Journal of Environmental Biology
p-ISSN: 0254-8704 • e-ISSN: 2394-0379 • CODEN: JEBIDP

JEB®

Original Research Paper
Volume 47 Issue 5 September 2026 pp. 1094-1103
DOI: http://doi.org/10.22438/jeb/47/5/MRN-6029

J. Environ. Biol., 2026
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Journal website : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Growth performance, physiological response, and economic viability of *Anabas testudineus* reared in an airlift biofloc aquaculture system

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Received: 30 March 2026 **Revised:** 03 June 2026 **Accepted:** 24 July 2026

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Abstract

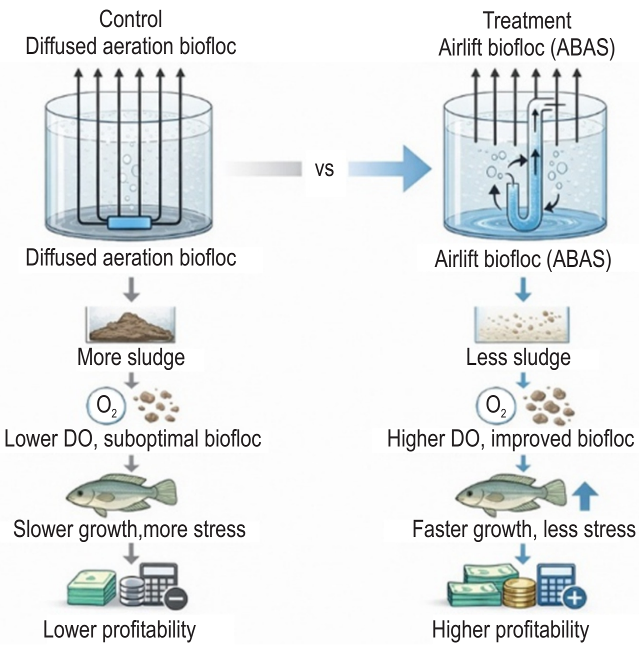
Aim: The study evaluates the feasibility of an airlift biofloc aquaculture system (ABAS) by assessing the welfare parameters of *Anabas testudineus* (Bloch, 1792) and the economic analysis of the system.

Methodology: The experiment was conducted for 90 days in 1500 litre capacity FRP tanks. The design included a control with six diffusion air stones and a treatment with six airlift pumps, each in triplicate. Growth, water quality, haematological parameters, antioxidant enzymes (superoxide dismutase and catalase), and stress indicators (cortisol and glucose) were evaluated. Economic performance was assessed using BEP, ROI, and BCR for *A. testudineus* culture in ABAS.

Results: ABAS outperformed the diffusion-aerated biofloc system, achieving higher dissolved oxygen (6.4 mg l^{-1}), biofloc volume (7.8 m l l^{-1}), and growth, including specific growth rate (3.58% day^{-1}), feed conversion ratio (0.95), weight gain (1931.5%), and biomass production (10.46 kg m^{-3}). Lower haematological, antioxidant and stress indicators indicated reduced physiological and oxidative stress. Economic analysis showed greater profitability, with BEP (1.69 kg), ROI (68.75%) and BCR (1.69) than the control.

Interpretation: Under the experimental conditions, ABAS improved the growth performance, water quality, stress-related biomarker responses, and economic returns compared with the control. These findings highlight its potential as a sustainable approach for *A. testudineus* culture.

Key words: Aeration, Airlift pump, *Anabas testudineus*, Biofloc, Sludge management



How to cite: Hussain, J., P.S. Prathib, D. Sarma, A.K. Singh and V. Kima: Growth performance, physiological response, and economic viability of *Anabas testudineus* reared in an airlift biofloc aquaculture system. *J. Environ. Biol.*, **47,** 1094-1103 (2026).

Introduction

Biofloc technology has emerged globally as a modern, sustainable aquaculture system that integrates principles of zero-water-exchange systems with the activated-sludge approach of wastewater treatment (Li *et al.,* 2025). It offers an environmentally efficient solution for intensive fish and shrimp production (Yu *et al.,* 2023). This aquaculture technology is widely adopted in tropical regions where the availability of land and water for aquaculture is limited (Yadav *et al.,* 2025). The biofloc or suspended microbial aggregates comprising bacteria, algae, protozoa, and other microorganisms function simultaneously as biological filters as well as supplemental nutrient-rich feed source for cultured species. The continuous assimilation of nitrogenous waste by heterotrophic and chemoautotrophic microbial communities substantially reduces the requirement for water exchange and mitigates the discharge of nutrient-laden effluents into natural water bodies (Khanjani *et al.,* 2022). Biofloc technology relies on heterotrophic microorganisms that convert organic wastes and nitrogenous compounds into microbial biomass under a suitable C: N ratio. The formed biofloc improves the water quality and provides a protein-rich natural feed source for cultured fish. Numerous studies have demonstrated the broader benefits of biofloc technology, including improved feed conversion ratios, higher survival rates, and reduced environmental footprints associated with aquaculture operations (Khanjani and Sharifinia, 2020; Li *et al.,* 2025; Jan *et al.,* 2026).

The performance of biofloc system depends on maintaining an optimal C:N ratio and regular monitoring of key water quality parameters to support microbial activity and system stability (Emerenciano *et al.,* 2017; Khanjani *et al.,* 2024). Consequently, effective management is essential for sustainable biofloc aquaculture. This aquaculture technology is widely adopted in tropical regions where the availability of land and water for aquaculture is limited. BFT also enhances water quality, improves the availability of naturalfood, and contributes to a reduction in disease incidence (Yadav *et al.,* 2025; Avnimelech, 2007). Despite these advantages, sludge accumulation and inefficient circulation in conventional diffusion-aerated biofloc systems may adversely influence the water quality, operational efficiency, and performance of cultured species, highlighting the need for improved system design and management strategies (Minaz *et al.,* 2024). The airlift biofloc aquaculture system (ABAS) is an innovative approach that integrates airlift-assisted aeration and water circulation within a biofloc environment.

The system has been patented (Design Patent No. 425955-001) (Hussain *et al.,* 2024). Similar to conventional biofloc technology, ABAS employs organic carbon sources to stimulate heterotrophic bacterial growth and biofloc formation, providing an additional nutrient source for cultured organisms (Avnimelech, 2006). Airlift-driven circulation enhances nutrient recycling, microbial activity, dissolved oxygen distribution, and the recirculation of settled solids, thereby improving water quality and system efficiency (Abakari *et al.,* 2021; Hussain, 2023). Despite the reported benefits of biofloc technology and airlift-assisted circulation, information on the application of ABAS for *Anabas testudineus* culture remains limited. The success of biofloc systems depend on selecting species that are adaptable to fluctuating water-quality conditions and compatible with intensive culture environments (Raza *et al.,* 2024; Laboni *et al.,* 2023). In the present study, *A. testudineus* (Climbing perch), an indigenous freshwater species of India, was selected due to its physiological adaptability, air-breathing ability, omnivorous feeding habit, and its ability to utilize bioflocs as a supplementary nutrient source, which may reduce dependence on formulated feed and tolerance to particulate-rich and variable water-quality conditions, making it suitable for biofloc-based culture systems (Debnath *et al.,* 2018; Hanafie *et al.,* 2023; Wankanapol *et al.,* 2020).

Therefore, the present study was undertaken to compare the airlift biofloc aquaculture system (ABAS) with a conventional diffused-aerated biofloc culture system in terms of sludge management, water quality characteristics, growth performance, physiological responses of *Anabas testudineus,* and the economic performance of the culture system.

Materials and Methods

Experimental site: The study was carried out during 2025 at the Division of Aquaculture, ICAR-Central Institute of Fisheries Education, Mumbai, India. All the methods and procedures were performed in accordance with relevant guidelines and regulations. All the methods were reported in accordance with ARRIVE 2.0 guidelines (Percie Du Sert *et al.,* 2020).

Experimental design: The experiment was conducted for 90 days in 1500 litre capacity FRP tanks to evaluate the growth, physiological responses, and economic viability of Climbing perch (*Anabas testudineus*). A completely randomized design with three replicates per treatment was adopted. Control tanks were equipped with six diffusion air stones whereas treatment tanks contained six airlift pumps mounted on a circular framework (Design Patent No. 425955-001) (Fig. 1a–1c). Uniform aeration was maintained at 172 mbar and 10 l min^{-1} in all tanks using a single blower with separate airlines for each treatment. The airlift system was operated at a head height of 10 cm and a submergence ratio of 0.83 throughout the study period. The submergence ratio was calculated using Stenning and Martin (1968).

Experimental fish and stocking density: Juvenile Climbing perch (*A. testudineus*) with an initial mean body weight of 4.05 ± 0.06 g were obtained from Ali Fishery Fish Seed Hatchery, West Bengal, and stocked at a density of 250 fish m^{-3}. Fish were fed a commercial floating pellet diet (0.8–2 mm; 32% crude protein) three times a day at 3% body weight during the first month and 2% during the subsequent two months. No water exchange was performed during the 90-day-culture period; however, small volumes of water were added periodically to compensate for evaporation losses.

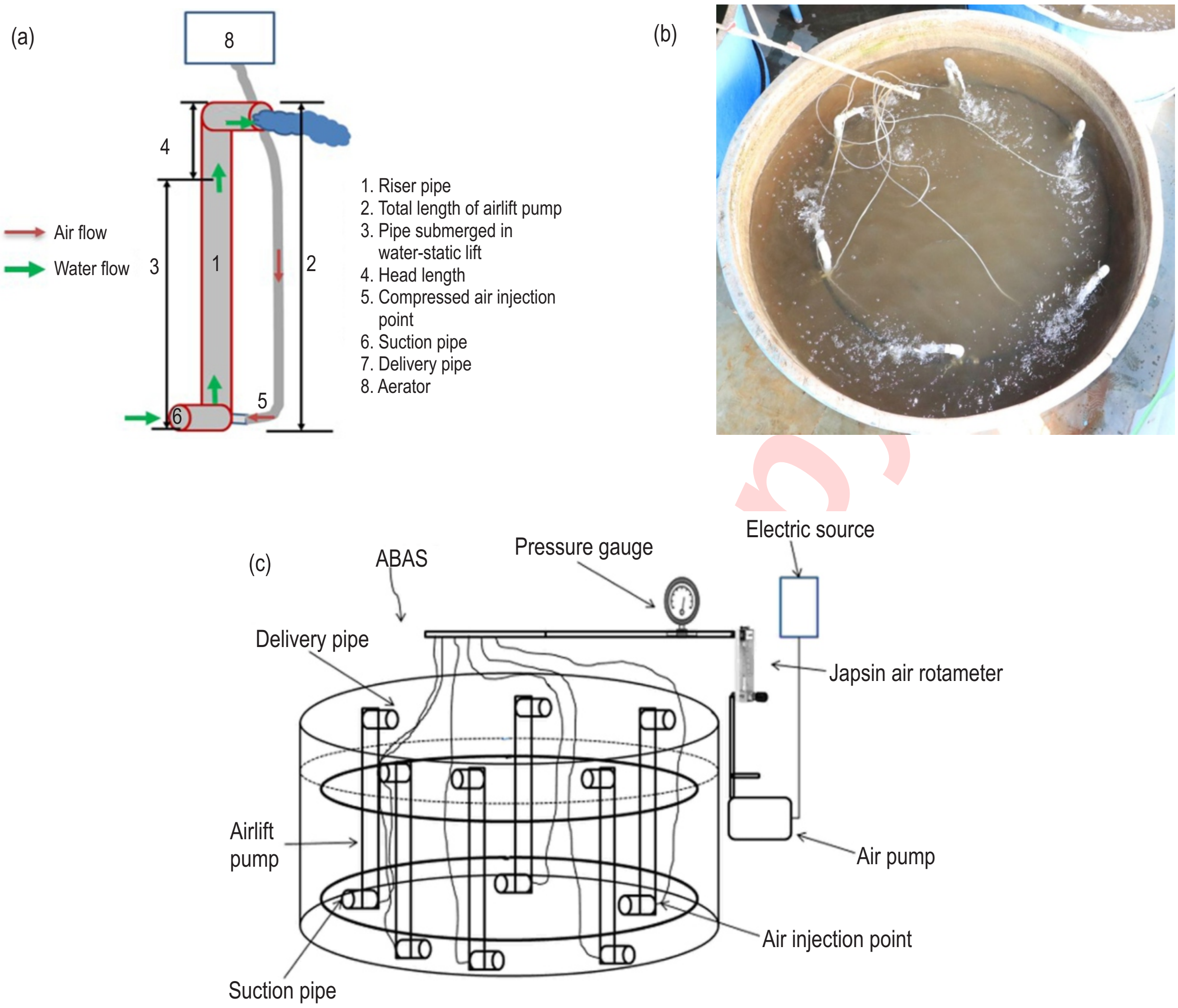


Fig. 1: (a) Schematic diagram of an airlift pump designed for the experiment. (b) Top view of ABAS designed for the experiment and (c) Schematic diagram of ABAS (design patent no: 425955-001) (Hussain, 2024)

Growth parameters: Key growth performance indicators viz., weight gain percentage, specific growth rate (SGR), feed conversion ratio (FCR), feed efficiency ratio (FER), and protein efficiency ratio (PER) were calculated (Zonneveld *et al.*, 1991).

Physico-chemical parameters of water and biofloc parameters: Water quality parameters were monitored at 10-day intervals throughout the experimental period. Dissolved oxygen (DO), free carbon dioxide (CO_2), total hardness, and total alkalinity were determined following APHA (2023) standard procedures. Total ammonia nitrogen (TAN), nitrite-nitrogen (NO_2^--N) and nitrate-nitrogen (NO_3^--N) were analyzed by phenate method with a UV–Visible spectrophotometer at wavelengths of 635, 543 and 540 nm, respectively, and expressed in mg l^{-1}. Water temperature and pH were recorded using a digital thermometer and pH meter. Biofloc volume was measured at 10-day intervals using an Imhoff cone and expressed in ml l^{-1}.

Total suspended solids (TSS) were determined using standard methods, while water transparency was measured using a 30-cm Secchi disk. Biological oxygen demand (BOD) was estimated following NEMI guidelines, and total dissolved solids (TDS) were measured using a digital TDS meter (SKADIOO). Settling solids were assessed weekly by siphoning bottom water and quantifying the collected solids using an Imhoff cone and was expressed in ml l^{-1}.

Inoculum preparation and C/N ratio maintenance: Jaggery was used as the carbon source throughout the experiment, and the C:N ratio was maintained at 15:1 (Avnimelech, 2009). For initial biofloc development, pond bottom soil collected from a fish pond at ICAR-CIFE, Mumbai, was used as inoculum. Fermented jaggery and yeast (100:1) were prepared by incubating for 24 h. The inoculum (300 l) was developed using 10 mg l^{-1} ammonium sulphate, 200 mg l^{-1} fermented jaggery, and 20 g l^{-1} pond soil under vigorous aeration (Avnimelech, 1999). Following the procedures the Avnimelech (1999) and Crab *et al.* (2012), the carbohydrate requirement was calculated based on feed protein and jaggery carbon content. Fish were fed a 32% protein diet at 3% body weight per day. For every 30 g feed supplied per kg fish biomass, 9.6 g protein containing 1.54 g nitrogen was provided, of which about 75% (1.15 g) was released into the culture water (Piedrahita, 2003). To maintain a C:N ratio of 15:1, 17.25 g carbon was required daily. As jaggery contains approximately 50% carbon, 34.5 g fermented jaggery was added daily per 30 g feed supplied per kg fish biomass.

Euthanasia process: Prior to sampling the fish were anesthetized with clove oil at a concentration of 50 μl l^{-1} for 5 min followed by ice killing (Keene *et al.*, 1998).

Haematological parameters: To minimize handling-induced stress, blood sampling was completed within 2 min of tank disturbance. Nine fish from each treatment were anesthetized with clove oil (50 μl l^{-1}), and blood was collected from the caudal vein using sterile 1 ml BD Tuberculin syringes. Samples were transferred to 1.5 ml microcentrifuge tubes coated with 2.7% EDTA and subjected to complete blood count (CBC) analysis. Red and white blood cell counts were determined using a hemacytometer, while haematocrit was measured by the microhaematocrit method (Witeska *et al.,* 2022) and expressed as packed cell volume (% PCV). Haemoglobin concentration was estimated using the cyanmethemoglobin method. Erythrocyte indices, including mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC), were calculated using standard formulae (Fazio, 2019).

Antioxidant and stress parameters: Catalase (CAT) activity was determined following Hadwan *et al.* (2024), while superoxide dismutase (SOD) activity was measured using a Rendox assay kit (England). Serum glucose was estimated using an Erba Diagnostic Mannheim kit (Transasia Biomedicals Ltd., India), with absorbance measured at 505 nm. Serum cortisol was quantified using an LDNMS E-5000 ELISA kit according to the manufacturer's instructions.

Economic analysis: Economic analysis was performed to evaluate the viability of ABAS and conventional biofloc systems. Profit, revenue, breakeven point (BEP), return on investment (ROI), and benefit–cost ratio (BCR) were calculated. Fixed cost was estimated as 10% depreciation of total capital investment, while variable cost included all recurring expenses. The fixed and variable costs of both production systems are presented in Table 1.

Profit = Revenue - Production cost
Revenue = Total fish produced (kg) X Selling price per kg

Breakeven point (BEP) is a parameter used to analyze the relationship between variable costs, fixed costs, sales volume, and profits (Utami and Mubarok, 2021). Return on Investment (ROI) is a profit ratio that aims to analyze the ability of a business to generate profits for one cycle (Wangarry *et al.,* 2015). Benefit cost ratio (BCR) is the ratio between revenue and the cost of producing a business (Sarker *et al.,* 2022).

Statistical analyses: Statistical analysis was performed using an independent samples t-test in SPSS software (version 25.0, IBM Corp.) to compare the means between the two treatment groups, with the significance level set at $p < 0.05$. Data normality was assessed using the Shapiro–Wilk test. Homogeneity of variances was evaluated using Levene's test to confirm that the assumption of equal variances was satisfied before conducting the independent samples t-test.Repeated-measures ANOVA was not performed in the present study. Temporal comparisons between control and treatment groups at corresponding sampling points were analyzed using independent samples t-test.

Results and Discussion

The physico-chemical parameters monitored during the experimental period are summarized in Table 2. Despite a uniform airflow rate across all units, DO differed significantly between the control and treatment groups. In the treatment group, the airlift pump continuously circulated water by drawing it from the bottom and discharging it at the surface. This process enhanced both vertical and horizontal water mixing, thereby improving dissolved oxygen (DO) levels through increased atmospheric aeration. However, DO levels gradually declined over the experimental period due to the increase in fish biomass and were negatively correlated with biofloc volume, settling solids, biochemical oxygen demand (BOD), and reduced water transparency (Matishov *et al.,* 2025). The decrease in DO concentrations was attributed to the cumulative effect of oxygen consumption by both cultured fish and microbial communities engaged in organic matter decomposition and nitrification. Hargreaves (2013) similarly reported elevated respiration rates in biofloc systems due to increased concentrations of suspended solids and fish biomass. Water temperature remained stable across treatments

Table 1: Fixed and variable costs for economic analysis of two different biofloc production systems

Parameters	Particular	Method
Fixed cost per cycle (Rupees)	Biofloc tank, shed material, aerator, water pump, and other capital accessories	10% depreciation cost of total capital investment
Variable cost per cycle (Rupees)	Fish seed,fish feed,carbon source,chemicals, electricity, and other accessories.	Sum of all recurring expenses

Table 2: Physico-chemical parameters of water during the experimental periods

Parameter	Control	Treatment	p Value
Dissolved Oxygen (mg l^{-1})	6.12 ± 0.081[a]	6.40 ± 0.051[b]	0.011
Total Ammonia Nitrogen (mg l^{-1})	0.88 ± 0.188[a]	0.45 ± 0.152[b]	0.025
Nitrite (mg l^{-1})	0.41 ± 0.061[a]	0.29 ± 0.060[b]	0.013
Nitrate (mg l^{-1})	3.15 ± 0.246[a]	3.31 ± 0.275[b]	0.043
Alkalinity (mg l^{-1})	176.54 ± 4.012[a]	165.25 ± 4.532[a]	0.035
Hardness (mg l^{-1})	124.83 ± 3.013[a]	122.36 ± 2.650[a]	0.002
Biofloc Volume (ml l^{-1})	12.97 ± 0.610[a]	7.85 ± 0.602[b]	0.001
Total Suspended Solids (mg l^{-1})	488.75 ± 8.012[a]	384.63 ± 2.410[b]	0.001
Total Dissolved Solids (mg l^{-1})	394.66 ± 3.890[a]	358.25 ± 2.601[b]	0.001
Transparency (cm)	11.95 ± 0.210[a]	19.98 ± 0.313[b]	0.001
Free CO_2 (mg l^{-1})	7.08 ± 0.360[a]	3.25 ± 0.130[b]	0.001
pH	7.93 ± 0.022[a]	7.61 ± 0.029[b]	0.012
Temperature (°C)	27.45 ± 0.072[a]	26.80 ± 0.050[b]	0.021
Biochemical Oxygen Demand (mg l^{-1})	5.92 ± 0.023[a]	5.51 ± 0.061[b]	0.034
Settling Solids (ml l^{-1})	51.15 ± 3.21[a]	17.10 ± 0.73[b]	0.000

Data expressed as mean ± S.E. (n=27); Data with different superscripts in the same row are significantly different ($p < 0.05$).

Table 3: Growth parameters of Climbing perch reared in two different culture systems

Parameter	Control	Treatment	p Value
Mean Body Weight (MBW, in g)	74.02 ± 1.45[a]	81.26 ± 1.32[b]	0.003
Percentage Weight Gain (PWG, in %)	1,750.5 ± 24.6[a]	1,931.5 ± 27.3[b]	<0.001
Specific Growth Rate (SGR, %/day)	3.48 ± 0.037[a]	3.58 ± 0.035[b]	0.003
Feed Conversion Ratio (FCR)	1.14 ± 0.034[a]	0.95 ± 0.028[b]	0.007
Protein Efficiency Ratio (PER)	2.81 ± 0.089[a]	3.39 ± 0.081[b]	0.002
Feed Efficiency Ratio (FER)	0.88 ± 0.028[b]	1.07 ± 0.024[a]	0.003
Total Biomass Production (TBP, in kg)	8.71 ± 0.25[b]	10.46 ± 0.29[a]	0.003
Survival Rate (%)	100 ± 0.00[a]	100 ± 0.00[a]	1.000

Data expressed as mean ± S.E. (n=27); Data with different superscripts in the same row are significantly different ($p < 0.05$)

without significant variation. However, pH and TAN levels were significantly higher in the control group than in the treatment group. In biofloc systems, pH plays a critical role in regulating ammonia toxicity, with lower pH favouring the conversion of toxic unionized ammonia (NH_3) to less harmful ionic form (NH_4^+), while higher pH promotes ammonia accumulation. In the present study, pH and TAN increased during the initial two weeks and declined thereafter (Jan *et al.,* 2026). The comparatively elevated TAN observed during the early culture phase may reflect the time required for the establishment and stabilization of heterotrophic microbial communities within the biofloc system (Crab *et al.,* 2012). The carbon addition strategy was based on the target C:N ratio estimated from feed nitrogen input and may not have fully represented the actual C:N dynamics of the culture system, as contributions from pre-existing TAN and microbial biomass were not considered. Alkalinity and hardness did not differ significantly between treatments. The significantly lower TAN concentrations observed in the ABAS treatment were likely associated with improved dissolved oxygen levels, lower pH and continuous water circulation, which enhanced ammonia removal processes (Ebeling *et al.,* 2006; Zhang *et al.,* 2011).

Greater sludge accumulation in the control likely created anaerobic zones that inhibited heterotrophic bacteria involved in biofloc stability and nutrient recycling, resulting in higher TAN and nitrite concentrations. Both parameters increased during the initial culture phase and declined following microbial stabilization. Higher nitrate concentrations in the treatment indicated enhanced nitrification activity (Akange *et al.,* 2025), while greater transparency reflected lower biofloc and TSS concentrations, likely due to biofloc consumption by *A. testudineus* (Wetzel, 2001). Overall, ABAS effectively controlled floc accumulation compared with conventional diffusion aeration.

Higher BOD and CO_2 concentrations in the control were associated with greater biofloc volume (Garcés and Lara, 2023). In contrast, the airlift system enhanced CO_2 removal through effective gas stripping (Colt *et al*., 2012). The treatment also maintained lower biofloc volume, TSS and FCR, indicating improved nutrient utilization (Lal *et al.,* 2024). Comparatively lower biofloc volume observed in ABAS may reflect differences in solids management and water circulation characteristics under the experimental conditions. However, lower BFV should not be interpreted as universally advantageous, as optimal biofloc volume ranges for *A. testudineus* under biofloc culture conditions are not yet clearly established. Therefore, the BFV values observed in the present study should be interpreted in relation to system performance rather than as independent indicators of culture suitability. Sludge volume in the control exceeded 70 ml l^{-1}, while ABAS limited sludge accumulation through continuous lifting of water and solids. Given that optimal settling solids concentrations in biofloc systems ranged from 25 to 50 ml l^{-1} (Hargreaves, 2013), effective solids management is critical for fish growth and physiological performance. In the present study, the water quality parameters (Table 2) and growth parameters (Table 3) clearly indicated that the ABAS system is better for the culture of Climbing perch. The treatment group was providing better water quality and biofloc-parameters for the successful culture of Climbing perch. Although aeration was supplied through a common blower pump, separate airlines were provided to individual tanks, and airflow conditions were maintained uniformly across treatments. Therefore, the observed responses should be interpreted within the experimental conditions adopted in the present study.Temporal variations observed during the experimental period are reflected in the average values presented in Table 2.

The observed responses in ABAS may reflect the combined influence of differences in aeration mechanism and water circulation pattern, in addition to sludge management. Therefore, the individual contributions of sludge lifting and enhanced mixing could not be independently distinguished within the present experimental design. Significant differences ($p<0.05$) in body weight gain (BWG), percentage weight gain (PWG), specific growth rate (SGR), and total biomass production were observed between the control and treatment groups.Survival remained 100% in both experimental groups throughout the culture period, indicating no mortality under the experimental conditions (Table 3). The treatment group, equipped with an airlift biofloc aquaculture system (ABAS), demonstrated superior growth performance across all measured parameters. The highest mean values of BWG, PWG, SGR, and biomass yield (kg m^{-3}) were recorded in the treatment group. The treatment group also indicated lower FCR, higher protein efficiency ratio (PER), and feed efficiency ratio (FER), revealing higher feed and biofloc utilization efficiency. Average individual weight gain (g) during the experimental period is presented in Fig. 2. Growth performance was consistently higher in ABAS, likely due to improved water quality, reduced suspended solids, enhanced biofloc utilization, and efficient aeration (Wisal and Danish, 2025). Improved water circulation also enhanced sludge management and floc accessibility, while excessive solids have been reported to adversely affect fish health (Hargreaves, 2013).

The study demonstrated that ABAS positively influences both the growth and physiological performance of *A. testudineus* cultured in bioflocsystems. A significant difference ($p < 0.05$) in haematological parameters was observed between the groups. Fish reared under ABAS exhibited higher TEC, Hb, TLC, PC and HCT values than the control (Table 4), indicating improved physiological and immunological status. The favourable haematological profile may be attributed to improved water quality, reduced sludge accumulation and higher oxygen availability (Geng *et al.,* 2012; Burgos-Aceves *et al.,* 2019; Raza *et al.,* 2024), highlighting the potential of ABAS to reduce stress under intensive biofloc culture conditions. A significant difference ($p < 0.05$) in acute stress biomarkers was observed between the control and treatment groups (Table 5). Fish reared in ABAS exhibited lower serum cortisol and glucose levels than the control, indicating a reduced

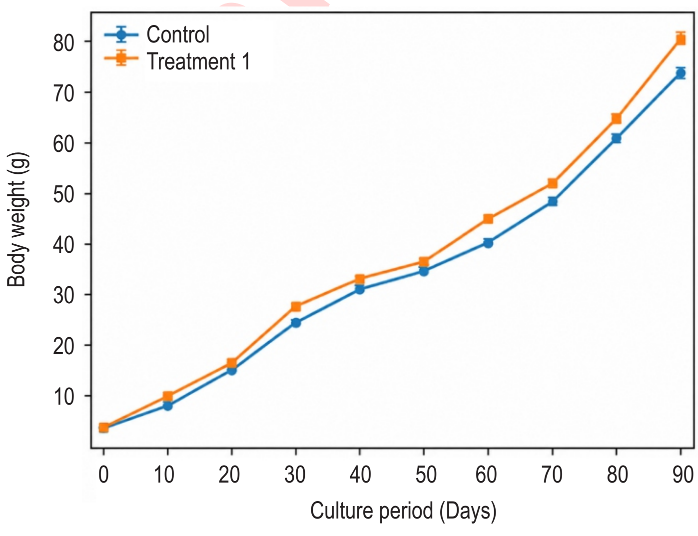


Fig. 2: Growth performance of *Anabas testudineus* under different treatments during the 90-day culture period (mean ± SE, n = 3). Error bars represent the standard error of the mean.

Table 4: Hematological parameters of Climbing perch in two different culture systems

Parameter	Control	Treatment	p Value
TEC (×10^6 µl^{-1})	0.92 ± 0.105[a]	1.69 ± 0.158[b]	0.001
TLC (×10^3µl^{-1})	2345.33 ± 112.74[a]	6987.11 ± 328.65[b]	<0.001
HCT (%)	3.45 ± 0.11[a]	5.72 ± 0.063[b]	0.003
Platelet Count (µ l^{-1})	32,145 ± 1180[a]	115,890 ± 1415[b]	<0.001
MCV (fl)	162.9 ± 1.75[a]	186.8 ± 1.42[a]	0.002
MCH (pg)	38.81 ± 0.09[a]	44.05 ± 0.11[b]	0.003
MCHC (g d l^{-1})	23.74 ± 0.04[a]	23.89 ± 0.007[a]	0.126
RDW (%)	87.41 ± 3.26[a]	108.3 ± 4.21[b]	0.002

Data expressed as mean ± S.E.(n=3). Data with different superscripts in the same row are significantly different ($p < 0.05$). TEC: total erythrocyte count; TLC:total leucocyte counts; PC:platelets count; HCT:Haematocrit value; MCV: mean corpuscular volume; MCH: mean corpuscular haemoglobin; MCHC, mean corpuscular haemoglobin concentration; RDW: red cell distribution width

Table 5: Antioxidant and stress parameters of Climbing perch in two different culture systems

Parameters		Control	Treatment	p Value
SOD (U mg^{-1} protein)	Gill	23.84 ± 0.41[a]	19.12 ± 0.89[b]	0.002
	Liver	31.26 ± 0.84[a]	22.13 ± 0.53[b]	0.003
Catalase (U mg^{-1} protein)	Gill	15.93 ± 0.52[a]	3.65 ± 0.21[b]	<0.001
	Liver	26.42 ± 0.65[a]	10.03 ± 0.61[b]	<0.001
Cortisol (ng d l^{-1})	Blood Serum	52.87 ± 0.71[a]	49.08 ± 0.19[b]	0.001
Glucose (mg d l^{-1})	Blood Serum	104.17 ± 0.56[a]	76.95 ± 1.28[b]	<0.001

Data expressed as Mean ± SE. Data with different superscripts in the same row are significantly different ($p < 0.05$).

Table 6: Economic analysis of a 1.5 m^3 water holding capacity of two different biofloc aquaculture production systems

Parameters	Particular	Treatment	Control
Fixed cost (Rupees)	Biofloc tank	500	500
	Shed material	200	200
	Aerator	150	150
	water pump	150	150
	Aeration facility (material cost only)	100	50
	Other Accessories	100	100
Total fixed cost		**1,200**	**1,150**
Variable cost (Rupees)	Fish seed (250 nos)	500	500
	Fish feed (20 kg)	1,200	1,200
	Carbon source	100	100
	Electricity	500	500
	Other accessories	100	100
Total variable cost		**2,400**	**2,400**
Total cost = Total fixed cost + Variable cost		**3,600**	**3,550**
Total fish Production (kg)		20.25	18.5
Revenue generated (Rupees)		6,075	5,550
Profit (Rupees)		2,475	2,000
Variable cost for per kg of fish production (Rupees)		118.52	129.73
Fixed cost for per kg of fish production (Rupees)		59.25	62.16
Total cost for per kg of fish production (Rupees)		177.77	191.89
BEP (kg)		6.61	6.75
ROI (%)		68.75%	56.34%
BCR		1.69	1.56

BEP: Breakeven point; ROI: Return on investment(%); BCR: Benefit–cost ratio. Material and operational costs presented in this analysis were directly associated with the experimental culture period. Costs related to labour, biosecurity measures, water quality testing, and mortality management were not included in the present analysis. The aeration facility cost represented only the material cost of aeration components used during the experimental setup and did not include additional fabrication or infrastructure expenses.

stress response. Similarly, the activities of antioxidant enzymes, including superoxide dismutase (SOD) and catalase were significantly lower in the ABAS treatment, suggesting a reduced oxidative challenge under the experimental conditions.

Higher concentrations of suspended solids in biofloc systems have been reported to impair gill function and induce physiological stress (Hargreaves, 2013). Therefore, the lower antioxidant enzyme activities observed in ABAS may be associated with improved solids management, enhanced water circulation, and more favourable culture conditions (Abdel-Rahim *et al.,* 2024). However, interpretation of antioxidant responses should be made cautiously, as species-specific reference values for *A. testudineus* under biofloc conditions are not yet well established. Overall, the observed stress and antioxidant profiles suggest that ABAS may reduce oxidative and stress-related responses under intensive biofloc culture conditions, although physiological status was assessed using selected biomarkers and should not be considered direct evidence of overall fish health. The economic performance of 1.5 m^3 biofloc system is presented in Table 6. The treatment exhibited a lower BEP (6.61 kg) than the control (6.75 kg), indicating lower production requirements to recover costs. ROI and BCR were also higher in the treatment group (68.75% and 1.69) than in the control group (56.34% and 1.56), demonstrating greater profitability and cost-effectiveness (Burad-Méndez *et al.,* 2023; Serafini *et al.,* 2025; Lovejan *et al.,* 2026). Overall, ABAS improved the economic returns and sustainability in biofloc aquaculture.

The present study demonstrated that ABAS improved the growth performance, water quality, sludge management, and economic returns compared to conventional diffusion aeration. Continuous water circulation generated by airlift pumps promoted efficient waste removal and favourable culture conditions for *A. testudineus.* These findings highlight ABAS as a techno-economically viable, environmentally sustainable, and water-efficient alternative for intensive biofloc aquaculture. Further studies should evaluate the individual effects of sludge lifting and water circulation and assess long-term physiological responses under commercial-scale culture conditions.

Acknowledgments

The authors gratefully acknowledge the Director and Joint Director,ICAR–Central Institute of Fisheries Education, Mumbai, India, for institutional support under the National Agricultural Higher Education Project (NAHEP)–Student Entrepreneurship Development Program.

Authors' contribution: J. Hussain: Conceptualization, methodology, investigation, data curation and writing original draft. **P.S. Prathib:** Investigation, writing original draft, data analysis and visualization. **D. Sarma:** Supervision, conceptualization, project administration, Writing–revision and editing. **A.K. Singh:** Formal analysis, validation. **V. Kima:** Investigation, data collection.

Funding: Not applicable.

Research content: The research content presented in this manuscript is entirely original and has not been previously published or submitted elsewhere.

Ethical approval: The research was conducted as per the ethical procedures for the Animal Care of ICAR-Central Institute of Fisheries Education, Mumbai, India- 400061. The research was approved by the Board of Studies (Division of Aquaculture) and the academic cell of the ICAR-Central Institute of Fisheries Education (Deemed University), Mumbai, India- 400061.

Conflict of interest: The authors declare that they have no conflict of interest.

Data availability: The data that support the findings of this study are available on request from the Corresponding author.

Consent to publish: All authors agree to publish the paper in the *Journal of Environmental Biology.*

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