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Assessment of Tilapia (*Oreochromis niloticus*-C. Linnaeus 1758) Culture Practices and Their Socio-Economic Impact in Kamareddy Area, Kamareddy District, Telangana, India

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Abstract

Inland aquaculture diversification toward fast-growing, high-yielding finfish species is vital for enhancing rural food security and livelihoods across semi-arid tropics. This study provides an empirical techno-economic and socio-economic evaluation of Nile Tilapia (*Oreochromis niloticus*) farming practices in the Kamareddy district of Telangana, India. Utilizing a multi-stage stratified random sampling framework, primary cross-sectional data were collected from 120 operational fish farms across four mandals (Kamareddy, Bhiknoor, Domakonda, and Machareddy). Technical parameters, cost-return structures, econometric drivers, livelihood indicators, and operational bottlenecks were evaluated using standard production models, Ordinary Least Squares (OLS) Cobb-Douglas regression, and Henry Garrett's Ranking Technique. The findings indicate a mean gross yield of 25.49 ± 9.42 the^{-1} $cycle^{-1}$, varying from 16.49 ± 3.12 the^{-1} in smallholdings (< 0.5 ha) to 39.84 ± 4.88 the^{-1} in large commercial farms (> 1.5 ha). Mean Feed Conversion Ratio (FCR) and Specific Growth Rate (SGR) averaged 1.52 ± 0.15 and 2.89 ± 0.18% day^{-1}, respectively. Feed comprised the largest variable expenditure (71.93%). Tilapia culture demonstrated robust economic viability with a pooled Benefit-Cost Ratio (BCR) of 1.55 and a Net Farm Income of INR 8,90,546 ha^{-1} $cycle^{-1}$ (USD 10,665.22). Econometric estimation (R^2 = 0.814) revealed that feed input (β = 0.442, p<0.001), stocking density (β = 0.0384, p<0.001), mechanical aeration (p<0.001), and formal training (p = 0.003) significantly enhanced net returns, whereas prolonged culture duration (β = -0.194, p = 0.018) reduced profitability. Socio-economically, adoption increased mean annual household income by 166.83%, elevated labor absorption to 118.4 person-days ha^{-1} $cycle^{-1}$ (+177.93%), and reduced income inequality (Gini coefficient decreased from 0.462 to 0.354). Garrett's ranking identified volatile feed prices (Score: 69.70), certified mono-sex seed scarcity (63.80), and intermediary market control (58.70) as primary constraints. Targeted institutional credit, government-accredited local hatcheries, and cold-chain marketing support are recommended to sustain commercial Tilapia farming in semi-arid agrarian systems.

Keywords: *Oreochromis niloticus*, Tilapia, Farm economics, Cobb-Douglas production function, Socio-economic impact, Garrett's ranking, Telangana aquaculture

1. Introduction

Aquaculture is the fastest-growing food-producing sector worldwide and plays a vital role in relieving rural poverty, addressing global protein shortages, and assisting sustainable livelihood systems (FAO (2024) [9]. Intensive diversification of inland aquaculture development has become a cornerstone to rural economic transformation in developing economies. Of the generally valuable freshwater finfish candidates, Nile Tilapia (*Oreochromis niloticus*), called "chicken of aquatics" with reputed food costs and features has now been a paramount cultivated fish past across tropical lower districts. Due to wide tropic plasticity, rapid growth rate and its suitable properties as a commercial species for smallholder food production systems (Prabu *et al*., 2019; Borski *et al*., 2022) [17, 4], it is considered widespread in warm water aquaculture.

In India, freshwater aquaculture had been traditionally focused with the use of polyculture system involving Indian Major Carps (IMCs) which includes fish species *Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*. Carp systems, which still account for the majority of total aquaculture production, have their own operational challenges associated with longer (10–12 months) culture cycles; relative susceptibility to infectious disease outbreaks and restrained margins in volatile markets (Jayaraman 2021) [10]. As a result, progressive farming systems moved from the traditional long-term varieties to high-yielding short-duration diversified species. The implementation and control of judicious dissemination of Genetically Improved Farmed Tilapia (GIFT) strains and mono-sex all-male populations as per guidelines formulated by the Department of Fisheries, Ministry Government or purposes Trading Animal Husbandry & Dairying (DAHD), India-but brought in a significant commercial interest for cultures from peninsular to central India as prevalent-Through NFDB [National Fisheries Development Board; 2000]. Telangana is located in the semiarid part of India's Deccan Plateau, and it has seen a rural agriculture revival - coupled with blue-economy developments over its ten-year existence. The basic reason being the state government focused interventions like the systematic restoration of minor irrigation tank under Mission Kakatiya, mega-irrigation projects for expanding reservoir capacities coupled with subsidised fingerling stocking programs have helped enhance the inland aquatic resource base in-state. Traditionally the supporting role to inland fishers, although reservoir open-water fisheries have contributed an important proportion of national production in a society that is resource full (Rathod *et al*., 2021) [20]; while rapid growth has been achieved by developing earthen pond aquaculture and subsequently intensive cage culture systems within neighbouring agrarian districts meeting unprecedented domestic urban demand.

Kamareddy district is one of the crucial agro climatic zones in this region with semi-arid conditions, tank fed agrarian system and having dynamic transitions from conventional agriculture (paddy, sugarcane and maize) to commercial aquaculture enterprises. Nile Tilapia and mono-sex TILAPIA culture within excavated earthen ponds along with community tank peripheries are increasingly being adopted by farmers in Kamareddy area. Tilapia is a quick producer (5–6 months) and has two-crop annual turnover; thus, lends itself as attractive to cash crops that are commonly diminished by climatic variations or market price fluctuations.

However, empirical assessments of the operational efficiency and socio-economic outcomes associated with Tilapia culture in northern and central Telangana has been limited despite its growing field-level adoption. Indian literature largely pertains to well-established coastal aquaculture belts of Andhra Pradesh (e.g. Krishna-Godavari deltas) or enthusiastic cage-culture installations in large reservoirs (De Silva *et al*., 2021; Radheyshyam *et al*., 2022) [6, 18]. Across landlocked, semi-arid regions like Kamareddy, farm-level management practices are highly heterogeneous:

Reliance on hatchery and genetic capacity: There is high variability in the certification of mono-sex populations, as well as quality control for hormonal sex-reversal agents. This results in unwanted reproduction in-pond, making mass harvesting problematic (resulting also by stunting), causing skewed size grading at harvest time; Cost-efficiency in feeding: Feeding commercially extruded floating pellets compared to sinking mash diets entails a direct impact on the total variable costs, with feed constituting between 60 and 70% of operational expenditure.

Biosecurity and health dynamics: varied use of water quality monitoring (dissolved oxygen, unionized ammonia, alkalinity) with restricted prophylactic health regimes in extreme summer heat.

Supply chain asymmetries: 'Weaknesses in infrastructure for localized cold-chain and live-fish marketing that make producers vulnerable to exploitive price-making by intermediaries' Further, limited quantitative evidence exists on the impact of increased Tilapia fish culture in terms of influencing household income distribution and rural employment creation along this semi-arid belt as well as Overall poverty alleviation.

2. Materials and Methods

2.1 Study Area and Agro-Climatic Profile

The investigation was conducted across the Kamareddy district of Telangana, India (geographical coordinates: 18.3245º N to 18.5521º N latitude and 78.1420º E to 78.4812º E longitude). The study zone is characterized by a semi-arid tropical climate with three distinct seasons: summer (March–June), South-West monsoon (July–October), and winter (November–February). The mean annual precipitation ranges from 850 mm to 1050 mm, with peak rainfall occurring during the monsoon. Ambient temperatures range from 13.5 ºC in winter to 43.0 ºC during peak summer.

The soils of the target pond networks are predominantly red sandy loams (*Alfisols*) and medium-to-deep black cotton soils (*Vertisols*), with water retention sustained via groundwater borewells, minor irrigation channels, and perennial village tanks restored under regional water-harvesting initiatives.

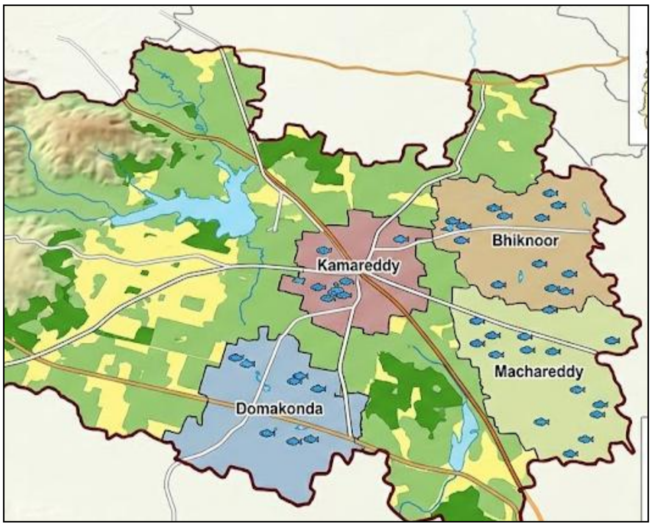

Fig 1: Study area map of Kamareddy

2.2 Sampling Framework and Sample Size Determination

A multi-stage, stratified random sampling design was implemented to select active commercial and smallholder Tilapia (*Oreochromis niloticus* / TILAPIA strain) producers:

1. **Stage 1 (Mandal Selection):** Four mandals with high concentrations of active inland earthen fish farms were purposively selected: Kamareddy, Bhiknoor,

Domakonda, and Machareddy.
2. **Stage 2 (Village Selection):** Within each mandal, 3 to 5 villages with operational Tilapia culture units were identified using registration registries from the Department of Fisheries, Government of Telangana.
3. **Stage 3 (Farmer Stratification):** Farmers were stratified based on effective water spread area (*WSA*):
   - Small- scale / marginal: WSA < 0.5 ha
   - Medium-scale: 0.5 ha ≤ WSA ≤ 1.5 h
   - Commercial / large-scale: WSA > 1.5 ha

The minimum sample size (*n*) was computed via Cochran's formula for finite and continuous populations:

$$n = \frac{Z^2 \cdot p \cdot (1-p)}{e^2}$$

Where:
- Z = 1.96 at a 95% confidence interval,
- p = 0.5 (Assumed population variance to ensure maximum sample size),
- e = 0.08 (acceptable margin of error, 8%).

Applying a 10% non-response and outlier contingency buffer, the final sample size was established at n = 120 active fish farming households (n_1 = 48 small, n_2 = 44 medium, and n_3 = 28 large-scale operators).

2.3 Data Collection Protocol

Primary empirical data were gathered across two consecutive production cycles via face-to-face interviews using a pre-tested, structured questionnaire. The instrument captured:

- **Demographic parameters:** Household size, age, formal education, primary vs. secondary occupation, credit accessibility.
- **Husbandry practices:** Pond area, stocking size, nursery rearing, stocking density, daily feeding schedules, brand and crude protein (CP %) content of feeds, aeration regimes, water exchange rates, and disease interventions.
- **Input-output parameters:** Quantity and monetary valuation of variable inputs (seed, floating feed, lime/fertilizers, chemicals/probiotics, electricity/diesel, hired and family labor) and harvest output (total biomass harvested, average individual body weight, farm-gate realization price).

Triangulation of field responses was conducted through Focus Group Discussions (FGDs, k = 4) and Key Informant Interviews (K11s) with district fisheries development officers, commercial feed distributors, and local seed hatchery managers.

2.4 Technical and Biological Metrics: The biological productivity and technical efficiency of Tilapia culture were evaluated using the following equations:

Specific Growth Rate (SGR, % day^{-1})

$$\text{SGR} = \left[\frac{\ln(W_t) - \ln(W_0)}{t}\right] \times 100$$

Where W_0 is the mean initial stocking weight (g), W_t is the mean final harvest weight (g), and t is the culture duration (days).

Feed Conversion Ratio (FCR)

$$\text{FCR} = \frac{\text{Total Dry Feed Administered (kg)}}{\text{Total Wet Biomass Gain (kg)}} = \frac{F_{\text{feed}}}{B_{\text{harvest}} - B_{\text{stocked}}}$$

Survival Rate (SR, %)

$$\text{SR} = \left(\frac{N_t}{N_0}\right) \times 100$$

Where N_0 is the total number of fingerlings stocked, and N_t is the total count of harvested fish.

2.5 Economic Assessment and Production Viability Models: Cost-return structures were calculated on a standardized per-hectare per-cycle (he^{-1} cycle^{-1}) basis. Total Cost (*TC*) was partitioned into Total Variable Cost (TVC) and Total Fixed Cost (TFC):

TC = TVC + TFC

$$TVC = \sum_{i=1}^{m}(Q_i \cdot P_i) + C_{\text{labor}} + C_{\text{energy}} + C_{\text{misc}} + I_{\text{working}}$$

Where Q_i and P_i denote the quantity and unit price of the i^{th} operational input (seed, feed, probiotics, lime, fertilizers), and $I_{working}$ represents interest on operational capital (charged at the standard institutional agricultural lending rate of 70% p.a. for the cycle duration). Fixed costs included land lease value, annualized pond construction depreciation (straight-line method over a 10-year lifespan), and equipment depreciation (aerators, pumps, nets over a 5-year lifespan).

$$D = \frac{V_{\text{initial}} - V_{\text{salvage}}}{L}$$

Where V_{initial} is asset cost, V_{salvage} is salvage value (0), and L is economic life in years.

Economic Returns & Margins

Gross Revenue (GR) = Y × P_y
Gross Margin (GM) = GR - *TVC*
Net Farm Income (NFI) = GR - *TC*

$$\text{Benefit-Cost Ratio (BCR)} = \frac{\text{GR}}{TC}$$

Where Y is total fish yield (kg ha^{-1} cycle^{-1}) and *Py* is the mean farm-gate selling price (INR kg^{-1}).

2.6 Econometric and Socio-Economic Analytical Framework

2.6.1 Determinants of Farm Net Returns (Multiple Linear Regression): An Ordinary Least Squares (OLS) Cobb-Douglas production function was specified to identify technical and managerial factors driving net income:

$$\ln(Y_j) = \beta_0 + \beta_1 \ln(X_{1j}) + \beta_2 \ln(X_{2j}) + \beta_3 \ln(X_{3j}) + \beta_4 \ln(X_{4j}) + \beta_5 D_{1j} + \beta_6 D_{2j} + \varepsilon_j$$

Where:

- Y_j = Net farm returns (INR ha^{-1}),
- X_{1j} = Stocking density (fingerlings m^{-2}),
- X_{2j} = Total quantity of pelleted feed applied (kg ha^{-1}),
- X_{3j} = Water spread area (WSA, ha),
- X_{4j} = Culture period (days),
- D_{1j} = Dummy for aeration system usage (1 = Mechanized/paddle-wheel, 0 = None),
- D_{2j} = Dummy for formal aquaculture training participation (1 = Trained, 0 = Untrained),
- $\beta_0 \ldots \beta_6$ = Parameters to be estimated,
- ε_j = Stochastic error term~N (0, σ^2).

2.6.2 Employment Generation and Income Inequality Metrics

Labor absorptive capacity was quantified as total standard adult person-days generated per hectare per cycle:

$$\text{Labor Days} = \sum \left(\frac{\text{Total Labor Hours (Hired + Family)}}{8 \text{ hours}} \right)$$

Income distribution among households before and after the adoption of Tilapia culture was assessed using the Gini Coefficient (*G*):

$$G = 1 - \sum_{k=1}^{n} (X_k - X_{k-1})(Y_k + Y_{k-1})$$

Where X_k is the cumulative proportion of the farming population, and Y_k is the cumulative proportion of household income.

2.7 Constraints Analysis (Garrett's Ranking Technique)

Operational, institutional, and environmental constraints reported by respondents were prioritized using Henry Garrett's ranking formula:

$$\text{Percent Position} = \frac{100 \cdot (R_{ij} - 0.50)}{N_j}$$

Where:

- R_{ij}= Rank assigned to the i^{th} constraint by the j^{th} farmer,
- N_j = Total number of constraints ranked by the j^{th} respondent.

The calculated percentage positions were converted into score values using Garrett's conversion scale. Mean scores for each constraint were computed and arranged in descending order to assign final hierarchical ranks.

2.8 Statistical Software and Data Screening

All empirical data were entered into a relational database and analyzed using IBM SPSS Statistics (Version 28.0) and R (Version 4.3.2). Descriptive metrics were presented as Mean ± Standard Deviation (SD). Prior to parametric testing (One-way ANOVA and Regression analysis), normality was verified via the Shapiro-Wilk test, and homoscedasticity was assessed using Levene's test. Multicollinearity among independent regressors was confirmed to be negligible (Variance Inflation Factor, VIF < 3.5).

3. Results

3.1 Socio-Demographic Profile of Tilapia Farmers

The socio-demographic characteristics of the sampled Tilapia cultivators (*n* = 120) across the four mandals in Kamareddy district are presented in Table 1.

Table 1: Socio-demographic characteristics of sampled Tilapia farmers in Kamareddy district (*n* = 120).

Variable	Category	Frequency (n)	Percentage (%)	Mean ± SD
Age (years)	< 35	31	25.83	42.6 ± 8.4
	35-50	64	53.33	
	> 50	25	20.84	
Education Level	Illiterate / Primary	18	15.00	—
	Secondary / High School	58	48.33	—
	Graduate & Above	44	36.67	—
Aquaculture Experience	< 3 years	46	38.33	4.8 ± 2.6
	3-6 years	52	43.33	
	> 6 years	22	18.34	
Farm Operational Scale	Small (< 0.5 ha)	48	40.00	0.34 ± 0.08
	Medium (0.5 – 1.5 ha)	44	36.67	0.88 ± 0.24
	Commercial (> 1.5 ha)	28	23.33	2.42 ± 0.65
Primary Occupation	Full-time Aquaculture	49	40.83	—
	Agriculture + Aquaculture	63	52.50	—
	Business / Service	8	6.67	—
Institutional Training	Formal Training Received	41	34.17	—
	No Formal Training	79	65.83	—

The majority of producers (53.33%) belonged to the middle-age group (35-50 years), with a mean age of 42.6 ± 8.4 years. A substantial proportion of respondents had attained secondary (48.33%) or tertiary (36.67%) education. Over 81% had less than six years of dedicated experience in Tilapia culture, reflecting the recent transition toward mono-sex TILAPIA farming in the district. Smallholders constituted 40.00% of the farming community, while integrated agriculture-aquaculture remained the dominant occupational strategy (52.50%). Only 34.17% had participated in formal capacity-building programs organized by state or central agencies.

3.2 Husbandry Practices and Technical Performance

Technical indices varied significantly across farm operational scales ($p<0.05$), as summarized in Table 2.

Table 2: Technical and biological performance metrics of Tilapia culture across farm sizes (Mean ± SD).

Performance Metric	Small (n=48)	Medium (n=44)	Large (n=28)	Overall Pooled (n=120)	F-value
Stocking Size (g)	4.2 ± 1.1^{b}	5.8 ± 1.4^{a}	6.5 ± 1.2^{a}	5.3 ± 1.5	18.42***
Stocking Density (fish m^{-2})	4.8 ± 1.2^{c}	6.2 ± 1.5^{b}	8.4 ± 1.8^{a}	6.1 ± 1.9	42.11***
Culture Duration (days)	168.4 ± 14.2^{a}	154.2 ± 11.5^{b}	145 ± 8.6^{c}	157.7 ± 14.8	33.56***
Final Body Weight (g)	462.5 ± 42.1^{b}	518.4 ± 38.6^{a}	545.2 ± 31.4^{a}	502.3 ± 48.2	45.18***
Specific Growth Rate (% day^{-1})	2.79 ± 0.18^{b}	2.91 ± 0.15^{a}	3.05 ± 0.12^{a}	2.89 ± 0.18	24.73***
Feed Conversion Ratio (FCR)	1.64 ± 0.14^{a}	1.48 ± 0.11^{b}	1.36 ± 0.08^{c}	1.52 ± 0.15	58.91***
Survival Rate (%)	74.2 ± 6.8^{c}	81.5 ± 5.2^{b}	87.1 ± 4.1^{a}	79.9 ± 7.4	48.27***
Gross Yield (tha^{-1} cycle^{-1})	16.46 ± 3.12^{c}	26.20 ± 4.05^{b}	39.84 ± 4.88^{a}	25.49 ± 9.42	264.30***

Values in the same row with different superscripts (a, b, c) differ significantly ($p<0.05$, Tukey's HSD test). $^{*}p<0.001$.

Large-scale commercial farms exhibited superior biological performance, recording an average gross yield of 39.84 ± 4.88 the^{-1} compared to 16.46 ± 3.12 tha^{-1} cycle in smallholdings. This difference was driven by higher stocking densities (8.4 fish m^{-2}), optimized commercial floating feed usage leading to a lower FCR (1.36 ± 0.08), and mechanical aeration that supported higher survival rates (87.1 ± 4.1%). In contrast, smallholder ponds relied partially on sinking farm-made diets and experienced greater water quality fluctuations, resulting in a higher pooled FCR of 1.64 ± 0.14.

3.3 Production Economics and Cost-Return Structure

The per-hectare economic balance sheet per production cycle is presented in Table 3. All financial parameters are expressed in Indian Rupees (INR) and US Dollars (USD, at an exchange rate of 1 USD = 83.50 INR).

Table 3: Economic cost-return matrix of Tilapia culture per hectare per cycle across farm scales.

Cost / Return Component	Small (INR)	Medium (INR)	Large (INR)	Overall Mean (INR)	Share (%)	Overall Mean (USD)
A. Variable Costs (TVC)						
Seed / Fingerlings	1,44,000	1,86,000	2,52,000	1,84,600	12.28	2,210.78
Commercial Floating Feed	7,55,000	11,24,000	15,72,000	10,81,000	71.93	12,946.11
Lime, Manure & Probiotics	28,500	36,000	48,000	35,800	2.38	428.74
Electricity & Diesel Fuel	32,000	54,000	88,000	53,130	3.54	636.29
Labor (Hired + Imputed Family)	52,000	68,000	94,000	67,670	4.50	810.42
Harvesting & Transport	22,000	34,000	52,000	33,400	2.22	400.00
Interest on Working Capital (7%)	36,173	52,570	73,710	50,967	3.39	610.38
Total Variable Cost (TVC)	10,69,673	15,54,570	21,79,710	15,06,567	100.00	18,042.72
B. Fixed Costs (TFC)						
Land Lease Value	45,000	45,000	45,000	45,000	49.33	538.92
Pond Construction Depreciation	22,000	22,000	22,000	22,000	24.12	263.47
Equipment Depreciation & Repairs	14,500	24,000	38,000	23,470	25.73	281.08
Cost of Fixed Capital (9%)	7,335	8,190	9,450	8,142	8.93	97.51
Total Fixed Cost (TFC)	88,835	99,190	1,14,450	98,612	—	1,180.98
Total Cost of Production (TC)	11,58,508	16,53,760	22,94,160	16,05,179	—	19,223.70
C. Returns & Viability Metrics						
Gross Yield (kg ha^{-1})	16,460	26,200	39,840	25,490	—	—
Farm-gate Price (INR kg^{-1})	95.00	98.50	102.00	97.91	—	1.17 kg^{-1}
Gross Revenue (GR)	15,63,700	25,80,700	40,63,680	24,95,725	—	29,888.92
Gross Margin (GM)	4,94,027	10,26,130	18,83,970	9,89,158	—	11,846.20
Net Farm Income (NFI)	4,05,192	9,26,940	17,69,520	8,90,546	—	10,665.22
Benefit-Cost Ratio (BCR)	1.35	1.56	1.77	1.55	—	—
Cost of Production (INR kg^{-1})	70.38	63.12	57.58	62.97	—	0.75 kg^{-1}

Feed constituted the largest operational expenditure across all categories (71.93% of TVC), followed by seed input costs (12.28%). The overall pooled Benefit-Cost Ratio was 1.55, ranging from 1.35 in smallholder operations to 1.77 in large commercial enterprises. Economies of scale reduced the unit cost of production from INR 70.38 kg^{-1} in small farms to INR 57.58 kg^{-1} in large operations.

3.4 Econometric Determinants of Net Farm Returns

The Ordinary Least Squares (OLS) Cobb-Douglas regression model identified key technical and managerial variables influencing net farm income (Table 4).

Table 4: Determinants of net farm income (In Y) from Tilapia culture (n = 120).

Model Parameter	Unstandardized Coeff. (β)	Standard Error (SE)	t-statistic	p-value	VIF
(Intercept)	4.812	0.624	7.712	< 0.001***	—
In (Stocking Density, X_1)	0.384	0.076	5.053	< 0.001***	1.84
In (Feed Applied, X_2)	0.442	0.088	5.023	< 0.001***	2.15
In (Water Spread Area, X_3)	0.218	0.052	4.192	< 0.001***	1.62
In (Culture Duration, X_4)	-0.194	0.081	-2.395	< 0.018*	1.34
Aeration Usage Dummy (D_1)	0.162	0.045	3.600	< 0.001***	1.48
Training Dummy (D_2)	0.118	0.039	3.026	0.003**	1.21

R^2 = 0.814, Adjusted R^2 0.804; $F(6, 113) = 82.47^{}$; Durbin-Watson statistic = 1.91. $^{} p<0.001$, $^{*} p<0.01$, *p<0.05.

Feed input (β = 0.442, p<0.001), stocking density (β = 0.384, p<0.001), and effective water spread area (β = 0.218, p<0.001) positively and significantly influenced net farm returns. The use of mechanical aeration (D_1) and participation in formal training (D_2) contributed significantly to net earnings (β = 0.162 and β = 0.118, respectively). Culture duration exhibited a negative coefficient (β = -0.194, p = 0.018), indicating that extending the culture cycle past optimal market size (> 500-550g) increases feeding costs without proportional revenue gains.

3.5 Socio-Economic Impact and Rural Livelihoods

Adoption of Tilapia culture generated direct impacts on household income, labor dynamics, and income inequality in the study area (Table 5).

Table 5: Pre-and post-adoption socio-economic indicators among farming households (n = 120).

Indicator	Pre-Adoption (Baseline)	Post-Adoption (Current)	Absolute Change	% Change	t-statistic
Annual Household Income (INR)	1,84,500 ± 38,200	4,92,300 ± 84,600	+ 3,07,800	+166.83	36.14***
Aquaculture Income Share (%)	12.4 ± 4.6	64.8 ± 11.2	+52.40	+422.58	48.33***
Labor Utilization (person-days ha^{-1} $cycle^{-1}$)	42.6 ± 8.2	118.4 ± 16.5	+75.80	+177.93	45.82***
Female Labor Share (%)	14.2 ± 3.1	28.5 ± 5.4	+14.30	+100.70	25.12***
Gini Coefficient (G)	0.462	0.354	-0.108	-23.38	—

p<0.001 (Paired t-test).

Mean annual household income increased by 166.83% following the transition to Tilapia culture, with aquaculture's contribution rising from 12.4% to 64.8%. Labor absorption increased from 42.6 to 118.4 person-days ha^{-1} $cycle^{-1}$, driven by daily feeding, water exchange, net inspections, and post-harvest grading. Female labor engagement doubled, primarily in feed distribution and local retailing. Income inequality among adopters decreased, as indicated by a decline in the Gini coefficient from 0.462 to 0.354.

3.6 Constraints Analysis (Garrett's Ranking)

Operational, environmental, and institutional constraints prioritized by Tilapia farmers are detailed in Table 6.

Table 6: Prioritized constraints faced by Tilapia farmers in Kamareddy district (n = 120).

Constraint Description	Garrett Total Score	Mean Garrett Score	Overall Rank
High and Volatile Commercial Feed Costs	8,364	69.70	I
Non-Availability of Quality Mono-Sex Certified Seed	7,656	63.80	II
Price Volatility and Intermediary Cartelization	7,044	58.70	III
Winter Growth Stagnation (Low Water Temperatures)	6,216	51.80	IV
Inadequate Local Cold Storage & Processing Infrastructure	5,532	46.10	V
Groundwater Scarcity & Evaporative Losses in Peak Summer	4,776	39.80	VI
Limited Institutional Credit and High Insurance Premiums	4,140	34.50	VII
Disease Outbreaks (Streptococcus's / Parasitic Infestations)	3,468	28.90	VIII

Commercial feed pricing was identified as the primary operational constraint (Mean Garrett Score = 69.70), followed by seed quality issues (63.80), where unintended breeding occurred due to incomplete hormonal sex-reversal in uncertified hatcheries. Market price volatility (58.70) and winter growth retardation (51.80, when water temperatures drop below 20 ºC) ranked third and fourth, respectively.

4. Discussion

4.1 Technical Husbandry and Biological Performance

The mean gross yield observed in this study (25.49 ± 9.42 tha^{-1} $cycle^{-1}$) and the pronounced yield differential between large commercial enterprises (39.84 ± 4.88 tha^{-1} $cycle^{-1}$) and smallholders (16.46 ± 3.12 tha^{-1} $cycle^{-1}$) reflect the intensification gradient operating within the semi-arid Deccan Plateau. These yield figures align closely with performance benchmarks reported for semi-intensive and intensive mono-sex Nile Tilapia (*Oreochromis niloticus*) systems in tropical developing economies. For instance, commercial yields in Kamareddy exceed the national Indian average for carps (3.0-5.0 tha^{-1} $Year^{-1}$; DAHD, 2020) and compare favorably with commercial earthen pond yields in the Krishna-Godavari aquaculture corridor of Andhra Pradesh (25-35 tha^{-1} $cycle^{-1}$ $Year^{-1}$; Jayaraman, 2021) [10] and the Nile Delta in Egypt (20-30 tha^{-1} $cycle^{-1}$; Elsheshtawy *et al.*, 2021) [7].

The biological efficiency metrics-particularly the specific growth rate (SGR = 2.89 ± 0.18% day^{-1}) and feed conversion ratio (FCR = 1.52 ± 0.15)-reflect the physiological advantages of Genetically Improved Farmed Tilapia (GIFT) strains reared in warm, tropical waters. Commercial operators attained lower FCR values (1.36 ± 0.08) than smallholders (1.64 ± 0.14), primarily driven by:

- **Precision feeding protocols:** Use of extruded floating pellets with fixed crude protein regimes (28-32% CP) adjusted to temperature-dependent feeding tables, contrasted with smallholders' reliance on supplementary sinking mash diets.
- **Mechanical aeration:** Installation of paddle-wheel aerators (2-4 HP ha^{-1}) sustained nocturnal dissolved oxygen (DO > 4.0 mg L^{-1}), preventing respiratory stress, maximizing nitrogen assimilation, and reducing mortality (12.9% vs. 25.8% in un-aerated smallholder ponds), consistent with findings by Borski *et al*. (2022) [4].

4.2 Economic Viability, Cost Structures, and Economies of Scale

The cost-return structural economic angel typifies the commercial feasibility of Tilapia aquaculture and its subsequent extreme sensitivity to operational input pricing. The pooled BCR and NFI (or) reaffirm that Tilapia monoculture outperforms local agrarian cash crops (e.g., paddy, sugarcane, maize) in terms of financial returns within Kamareddy where annual net farm returns seldom exceed $478.00 [7293] (Rathod *et al*., 2021) [20].

Commercial feed accounted for at least of total variable costs and operational expenses were particularly weighted toward commercial feeds. The concentration of this cost is in line with estimates from global semi-intensive finfish operations, which report feed inputs closer to -of operational budgets (FAO 2024) [9]. This high proportion of feed costs leave producers vulnerable to external commodity price shocks (soybean meal, fishmeal, de-oiled rice bran & maize).

The data show clear scale economies: fish were produced at a cost of, unit costs within large farms versus smallholders (who incurred production costs) resulted in net margins for large holders compared with my small ones. This divergence is due to volume-discount purchases of bagged feeds, mechanization gains in harvesting efficiency and greater bargaining power at the farm gate (vs. bulk-buyers and urban live-fish wholesaling from Hyderabad).

4.3 Econometric Interpretation of Production Elasticities

The estimated Cobb-Douglas production function (R^2 = 0.814) provides empirical insight into farm-level resource allocation efficiency:

Feed Input (β_2 = 0.442, p<0.001) and Stocking Density (β_1 = 0.384, p<0.001)

Input data on feed and stocking density showed positive output elasticities highest at 0.57, thus establishing that Tilapia production in the Deccan Plateau still positively responds to nutritional intensification and optimal biomass can be sustainably loaded within earthen systems. However, if stocking densities exceeded carrying capacity, with no additional aeration and water exchange the law of diminishing marginal returns start occurring.

Culture Duration (β_4 = 0.194, p<0.018)

The elasticity for culture duration is negative and statistically significant, which indicates a bio-economic threshold. The specific growth rates decrease dramatically with the fish reaching marketable weights in tropical TILAPIA culture (450-550gr). Living longer than however adds excess to maintenance feed costs and cumulative FCR without generating enough biomass or price premiums as indicated by regional retail markets, where there is little observed differentiation in fish prices for animals greater than.

Aeration (D_1 = 0.162) and Technical Training (D_2 = 0.118)

The positive impact of mechanized aeration (p<0.001) underscores that night-time supplemental oxygenation is a key technological driver for sustainable intensification. Similarly, the statistical significance of training (p = 0.003) demonstrates that extension programs-focusing on water monitoring, probiotic application, and feeding table adjustments-directly enhance farm income, corroborating previous adoption studies across South and Southeast Asia (De Silva *et al*., 2021; Radheyshyam *et al*., 2022) [6, 18].

4.4. Socio-Economic Transformations and Livelihood Resilience

The transition to Tilapia culture has generated substantial structural changes in household livelihood indicators:

- **Income generation and poverty reduction:** The 166.83% increase in total annual household income and the expansion of aquaculture's contribution to 64.8% of total revenue demonstrate that Tilapia farming serves as a viable commercial alternative to rainfed agriculture in drought-prone districts.
- **Labor absorption:** Labor demand rose by 177.93% (118.4 person-days ha^{-1} $cycle^{-1}$), offering year-round employment opportunities in rural areas where agricultural labor demand is typically seasonal.
- **Gender inclusion:** Female participation rose to 28.5% of the total farm labor force, primarily concentrated in daily feed feeding regimens, post-harvest sorting, and local retail operations.
- **Income equality:** The decline in the Gini coefficient from 0.462 (pre-adoption) to 0.354 (post-adoption) indicates that rapid aquaculture adoption has helped narrow intra-community income disparities by providing viable returns across small and medium-scale producers.

4.5 Biosecurity and Ecological Governance

Although bacterial infections (*Streptococcus agalactiae* and *Aeromonas hydrophila*) currently rank low in severity (Rank VIII), intensified stocking regimes in semi-arid earthen ponds pose emerging biosecurity risks under elevated summer water temperatures (>38 ºC).

From an ecological perspective, farming *Oreochromis niloticus* in proximity to seasonal tanks and flood-prone irrigation canals requires strict compliance with national biosecurity protocols (DAHD, 2020) to prevent escapement into indigenous river systems (such as the Godavari and

Manjeera basins). Establishing perimeter fencing, anti-escape screens on sluice gates, and regional hatcheries certified for mono-sex TILAPIA seed will be vital to ensure environmental sustainability alongside commercial growth.

5. Conclusion

The study showed that culture of Nile Tilapia (*Oreochromis niloticus*/GIFT strain) is a profitable and socio-economically change-making enterprise in semi-arid Deccan Plateau Telangana State India. In Kamareddy district, the shift from traditional carp polyculture and rainfed field agriculture to intensive and semi-intensive Tilapia farming has increased land and water productivity considerably beyond -78008125% per harvest thus achieving average net farm incomes of INR 8,90,546 ha^{-1} $Cycle^{-1}$ with a benefit cost Ratio > one (BCR = 1.55) is reported in this study respectively over ponds without or minimal silt removal whereas without or minimum tillage B.C.R 270 cm as yet unapproved.

The empirical results show that biological productivity and cost efficiency are both highly scale dependent. More productive39 entities were larger commercial enterprises. which saved up to 12 t ha^{-1} higher unit production costs (INR 57.58 kg^{-1}) through the use of mechanized paddle-wheel aeration and floating extruded pellet feeding tables along with economies of scale. In addition to farm profitability, fish farming has evolved as a key driver of rural livelihood transformation by

1. Increasing mean annual household incomes by over 166%,
2. Providing year-round rural employment (118.4 person-days ha^{-1} $cycle^{-1}$),
3. Expanding female labor participation in farm-level management and localized trade, and
4. Narrowing rural income disparities, as evidenced by a decline in the Gini coefficient from 0.462 to 0.354.

However, the long-term sustainability of the sector faces key operational bottlenecks, most notably volatile feed costs, quality degradation from uncertified mono-sex hatcheries, intermediary-dominated marketing channels, and winter growth retardation. Addressing these constraints through structured technological and institutional interventions will be critical for regional aquaculture resilience.

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