfish nursery rearing in net cages can be undertaken annually in a single pond, making it a viable livelihood option for coastal communities, particularly women SHGs in Gujarat.

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Ethical statement

The study was undertaken with the approval of the statutory authorities of the ICAR-Central Institute of Brackishwater Aquaculture, Chennai, India. Milkfish fry are not listed as an endangered fish under the provisions of the Government of India's Wildlife (Protection) Act, 1972.

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