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Operational Feasibility of *Litopenaeus vannamei* Culture in Modified Extensive Brackishwater Ponds with Rainwater-Based Salinity Modulation

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ABSTRACT

The Pacific white shrimp (Litopenaeus vannamei) has revolutionized global aquaculture due to its adaptability and productivity, yet its potential in low-input, rainfed pond systems remains underexplored in India. This study evaluates the feasibility of L. vannamei culture in a modified extensive system at the Centre for Advanced Study in Marine Biology, Tamil Nadu. Over a 90-day culture cycle, post-larvae (PL) were stocked at 3.5/m² in a 2,866 m² earthen pond, with water sourced exclusively from rainfall and occasional estuarine top-ups. Standardized pond preparation, phased feeding, water and soil quality monitoring, and pathogen screening protocols were followed. The study observed optimal environmental parameters, an average body weight of 19 g, 80% survival, and a feed conversion ratio (FCR) of 1:1. Stress tests, microscopic health assessments, and PCR confirmed the absence of major pathogens, including WSSV and MBV. The culture yielded 151 kg biomass, generating a modest net profit despite constraints like seepage and predator intrusion. These findings suggest that modified extensive systems using harvested rainwater can serve as a viable, cost-effective model for small-scale shrimp farmers in brackishwater zones with limited infrastructure.

Highlights

- Demonstrated feasibility of ***L. vannamei*** culture in rainfed, modified extensive systems under low-input conditions.
- Maintained optimal pond water and soil quality through simple, field-level monitoring protocols.
- Confirmed post-larvae health using stress tests, wet mounts, and PCR screening (WSSV and MBV negative).
- Achieved 80% survival, 19 g ABW, and 1:1 FCR within 90 days using phased feeding and minimal aeration.
- Realized net profit despite constraints like seepage, predators, and water inflow limitations.
- Supports low-cost aquaculture models for smallholder farmers using harvested rainwater.

1. INTRODUCTION

Fisheries and aquaculture play a critical role in ensuring food security, generating rural employment, and contributing to the economic growth of India. Since independence, the sector has witnessed a remarkable transformation, with total fish production increasing from 0.75 million tonnes in 1950–51 to over 14 million tonnes by 2021–22, making India the third-largest producer of fish and second-largest in aquaculture globally (FAO, 2022; DoF, 2022). Among the various aquaculture activities, shrimp farming stands out as the most lucrative and rapidly expanding sector, particularly along India's 8,000 km coastline and in brackishwater ecosystems (MPEDA, 2021). Initially, the shrimp aquaculture industry in India was dominated by the culture of black tiger shrimp (*Penaeus monodon*), which supported high-value exports. However, the sector faced a steep decline in the mid-2000s due to recurring disease outbreaks, largely caused by viral pathogens such as White Spot Syndrome Virus (WSSV), poor-quality seed, and lack of standardized biosecurity protocols (Lightner, 2011; CIBA, 2015). These setbacks prompted an urgent need for more resilient species and stricter regulatory oversight.

In response, the Government of India authorized the introduction of the exotic Pacific white shrimp, *Litopenaeus vannamei*, which had already demonstrated strong performance in countries such as Thailand, Vietnam, and Ecuador under strict biosecurity conditions (Wyban, 2007; FAO, 2017). The Coastal Aquaculture Authority (CAA), established under the Coastal Aquaculture Authority Act, 2005, set up a comprehensive legal framework for the registration of farms, broodstock quarantine, seed traceability, and input monitoring to support sustainable aquaculture (CAA, 2020). Since its introduction in 2009, *L. vannamei* has rapidly overtaken *P. monodon* in production volume, contributing to over 90% of shrimp exports from India by 2020 (MPEDA, 2021).

Most *L. vannamei* farming in India is conducted under semi-intensive and intensive systems, particularly in Andhra Pradesh, Gujarat, Odisha, and Tamil Nadu, using aerated ponds and high-protein feed (Rao et al., 2022; Sharma et al., 2023). However, these systems require significant capital, infrastructure, and consistent water and health management, which can limit adoption in low-resource or ecologically sensitive areas. In this context, modified extensive culture systems which combine low stocking densities with natural productivity enhancement through fertilization, limited supplemental feeding, and minimal mechanization — offer a sustainable alternative for marginal farmers and underutilized land (Boyd & Tucker, 2012; CIBA, 2020). Despite the growing interest in low-input culture models, there is limited scientific documentation on the performance of *L. vannamei* in modified extensive systems in India, particularly under real field conditions. Most research has focused on semi-intensive models, leaving a knowledge gap in evaluating how this species responds to extensive or low-management environments (Ranjan et al., 2023). Addressing this gap is critical for designing inclusive and scalable aquaculture policies.

In this context, the present study was conducted as a preliminary field-level evaluation of *L. vannamei* culture under modified extensive conditions in rehabilitated ponds at the Centre for Advanced Study in Marine Biology, Tamil Nadu. The objective was to assess shrimp growth, survival, and pond productivity under low-input, low-density, and infrastructure-light conditions, and to evaluate the viability of such systems as a sustainable culture model.

2. METHODOLOGY

***Study Site and Pond Preparation*:** The field experiment was carried out at the Centre for Advanced Study (CAS) in Marine Biology, Annamalai University, Tamil Nadu, India. The culture pond was located adjacent to the

Vellar estuary, providing access to estuarine water and rainfall harvesting. The total grow-out pond area was 2,866 m² (length: 65.51 m; breadth: 43.75 m). Prior to stocking, standard pond preparation practices were followed, including bund repair, desilting, and sluice gate maintenance.

***Soil Sampling and Analysis*:** Soil samples were collected at three different stages: pre-culture, during culture, and post-harvest. A soil corer (4 cm diameter) was used to collect sediment at 10 cm depth randomly from multiple locations. Samples were shade-dried and analyzed at the Instrumentation Laboratory, CAS in Marine Biology. The following parameters were analyzed: pH (digital pH meter), electrical conductivity (EC), organic carbon (OC), organic matter (OM), available nitrogen (AN), total nitrogen (TN), phosphorus (P), potassium (K), and soil texture. Analytical procedures followed standard protocols as described by Jackson (1973) and Black (1965).

***Water Quality Monitoring*:** Water samples were collected fortnightly from the surface using clean, labeled bottles. Salinity was measured using a hand-held refractometer (Erma-Japan). pH was recorded using an electronic pH pen. Water temperature was measured in situ using a standard centigrade thermometer. Dissolved oxygen (DO) was estimated using the modified Winkler's method (Strickland & Parsons, 1972). Transparency was recorded using a Secchi disc. Rainfall data were obtained from institutional meteorological records.

***Seed Stocking and Acclimatization*:** Specific Pathogen Free (SPF) *Litopenaeus vannamei* post-larvae (PL10-14) were procured from Vandayar Hatchery, Kumarapettai, Tamil Nadu. Approximately 10,000 seeds were transported in oxygenated bags and acclimatized to 0 ppt salinity in FRP tanks at CAS before stocking. About 8,000 PL21 juveniles were released into the pond, while 2,000 were retained in tanks for laboratory studies. Stocking density was maintained at 3.5 PL/m².

***Feeding Protocol*:** Commercial sinking pellets (CP Feeds) were used throughout the 90-day culture period. Feeding schedule: 250 g/day (days 1–30), 500 g/day (days 31–60), and 1 kg/day (days 61–90). Feed was administered twice daily at 9 AM and 4 PM.

***Monitoring Algae, Insects, and Predators*:** Weekly surveys were conducted to monitor algal proliferation and aquatic insect infestation. Samples were collected and analyzed for species identification. Filamentous algae (e.g., *Spirogyra*, *Anabaena*) and insects like water striders (*Gerridae*) and backswimmers (*Notonecta* spp.) were observed. Mechanical removal was performed where necessary. Predatory fish species were sampled using cast nets and preserved in 10% formalin for identification. Species included *Elops machnata*, *Oreochromis mossambicus*, *Anabas testudineus*, and *Arius maculatus*.

Disease and Stress Testing

***Stress Tests*:** Three stress tests were performed to evaluate the health of PLs:

- Formalin Stress Test – PLs were exposed to 150 mg/L formalin for 15–30 minutes.
- Osmotic Shock Test – PLs were subjected to sudden salinity reduction to 0 ppt for 15–30 minutes.
- Water Current Test – Water flow was created in a container to assess PLs' swimming response over 2–5 minutes.

Each test involved 50–100 PLs and was conducted following protocols adapted from Wyban et al. (1992) and CIBA guidelines.

***Health Assessment*:** Microscopic examination of 20–30 PLs was done under light microscopy to observe body parts, appendages, gill health, gut condition, and deformities. Further diagnostics included:

- Wet mount staining of hepatopancreas using 0.1% malachite green to test for Monodon Baculovirus (MBV)
- Single-nested PCR for detecting White Spot Syndrome Virus (WSSV)

***Harvesting and Post-Harvest Handling*:** Harvesting was done on day 90 using cast nets. Shrimps were weighed and measured for length and average body weight (ABW). A subsample was transferred to laboratory FRP tanks (200–500 L) for further observation. Feed Conversion Ratio (FCR) was calculated using:

FCR = Total feed given (kg) / Total biomass harvested (kg)

***Economic Analysis*:** Cost breakdown included recurring (feed, seed, fertilizers, pumping) and non-recurring (pond repair, carpentry, sluice gate, labor) components. Profit was estimated based on the market value of harvested biomass minus the total input costs.

3. RESULTS

Soil Quality and Composition During Culture: The soil quality of the shrimp culture pond exhibited progressive changes over the course of the culture cycle, reflecting both natural processes and anthropogenic interventions. Soil pH remained within alkaline limits throughout, ranging from 7.8 before stocking to 8.3 after harvest, with an average of 8.0. Such alkaline conditions are generally considered ideal for shrimp culture, as they facilitate nutrient availability and microbial activity. Electrical conductivity (EC), a measure of the soil's soluble salt content, increased from 1.7 mS/cm prior to culture to 3.2 mS/cm during the culture phase, followed by a slight reduction to 2.9 mS/cm post-harvest. This trend likely reflects nutrient accumulation during culture due to feed and organic matter input, with partial leaching or microbial transformation occurring toward the end of the cycle.

Organic carbon (OC) levels decreased from 0.74% before culture to 0.41% post-harvest, accompanied by a similar decline in organic matter (OM), from 1.28% to 0.71%. This reduction indicates active microbial degradation and uptake of organic substrates by benthic organisms, as well as oxidation processes within the pond sediment. Nitrogen content also followed a declining pattern, with available nitrogen (AN) decreasing from 0.0637% to 0.0353% and total nitrogen (TN) dropping from 0.6378% to 0.3534%. These reductions may be attributed to uptake by pond biota and potential losses through denitrification, especially under fluctuating redox conditions. Phosphorus and potassium levels showed slight variations, with phosphorus ranging from 11 to 30 kg/acre and potassium from 327 to 546 kg/acre, reflecting both input from feed and partial nutrient recycling within the pond.

Soil texture evolved notably during the culture period, transitioning from sandy clay before stocking to silty clay during culture, and finally to clay loam after harvest. This progression may result from organic accumulation, sedimentation of fine particles, and bioturbation. These textural changes, alongside chemical transformations, are important indicators of pond bottom condition, directly influencing benthic productivity and shrimp health (Table 1).

Table 1. Comparative Summary of Soil Parameters During Shrimp Culture

Stage of Culture	Soil pH	EC (dS/m)	OC (%)	OM (%)	AN (%)	TN (%)	P (kg/acre)	K (kg/acre)	Texture
Pre-culture	7.8	1.7	0.74	1.28	0.063	0.638	11	327	Sandy clay
During culture	8.0	3.2	0.55	0.95	0.047	0.474	30	516	Silty clay
Post-harvest	8.3	2.9	0.41	0.71	0.035	0.353	17	546	Clay loam

Water Quality Parameters and Environmental Monitoring: The physicochemical characteristics of the culture pond water showed significant variation over the culture period, influenced by seasonal rainfall, water management practices, and organic loading from shrimp biomass and feed inputs. Water salinity, initially at 0 ppt due to the pond being filled with rainwater, was gradually increased to 17 ppt through controlled pumping of estuarine water. This gradual acclimatization was essential for the proper growth of *Litopenaeus vannamei*, which tolerates a broad salinity range but performs optimally at moderate levels. The highest salinity levels were recorded during January, coinciding with the harvest phase, while the lowest were observed between August and November when monsoonal rainfall was at its peak.

Temperature fluctuated between 21°C and 28°C over the culture cycle. Lower temperatures were observed during early stages of water filling and initial stocking, while peak temperatures were recorded around November as the ambient climate stabilized. Dissolved oxygen (DO) values ranged from 3.7 to 4.6 mg/L. Maximum DO was recorded during the initial days of culture, likely due to the higher oxygen solubility in rain-fed, less organic-rich water. As the culture progressed, oxygen levels declined slightly, likely due to organic matter accumulation and respiratory demand from both shrimp and microbial communities. No significant hypoxia was observed, and the levels remained within acceptable thresholds for vannamei culture.

The pH of pond water varied between 7.5 and 8.9, staying consistently on the alkaline side, which is generally favorable for shrimp growth and pond productivity. Slight dips in pH were noticed during periods of high organic loading, particularly at the end of DOC cycles, possibly due to decomposition and organic acid production. Transparency values, measured using a Secchi disc, ranged from 22 to 65 cm. The initial low transparency was due to phytoplankton bloom development, while clearer water was observed toward the later part of the culture as plankton levels stabilized. The optimal transparency, indicating productive algal levels, remained between 30–40 cm during most of the cycle (Table 2 and Figure 1).

Table 2. Summary of Water Quality Parameters During Culture of *L. vannamei*

Parameter	Minimum Value	Maximum Value
Salinity (ppt)	0	17
pH	7.5	8.9
Temperature (°C)	21	28
Dissolved Oxygen (mg/L)	3.7	4.6
Transparency (cm)	22	65

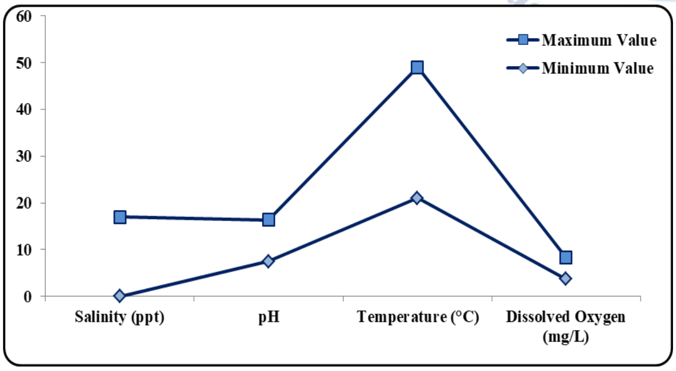

Fig. 1. Water quality parameters observed during the culture period

Rainfall played a critical role in water management. The pond, being primarily rain-fed, received significant water input during the northeast monsoon, particularly in November, which recorded the maximum rainfall of 687 mm. The lowest rainfall was in January (32 mm), corresponding with harvest. Rainwater not only contributed to the water volume but also significantly influenced salinity and nutrient dilution, particularly during early culture stages. (Figure 2)

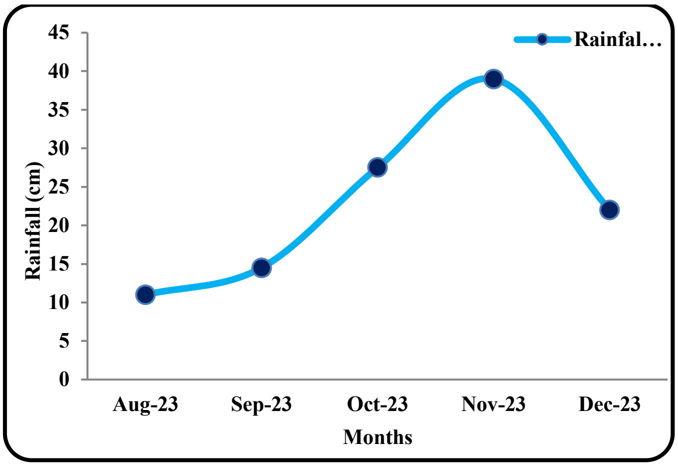

Figure 2. Monthly Rainfall Variation during August – December 2023

***Algal Bloom, Insect and Predator Infestation*:** Throughout the culture period, biological nuisances such as algal proliferation, insect infestations, and predatory fish intrusion were observed, all of which can negatively impact shrimp growth and pond productivity. Regular weekly monitoring was conducted to assess these biotic stressors. Among the algal groups, filamentous green algae particularly *Spirogyra* and *Anabaena*—were dominant throughout the study. These algae are known for their salt tolerance and rapid colonization in nutrient-rich, stagnant water, especially under alkaline pH conditions. Their continued presence indicated persistent nutrient availability, though unchecked growth could result in surface mat formation, reducing light penetration and dissolved oxygen during decomposition phases. Manual removal of filamentous mats and pond drying between culture cycles is recommended to control future algal dominance (Table 4).

Insects also posed a moderate nuisance in the pond ecosystem. The most frequently encountered were water striders (*Gerridae*) and backswimmers (*Notonecta* sp.), both of which were observed across salinity gradients (Table 4). Their tolerance to fluctuating salinity allowed them to persist from early culture stages through to harvest. These insects may compete with shrimp post-larvae for food and oxygen or may prey upon weaker individuals. Control measures, such as mechanical removal using fine-mesh scoops and application of light, regulated doses of chlorine or neem-based formulations, could be employed as precautionary actions in future operations.

Predatory fish posed a more direct threat to shrimp biomass. Despite initial pond drying and preparation, cast netting during the culture period and at harvest revealed the presence of *Elops machnata*, *Oreochromis mossambicus*, *Anabas testudineus*, and *Arius maculatus*. Of these, *Elops machnata* is particularly known in South India for its predatory impact in aquaculture ponds (Tampi, 1960). These fish likely entered the pond through sluice gates during water pumping or were introduced inadvertently with estuarine water inflows (Table 4). Their growth alongside the cultured shrimp could have caused significant biomass loss and feed competition. While manual removal helped reduce their numbers, future mitigation would require the installation of fine-screen filters at water inlets and chemical deterrents such as tea-seed cake or mahua oil cake during pond preparation.

Table 4 Nuisance Species Observed During Culture

Group	Species Identified	Frequency of Occurrence	Observed Impact
Algae	*Spirogyra, Anabaena*	Persistent throughout	Competes with phytoplankton
Insects	Water strider (Gerridae), Common backswimmer (*Notonecta* sp.)	Regularly encountered	Predatory, minor stress to PLs
Predatory Fish	*Elops machnata, Oreochromis mossambicus, Anabas testudineus, Arius maculatus*	Occasionally caught post-harvest	Direct predation on PLs, biomass loss

***Post-Larval Shrimp Health Assessment and Stress Tests*:** To ensure the health status and pathogen-free nature of *Litopenaeus vannamei* post-larvae (PL), a series of stress tolerance and diagnostic tests were conducted before stocking and during early stages of culture. These included formalin stress, osmosis (salinity shock), and water current challenge tests. All tests were carried out on PLs collected from the nursery tanks of the Shrimp Culture Project Unit at CAS in Marine Biology. For each test, 50–100 PLs were used in 1 L containers, and test durations ranged between 15–30 minutes depending on PL size.

In the formalin stress test, the PLs were exposed to a 150 mg/L formalin solution. The osmosis stress test involved sudden exposure of PLs to freshwater (0 ppt) from ambient salinity, while in the water current test, PLs were exposed to an artificial water current to evaluate their swimming ability and endurance. All stress tests were successful, with over 95% of PLs surviving and actively responding, indicating robust physiological health and readiness for pond stocking.

In addition to physical stress tests, general health assessments were performed using light microscopy. Observations of key morphological and anatomical features (body color, appendages, gill health, rostrum integrity, hepatopancreas condition) revealed no major deformities or infections. Only mild signs of necrosis were noted in pleopods and pereopods (G1 level), and moderate signs of gill fouling and necrosis were recorded (G2 level), which were not considered critical. Gut fullness was moderate (G2), while hepatopancreas condition was optimal (G0). No *Zoothamnium* parasites were detected in appendages or mouthparts. To rule out viral pathogens, a two-tiered diagnostic protocol was followed. For *Monodon baculovirus* (MBV) detection, a wet mount squash method was performed on hepatopancreas tissues stained with 0.1% aqueous malachite green. No occlusion bodies were detected under the microscope, suggesting a negative MBV status in the sampled PLs. Further, nested PCR screening for *White Spot Syndrome Virus* (WSSV) was conducted using 2–3 individual PLs. PCR results confirmed the absence of WSSV, as indicated by the lack of a characteristic 848 bp amplicon.

These health and pathogen screenings served as critical quality control steps to eliminate weak or infected larvae prior to stocking. The results collectively confirmed that the PL batch used for culture was specific-pathogen-free (SPF), with high tolerance to environmental stressors and no viral infections detected (Table 5).

Table 5. Stress Test Performance and Health Status of Post-Larvae

(A) Stress Test Results		
Test Type	Exposure Conditions	PL Survival (%)
Formalin Stress	150 mg/L for 15–30 min	>95%
Osmotic Shock	0 ppt for 15–30 min	>95%
Water Current Test	Circulation for 2–5 min	>95%
(B) General Health Assessment and Diagnostic Results		
Observation	Status	Grade
Body Color	Translucent	G0
Appendages, Rostrum	Normal	G0
Gill Color	Normal	G0
Pleopods/Pereopods Necrosis	Present	G1
Zoothamnium (external parasite)	Absent	G0
Gut Fullness	Medium	G2
Gill Necrosis/Fouling	Moderate	G2
MBV Test (Wet Mount)	Negative	–
WSSV (PCR)	Negative (848 bp band absent)	–

***Shrimp Growth, Survival, and Production*:** For the present culture, post-larvae (PL) of *Litopenaeus vannamei* were procured from Vandayar Hatchery, located at Kumarapettai, Tamil Nadu. The hatchery uses seawater drawn directly from the Bay of Bengal and raises PLs to stage PL10–14 before dispatch. The PLs brought to the Centre for Advanced Study in Marine Biology were initially acclimatized at 2 ppt salinity in hatchery conditions and further acclimated to 0 ppt in FRP stock tanks at the institute. A total of 10,000 seeds were procured, of which 2,000 were maintained in tanks for laboratory purposes, and 8,000 PLs were released into the grow-out pond after reaching PL21 stage. The culture period spanned 90 days, from November to January.

The grow-out pond measured approximately 2,866 m² in area (65.51 m × 43.75 m), with a stocking density of 3.5 PL/m². Survival rate at the end of the culture was estimated at 80%, resulting in approximately 8,000 surviving animals. The shrimps were fed with commercial CP feed (sinking pellets), and the feed ration was adjusted as per growth and biomass over time. The feeding schedule followed a progressive plan:

- Days 1–30: 250 g/day, administered in two split doses
- Days 31–60: 500 g/day, administered in two split doses
- Days 61–90: 1,000 g/day, administered in two split doses

Total feed used during the culture was 151 kg. Shrimp growth was consistent, with average body weight (ABW) at harvest reaching 19 g. The average daily gain (ADG) was 0.2 g/day, which is considered acceptable for modified extensive culture systems. Harvest was conducted using cast nets at midday, after which all harvested animals were shifted to FRP tanks (200–500 L) in the laboratory for post-harvest handling and further observation.

The final biomass harvested from the pond was approximately 151 kg, resulting in a feed conversion ratio (FCR) of 1:1. This low FCR highlights efficient feed utilization and minimal wastage, reflecting good health status and favorable pond conditions throughout the culture cycle (Table 6).

Table 6. Stocking and Harvest Summary of *L. vannamei*

Parameter	Value
Pond Dimensions	65.51 m × 43.75 m (2,866 m^2)
Total Seeds Stocked	10,000
Stocking Density	3.5/m^2
Survival Rate	80% (8,000 shrimps)
Average Body Weight	19 g
Total Feed Supplied	151 kg
Final Biomass Harvested	151 kg
Feed Conversion Ratio (FCR)	1:1

1) Economic Analysis and Operational Constraints: ***The overall economic performance of the* Litopenaeus vannamei *culture in the rehabilitated pond system at the Centre for Advanced Study in Marine Biology was modestly profitable. A total of 10,000 seeds were stocked in a pond measuring approximately 2,866 m² (65.51 m × 43.75 m), resulting in a stocking density of 3.5 post-larvae per square metre. After 90 days of culture, the survival rate was estimated at 80%, with around 8,000 animals harvested.***

The total harvested biomass was 151 kg, yielding an average body weight (ABW) of 19 g per shrimp. The average daily growth (ADG) recorded was 0.2 g/day. Feed conversion ratio (FCR) was found to be 1:1, as the total feed input and the biomass output were both 151 kg. The economic breakdown revealed recurring costs amounting to ₹19,675, which included ₹11,325 for feed, ₹5,000 for seed, ₹2,000 for lime and fertilizers, and ₹1,350 for pumping expenses. In addition, non-recurring costs such as bund repair and levelling (₹20,000), catwalk construction and carpentry (₹5,000), sluice gate repairs (₹4,000), and labour for sampling and pond maintenance (₹3,000) added up to ₹33,000.

At a market selling price of ₹200 per kilogram, the 151 kg harvest brought in a gross income of ₹30,200. When recurring costs are subtracted, the net operational profit stood at ₹10,525. However, after accounting for non-recurring costs, the total capital investment was not fully recovered within a single culture cycle, indicating that these capital expenses would need to be amortized over several cycles for sustainable profitability.

Several constraints were encountered during the culture period, which affected operational efficiency and profitability. One major limitation was seepage, caused by structural weaknesses and cracks in the bunds. The limited capacity of the water pumping system only a 5 HP motor was available restricted sufficient water inflow during critical times, particularly in dry spells. Predatory fish infestation was another issue, as species such as *Elops machnata*, *Oreochromis mossambicus*, and *Arius maculatus* entered the system either through rainwater runoff or sluice gate leaks, resulting in predation of juvenile shrimp. Additionally, the absence of fencing allowed for poaching by local fishers, which further reduced the effective yield. These operational constraints highlight the need for infrastructural reinforcement and enhanced biosecurity to improve system reliability and profitability in future cycles.

4. DISCUSSION

The present study highlights the suitability of modified extensive systems for the culture of *Litopenaeus vannamei* in brackishwater ponds managed with low-input strategies. Soil and water quality parameters remained within the optimal range for shrimp growth, reflecting effective pond rehabilitation and basic monitoring. Soil pH (7.8–8.3), organic carbon content (0.41–0.74%), and moderate electrical conductivity (1.7–3.2 dS/m) aligned well with earlier recommendations for shrimp pond soils (Boyd et al., 1994; Chakraborty et al., 2016). Slightly alkaline soils enhance nutrient availability and benthic productivity, supporting algal proliferation crucial for natural food availability (Nayak & Pillai, 2015). Nutrient enrichment during the culture cycle particularly in phosphorus and potassium suggested microbial mineralization and sediment–water nutrient exchange, in line with studies by CIBA (2020) and Subramaniyan et al. (1976).

Water quality remained conducive for shrimp growth throughout the 90-day culture period. Salinity increased gradually from 0 to 17 ppt through estuarine inflow, supporting osmoregulation and growth, especially for *L. vannamei*, which tolerates a broad salinity range (Wyban & Sweeney, 1991; Roy et al., 2010). Dissolved oxygen levels (3.7–4.6 mg/L), pH (7.5–8.9), and temperature (21–28°C) fell within the recommended ranges reported by Shigueno (1972) and Boyd & Tucker (2012). Transparency levels (22–65 cm) indicated moderate phytoplankton blooms and were comparable to successful modified extensive systems described by Sahu et al. (2020). The absence of drastic diurnal fluctuations further confirmed the system's ecological stability.

Biological performance of the cultured shrimp was consistent with benchmark metrics for extensive and semi-intensive farming. A 90-day grow-out period yielded an average body weight of 19 g with 80% survival and an FCR of 1:1. These results compare favourably with national averages (MPEDA, 2016) and findings by Kumar et al. (2019), who observed ADGs of 0.15–0.22 g/day and FCRs of 1.2–1.5 in semi-intensive systems. The uniformity in shrimp size and lack of growth disparity suggest optimal stocking density (3.5/m²) and feed management, echoing observations by Rajesh & Ali (2021). Notably, achieving such performance in a system without mechanical aeration or filtration highlights the adaptability of *L. vannamei* and validates the feasibility of simplified operations under good management practices.

From a technical standpoint, this study reinforces the efficacy of low-tech, ecologically grounded aquaculture systems. Tools such as handheld refractometers, Secchi discs, and basic lab tests were sufficient to monitor key parameters, aligning with the FAO's (2017) recommendations for smallholder shrimp farming. The use of routine stress tests (formalin, salinity shock, water current) and microscopic health assessments (Gill, MBV, and PCR screening) provided a cost-effective strategy for health monitoring. Stress tolerance and pathogen exclusion were high—PLs scored >95% in all stress tests, and PCR confirmed WSSV-free status paralleling protocols suggested by Lightner (2011) and Hossain et al. (2018) for hatchery-based screenings. These results validate that field-level biosecurity can be effective even without intensive infrastructure, provided protocols are stringently followed.

Economic evaluation further substantiated the viability of this culture model. With a total biomass of 151 kg and a farm-gate value of ₹30,200, the net profit (₹10,525) after one cycle reflects a promising return for smallholders. The cost-efficiency was largely due to the low FCR and reliance on rainwater, which reduced pumping costs findings consistent with those of Kumaran et al. (2013), who emphasized water harvesting in hybrid shrimp systems. Although non-recurring costs were significant (₹33,000), their amortization over multiple cycles would improve profitability, as shown in cost–benefit analyses by MPEDA (2015) and Ramu & Jayanthi (2017). Thus, this study supports the argument that decentralized, low-capital shrimp systems can be economically rewarding when inputs are optimally used and health risks are managed.

Nevertheless, some operational challenges were evident. Seepage through cracked bunds, predator intrusion via open sluices, and poaching by local fishers highlight structural and social vulnerabilities often overlooked in economic evaluations. Predatory fish such as *Elops machnata* and *Arius maculatus*, previously reported as threats in open pond systems (Tampi, 1960; Raj & Lalitha, 2009), were observed here as well. Absence of fencing and insufficient pumping capacity further exacerbated management inefficiencies. These findings reinforce the need for basic physical infrastructure such as predator-exclusion screens and secure perimeters even in low-input systems. As noted by Boyd & Tucker (2012), economic viability depends not only on biological performance but also on long-term system reliability and risk mitigation.

In summary, this study contributes to the growing body of evidence supporting modified extensive shrimp farming as a viable strategy for small and medium-scale farmers. It provides empirical proof that environmental compatibility, low-stress animal husbandry, and basic biosecurity can deliver performance metrics comparable to more intensive systems. Moreover, it emphasizes the importance of integrating environmental monitoring, local infrastructure, and economic planning into sustainable aquaculture design. This model can serve as a replicable framework for regions with underutilized brackishwater resources and low access to capital, helping bridge the gap between resource potential and aquaculture output in India and beyond.

5. CONCLUSION

This study demonstrated the feasibility of culturing *Litopenaeus vannamei* in a modified extensive, rain-fed system with minimal inputs. Over a 90-day cycle, acceptable survival (80%), average body weight (19 g), and a good FCR (1:1) were achieved using strategic pond preparation, phased feeding, and basic water quality monitoring. Soil and water parameters remained within optimal ranges, while stress and pathogen tests confirmed the health status of stocked PLs. Despite minor challenges such as seepage, algal overgrowth, and predator intrusion, the system delivered a modest profit (₹10,525), proving viable for low-cost, small-scale shrimp farming.

Recommendations

- Promote modified extensive systems for smallholders with limited resources, especially in rain-fed zones.
- Use predator screens, fencing, and bund maintenance to prevent losses.
- Institutionalize simple health screening (stress tests + PCR) before stocking PLs.
- Support farmers with subsidies for seed, feed, fencing, and energy-efficient pumps.
- Conduct long-term trials in other coastal zones to confirm replicability.
- Integrate findings into rural training programs under NFDB/PMMSY initiatives.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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