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AQUACULTURE AND FISHERIES IN NEPAL: AN OVERVIEW OF CURRENT STATUS AND DEVELOPMENT TRENDS

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ABSTRACT

Aquaculture has emerged as one of the fastest-growing agricultural sub-sectors in Nepal, contributing significantly to food and nutritional security, rural livelihoods, employment, and economic development. This paper provides a comprehensive assessment of the status and development trends of fisheries and aquaculture sector of Nepal, drawing on the latest government statistics and placing national progress within the context of global fisheries and aquaculture development. It synthesizes recent production statistics, institutional structure, production systems, employment and trade patterns, and major challenges and policy priorities, and illustrates aquaculture diversification with a brief case study of pangasius (*Pangasianodon hypophthalmus*) and “chhadi” fish production. In fiscal year 2024/25, Nepal produced approximately 131,112 metric tonnes of fish, of which 110,112 metric tonnes originated from aquaculture and about 21,000 metric tonnes from the capture fisheries. Average national pond productivity in carp culture reached approximately 5.62 t/ha, whereas intensively managed pangasius ponds achieved production levels of up to 29.2 t/ha. The sector supports the livelihoods of an estimated 560,000 people and contributes approximately 0.95% to national GDP and 3.77% to agricultural GDP. This review also identifies key institutional, seed/feed, market and biodiversity-related constraints facing the sector and proposes policy and research priorities to support its continued, sustainable growth.

Keywords: Aquaculture, Capture fisheries, Global fisheries, Food security, Value chain

INTRODUCTION

Fish and other aquatic foods are among the most efficient sources of animal protein available for human nutrition, and aquaculture has become the fastest-growing food-production sector in the world over the past four decades (FAO 2024). For landlocked countries such as Nepal, inland aquaculture and small-scale capture fisheries are of considerable strategic importance, contributing to livelihood diversification, creating employment opportunities, including for returnee migrant workers, enhancing food and nutritional security through the supply of affordable animal protein, and reducing dependence on costly fish imports (Shrestha et al. 2022). Nepal is entirely dependent on inland water resources, including ponds, rivers, lakes, reservoirs, swamps (ghols), and irrigated paddy fields, for fish production. Its diverse agro-climatic zones, ranging from the subtropical terai plains to the temperate mid-hills and high Himalayan regions, provide favorable conditions for the culture and capture of a wide variety of warm-water and cold-water fish species.

Institutional development of fisheries sector in Nepal traces back to 1946/47 (2003 BS), when a fisheries unit was established under the Agriculture Council; the first dedicated fisheries program followed in 1947/48, and successful induced breeding of common carp, Chinese carps and Indian major carps was progressively achieved between the 1960s and late 1970s, laying the foundation for the polyculture systems that still dominate Nepalese pond aquaculture at present (Dhakal et al. 2022). Following the restructuring of the state under the Constitution of Nepal (2072 BS), the erstwhile Directorate of Fisheries Development was reconstituted as the Central Fisheries Promotion

and Conservation Center (CFPCC) under the Department of Livestock Services, Ministry of Agriculture, Forestry and Environment, with provincial and local-level counterparts now sharing responsibility for extension, seed production, quality control, research and policy.

In recent years, the sector has continued to evolve under this federal structure, with responsibilities for fisheries development redistributed among federal, provincial and local governments while CFPCC retains a central coordinating role in policy implementation, technical support and database management (Rijal and Jha 2019; CFPCC 2024/25). Government initiatives notably the National Agriculture Modernization Program (NAMP), together with targeted programs promoting fish seed production, pond expansion and commercialization, have accelerated modernization of the sector, alongside growing private-sector investment in hatcheries, feed supply and commercial farms, including by returnee labor migrants. Recently published government reports have provided updated national production statistics, documenting continued increases in aquaculture production, pond productivity, fish seed production, and per-capita fish availability (Rijal and Jha 2020; CFPCC 2024/25). Among emerging aquaculture species, pangasius (*Pangasianodon hypophthalmus*) has gained particular attention because of its rapid growth, high productivity and strong potential to substitute imported fish, and has been identified by the Government of Nepal as a priority commodity for aquaculture diversification.

This paper reviews the current status, structure and development trends of fisheries and aquaculture sector of Nepal using the latest government reports and peer-reviewed literature, and evaluates its progress within the context of global fisheries and aquaculture trends. The review also includes a brief case study of pangasius as an example of aquaculture diversification in Nepal, covering its introduction, culture practices, value chain, and the constraints and opportunities relevant to its further development.

GLOBAL STATUS OF FISHERIES AND AQUACULTURE AND NEPAL'S POSITION

Global fisheries and aquaculture continue to expand, with total production reaching a record 223.2 million tonnes in 2022, including approximately 185.4 million tonnes of aquatic animals and 37.8 million tonnes of algae (FAO 2024). Aquaculture has become the primary driver of global fish production, contributing an estimated 94.4 million tons of aquatic animals and surpassing capture fisheries for the first time in 2022 and then continued. In contrast, capture fisheries have remained relatively stable since the late 1980s, with marine and inland fisheries contributing approximately 80.7 and 11.3 million tonnes, respectively, indicating that future increases in aquatic food supply will depend largely on aquaculture.

Aquaculture production is highly concentrated, with ten countries accounting for nearly 89.8% of global production, while Asia contributes around 70% of total aquatic animal production. International trade in aquatic products involves more than 230 countries and reached a record value of USD 195 billion in 2022, highlighting the sector's growing economic importance, particularly for low- and middle-income countries that maintain substantial trade surpluses (FAO 2024). Global per capita aquatic animal consumption has increased from 9.1 kg in 1961 to 20.7 kg in 2022, supported by aquaculture expansion, technological advances, and improved post-harvest management. The sector provides direct employment for approximately 61.8 million people worldwide, with women accounting for 24% of primary production and 62% of post-harvest processing activities (FAO 2024).

Although Nepal contributes only a small proportion of global fish production (131,112 mt in 2024/25), its aquaculture sector has experienced one of the fastest growth rates in the SAARC

region, with an annual growth rate of approximately 11-13%. Aquaculture contributes about 84% of Nepal's total fish production, substantially exceeding the global average and reflecting the country's strong dependence on pond-based and other controlled culture systems. In contrast, capture fisheries remain relatively limited because of its landlocked geography, river regulation for hydropower, and comparatively restricted natural aquatic resources. These characteristics highlight the pivotal role of aquaculture in ensuring national fish production, food security, and livelihood development in Nepal.

STATUS AND DEVELOPMENT TREND OF AQUACULTURE AND FISHERIES IN NEPAL

Institutional framework

The fisheries and aquaculture development mandate in Nepal is carried out through the Central Fisheries Promotion and Conservation Center (CFPCC), Balaju, Kathmandu, under the Department of Livestock Services, Ministry of Agriculture and Livestock Development (Figure 1).

The CFPCC functions as the commodity-specific national focal body responsible for central-level policy, planning, monitoring, database management and regulatory functions, and it coordinates with national and international fisheries institutions. Supporting institutions include the Fisheries Technology Validation and Human Resource Development Center (Janakpur), the Fisheries Pure Line Breed Conservation and Promotion Resource Center (Bhairahawa), and the Natural Water Fisheries Promotion and Conservation Center (Hetauda), together with seven Provincial Directorates of Livestock and Fisheries, seven Fisheries Development Centers, and Livestock Services Training Centers. Aquaculture and fisheries research in Nepal is led by the Fisheries Research Division of the Nepal Agricultural Research Council (NARC), while the Agriculture and Forestry University (AFU), Tribhuvan University (TU) and some other universities provide education. Notably, Karnali and Koshi Provinces still lack a dedicated Fisheries Development Center or Research Station, and no separate fish-health referral laboratory exists nationally, both flagged as institutional gaps.

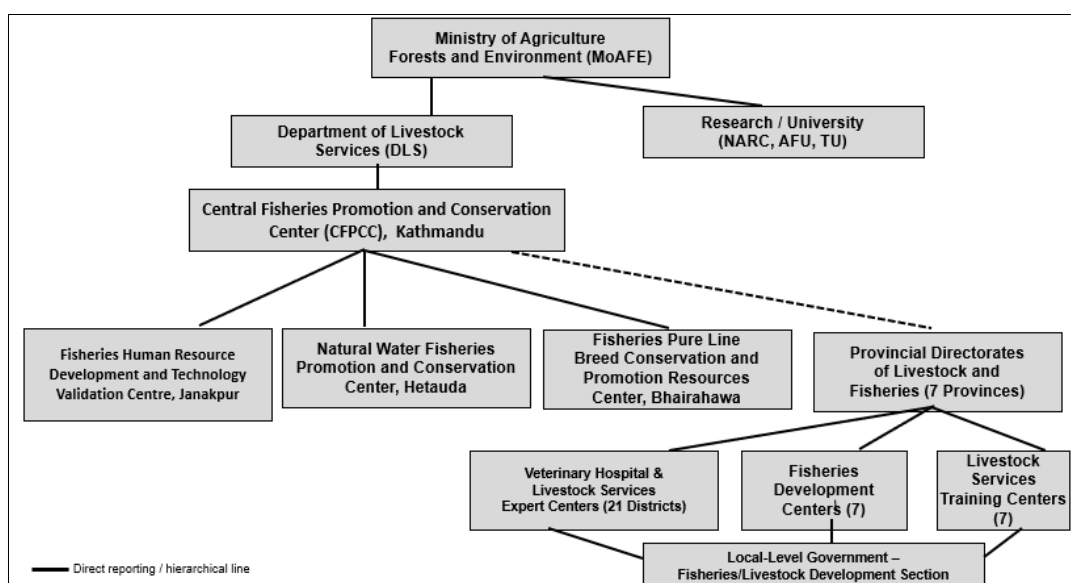


Figure 1: Institutional framework for fisheries and aquaculture development in Nepal.

National production trend

Total national fish production increased from approximately 500 mt in 1950, derived almost entirely from capture fisheries, to 3,530 mt in 1981/82, 91,832 mt in 2018/19, and 131,112 mt in 2024/25 (Table 1; Figure 2), reflecting sustained double-digit average annual growth in aquaculture over four decades. Aquaculture production was first recorded in 1966 at just 3 mt and has since become the dominant production stream, contributing 77% of national output in 2018/19 and about 84% in 2024/25. Average pond fish productivity (mostly carp polyculture) increased from 0.8 t/ha in 1981/82 to 4.92 t/ha in 2018/19 and approximately 5.62 t/ha nationally in 2024/25, reflecting improvements in seed availability, feeding, aeration, disease management, and production practices. In contrast, intensively managed pangasius ponds achieved yields of up to 29.2 t/ha, reflecting differences in species and management intensity rather than a shift in the national carp-based average.

This growth has been underpinned by sustained government policy support including pond-construction subsidy programs, the National Agriculture Modernization program (NAMP), the one-village-one-product initiative, and expansion of fisheries resource centers alongside growing private-sector investment in hatcheries and feed supply.

Table 1. Trends in national fish production and productivity in Nepal during selected years (CFPCC 2018/19; CFPCC 2024/25).

Parameters	1981/82	2018/19	2024/25
Total fish production (mt)	3,530	91,832	131,112
Aquaculture production (mt)	n/a	70,832	110,112
Capture fisheries production (mt)	n/a	21,000	21,000
Pond productivity (t/ha)	0.8	4.92	5.62*
			29.2**
Per-capita fish availability (kg/yr)	0.33	3.11-3.42	4.47-4.64

* National average; ** Average of intensive Pangasius culture

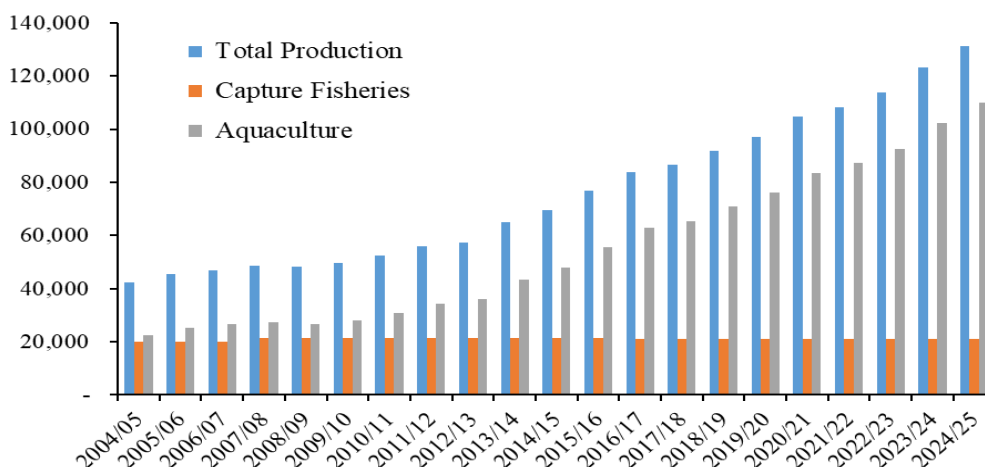


Figure 2: National fish production trends by source in metric tonnes (Total, Capture fisheries, and Aquaculture) in Nepal, FY 2004/05-2024/25.

Production systems

Pond aquaculture remains the predominant and highest-priority aquaculture production system in Nepal. The total area under pond culture has expanded considerably following the extension of the national pond-expansion program to the mid-hill districts from FY 2011/12, reaching approximately 15,707 ha by FY 2024/25. Pond-based production is primarily characterized by polyculture of indigenous and exotic carp species, including *Labeo (Catla) catla*, *Labeo rohita*, *Cirrhinus mrigala*, common carp (*Cyprinus carpio*), and the three Chinese carps. This production system constitutes the backbone of freshwater aquaculture in both the Terai and mid-hill regions and accounted for approximately two-thirds of the country's total aquaculture production in FY 2024/25. Alongside carp polyculture, aquaculture systems of Nepal include:

- Monoculture of common carp, Nile tilapia and catfish species in localized pockets across the country.
- Intensive single-stocking, multiple-harvest culture of small-size *Cirrhinus mrigala* known locally as 'Chhari' or 'Chhadi' a distinctive and highly profitable Nepalese innovation.
- Cage culture in lakes (notably Phewa and Begnas Lakes, Pokhara, since 1972) and reservoirs (e.g., Kulekhani), based mainly on plankton-feeding species without supplementary feeding, covering roughly 71,000-72,500 m³ of water at an average productivity of about 4.2 kg/m³ (Singh and Yadav 1996).
- Cold-water rainbow trout farming in raceways in hill and mountain districts, with productivity around 130 t/ha, increasingly linked to aqua-tourism.
- Intensive pangasius monoculture and pangasius-carp polyculture, currently the highest pond productivity system in the country.
- Utilization of natural swamps/ghols (about 12,500 ha, of which only ~28% is presently utilized) and limited paddy-cum-fish culture.
- Integrated aquaculture, bio-floc aquaculture, recirculating aquaculture systems (RAS) and aquaponics remain at an early, largely pilot or experimental stage in Nepal and do not yet contribute measurably to national production, though RAS-based hatchery technology is beginning to be adopted to improve seed quality.

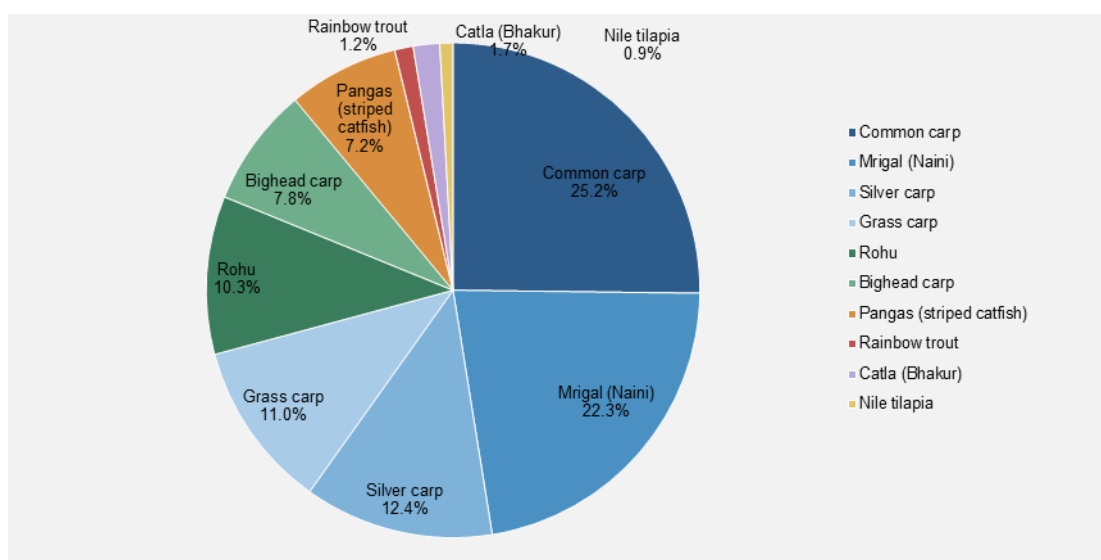


Figure 3: Contribution of different fish species on the total fish production in Nepal in FY 2024/25.

The contribution of different fish species on the total fish production in Nepal in FY 2024/25 is shown in Figure 3. Aquaculture activity has expanded geographically from about 30 districts a decade ago to 55 of Nepal's 77 districts, driven substantially by youth entrepreneurs, including returnee labor migrants, establishing commercial farms.

Capture fisheries

Capture fisheries production, drawn from rivers, lakes, reservoirs, marginal swamps and low-land irrigated paddy fields, has remained at roughly 21,000 metric tonnes for more than two decades, with low-land irrigated paddy fields and rivers each contributing the largest shares by volume, though at low per-hectare productivity (about 18 kg/ha), compared with much higher yields per hectare from reservoirs (about 350 kg/ha) and swamps (about 578 kg/ha) (Table 2). Around 370,000 people are engaged in capture fisheries nationally, with women constituting a majority (roughly 59-60%) of this workforce, engaged not only in fish handling and marketing but also in preparing fishing gear. Capture fisheries yields have remained essentially static since around FY 2000, a pattern consistent with the global plateau in capture output, and represent a persistent management challenge given pressures from damming, water abstraction, overfishing and climate variability. It is also likely attributable to the absence of a comprehensive and reliable data collection system.

Table 2. Capture fishery production from different inland water resources in Nepal (CFPCC 2024/25).

Water body	Area (ha)	Production (mt)	Productivity (kg/ha)
Rivers	395,000	7,110	18
Lakes	5,000	1,000	200
Reservoirs	1,500	525	350
Marginal swamps/ghols	9,000	5,200	578
Low-land irrigated paddy fields	398,000	7,165	18
Total	808,500	21,000	–

Employment, consumption, trade and economic contribution

The aquaculture and fisheries sectors together provide direct employment for an estimated 560,000 people nationwide, including approximately 193,000 engaged in aquaculture and 370,000 in capture fisheries. In addition, aquaculture is practiced by an estimated 76,000 households, highlighting its important contribution to rural livelihoods, employment generation, and the national economy. The sector contributes an estimated 0.95% of national GDP and 3.77% of Agricultural GDP. Annual per-capita fish availability has risen from 0.33 kg in 1981/82 to about 3.1-3.4 kg by 2018/19 and 4.5-4.6 kg in the most recent estimates (2024/25) that still well below Nepal's per-capita consumption of poultry, pork, buffalo and mutton, and far below the global average of about 21 kg (FAO 2024), underscoring substantial headroom for demand-led growth as health awareness and incomes rise.

Fish demand in Nepal is highly seasonal, peaking in the winter and falling to its lowest level during the monsoon months of Ashadh, Shrawan and Bhadra (June - August), and is also elevated around major festivals. Domestic production met about 89-91% of national fish consumption in 2024/25, with imports (chiefly from India, and to a lesser extent China, Vietnam and Bangladesh) covering the remainder; fish exports from Nepal remain negligible. Import volumes have grown substantially over time, from roughly 2,500 metric tonnes in 2004/05 to a peak of nearly 12,900 metric tonnes in

2013/14, moderating and fluctuating thereafter to about 4,338 mt in 2024/25 remaining a persistent drain on foreign exchange and a competitive pressure on domestic producers, particularly for pangasius (Figure 4). Fish prices have risen sharply, from about NRs 100/kg in 2001/02 to roughly NRs 300/kg on average in recent years, though fish remains comparatively cheaper than other animal-protein sources and thus an important accessible protein for lower- and middle-income households.

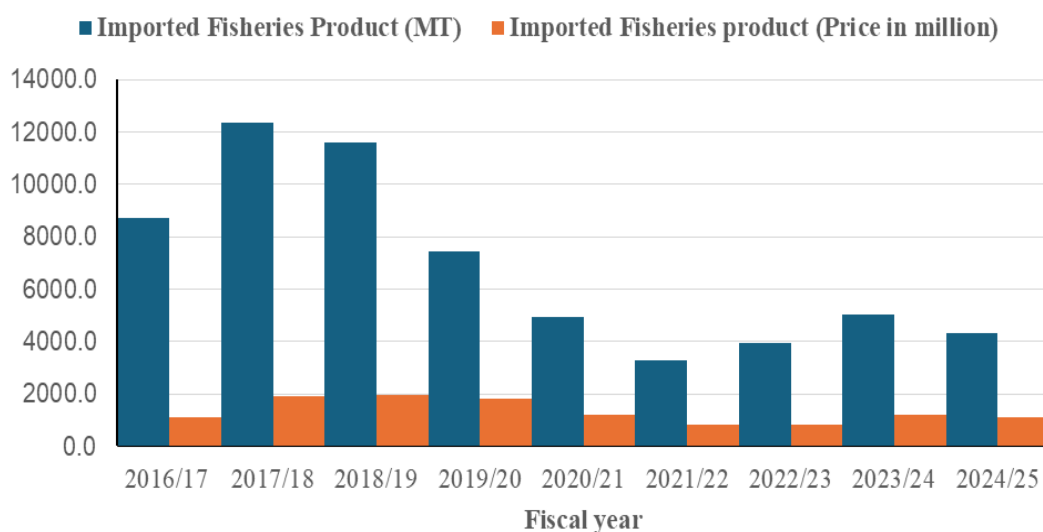


Figure 4: Fish import trend, FY 20016/17 to 2024/25 (CFPCC 2024/25).

CHHARI FISH PRODUCTION: AN ECONOMIC CASE STUDY

A notable Nepalese innovation is “Chhari” or “Chhadi” fish production, an intensive, single-stocking and multiple-harvest system for Naini or mrigal (*Cirrhinus mrigala*) that produces small, fast-turnover fish and is widely practiced in Terai pockets such as Bara district under programs including NAMP. A farm-level economic assessment involving 90 households in Bara district compared chhari production with conventional carp polyculture and demonstrated that chhari production was significantly more profitable, with a higher benefit-cost ratio (BCR) and greater gross and net margins ($p < 0.01$). Feed cost was the single largest cost component in both systems (29.5% of total cost on average), followed by labour (27.7%) and land rent (21.3%) (Table 3). Cobb-Douglas production-function analysis showed feed and labour costs to be the most significant determinants of gross return ($p < 0.01$), with the overall system in the productive (Stage II) region of the production function and moderate increasing-then-diminishing returns to scale (return-to-scale coefficient of 0.906) (Adhikari et al. 2019).

Table 3. Comparative profitability of chhari and marketable-size carp production in Bara district, Nepal (NRs/ha/year) (Adhikari et al. 2019).

Particular	Chhari production	Carp polyculture production
Total cost (TC), NRs	949,828.53	994,026.21
Total revenue/income, NRs	1,870,384.77	1,659,953.91
Gross margin, NRs	1,224,037.12	977,403.49
Net margin, NRs	920,556.24	665,927.70
Benefit-Cost Ratio (BCR)	1.97	1.67

These results confirm that Nepalese pond aquaculture, even without exotic high-value species, can be highly profitable when input allocation is optimized an economic benchmark against which the pangasius case study below can usefully be compared.

PANGASIUS: A CASE STUDY OF AQUACULTURE DIVERSIFICATION

Global context and relevance to Nepal

Pangasianodon hypophthalmus, commonly known as striped catfish or pangasius, is native to the Mekong and Chao Phraya river basins of Southeast Asia and has been introduced into aquaculture systems across South and Southeast Asia, including India, Bangladesh, Thailand, and most recently into Nepal (Shrestha et al. 2015). Its principal attraction to Nepalese farmers is its biological features: as a facultative air-breather tolerant of low dissolved oxygen and high stocking densities, it reaches market size (1.0-1.5 kg) within 6-8 months, faster than most cultured carps, while its scale-less, low-bone flesh facilitates local processing and value addition.

Globally, pangasius culture is dominated by Vietnam, which supplies the great majority of internationally traded pangasius and has built a large processing and export industry serving markets in the United States, China, the EU and elsewhere, with export revenue of roughly USD 2.0-2.1 billion in 2024-2025 (VASEP 2024; 2025). This scale gives Vietnamese exporters a significant cost advantage that Nepalese producers must contend with in the domestic market.

Introduction and development in Nepal

Pangasius farming in Nepal began in the private sector around 2010, with formal government reporting commencing in 2013. The Government of Nepal formally introduced and promoted the species from 2016/17, supporting hatchery development and including it among the officially recommended aquaculture species. Germplasm was introduced from Thailand and received by the Fisheries Development Center, Bhandara, the Fisheries Research Center, Tarahara, and at least one private farm. Since its formal promotion, both public and private hatcheries have produced and marketed pangasius seed, although production remains relatively small compared with national demand.

The adoption of pangasius farming has accelerated markedly in recent years. Ministry records indicate that the area under pangasius culture increased from approximately 297 ha in FY 2080/81 to 357 ha in FY 2081/82, representing an annual increase of about 20%. Over the same period, production rose from 7,409 to 10,427 metric tonnes (41% increase), while productivity improved from 24.9 to 29.2 t/ha, reflecting the rapid expansion and enhanced production efficiency of the sector. These trends indicate strong farmer adoption in the districts where pangasius has been

introduced, with productivity approximately five to six times higher than the national average for carp-based pond systems (Gautam and Sapkota 2023).

Culture practices, value chain, and trade competition

Pangasius is cultured either in polyculture with carps or as an intensive monoculture to maximize productivity. Formulated feed is the dominant recurrent cost, while winter water-quality deterioration and cold-related mortality (winter kill) remain the principal constraints to year-round production in Terai ponds. Detailed Nepal-specific data on optimal stocking density, feeding schedules and farm-level economics are not yet available in the published record and represent a priority for applied research.

Pangasius value chain comprises input supply (seed and feed), pond production, harvesting and limited primary processing, and marketing mostly to live-fish markets in urban centers. The main constraints identified are: lack of standard culture and product-technology guidelines (particularly for winter-kill management); limited technical-service and laboratory backup; inconsistent seed quality and year-round availability; and weak processing infrastructure and consumer awareness of processed product forms. Corresponding opportunities include developing standard Good Aquaculture Practice (GAP) guidelines, strengthening domestic hatchery and feed-milling capacity, and building basic cold-chain and processing capacity.

Despite domestic expansion, pangasius consumption in Nepal remains heavily dependent on imports, with domestic production meeting only about 30% of demand. Pangasius accounted for approximately 46% of fish import value in 2022/23 and 42% in 2023/24, indicating substantial import competition and significant potential for domestic import substitution. Given its high productivity, even modest increases in domestic production could improve the trade balance and enhance rural income generation.

FISH SEED PRODUCTION AND SUPPLY IN NEPAL

Current status and infrastructure

Seed is one of the most important inputs for aquaculture production. Quality seed is must to enhance productivity of aqua farms. In Nepal, fish seed are distributed in three forms: hatchlings (4-5 days old), fry (2-3 cm or ~1 g) and fingerlings (2-7 g body weight each in average). Both the public and private sectors contribute to pangasius seed supply. Over the past decade, public-sector seed production has remained relatively stable, whereas private-sector production increased substantially from 5.7 million in 2001/02 to 220 million in 2017/18 (Table 4; Figure 5), reflecting government efforts to promote private-sector participation. To further strengthen private-sector involvement, the government has implemented supportive initiatives like establishing fish seed resource centers under private ownership. Nepal has achieved self-sufficiency in the seed production of Carps and Rainbow trout. Across the country, there are currently 130 fish hatcheries operating to meet market demands, comprising 11 government-owned facilities and 119 private enterprises. Total annual fish seed production stands at 621.2 million (62 crore and 12 lakh), with the private sector serving as the primary contributor at 77.2%, while the government sector accounts for the remaining 22.8%.

Regional disparities and operational challenges

Despite the overall capacity exceeding national requirements, significant geographical imbalances persist in hatchery distribution. Most hatcheries are concentrated in Madhesh Province, while western Terai districts such as Banke, Bardiya, Kailali, and Kanchanpur face inadequate seed supply, highlighting the need for strategically distributed hatchery development to improve regional

balance. Furthermore, Pangasius seed production fails to meet domestic demand, forcing expensive imports from India and Bangladesh. Critical systemic issues including seed quality control, species variety alignment with market demand, size consistency, and timely supply availability remain fully unresolved despite achieving self-reliance in carps and trout.

Increasing demand has created challenges in ensuring both the quantity and quality of fish seed supply. The Government of Nepal is currently developing a fisheries policy expected to be approved soon, which could represent a significant milestone in strengthening domestic quality-seed production and supply.

Table 4. Status of Fish Seed Production in Nepal, FY 2024/25 (CFPCC 2024/25).

A. Fish seed (Fry) production/distribution (Numbers in '000) ($A^1 + A^2 + A^3$)	621,209
A ¹ . Public sector	141,609
a. Hatchling*	361,750
b. Fry	17,285
c. Fingerling	16,985
A ² . Private sector (Fry)	472,615
A ³ . Rainbow trout (Fry,000)	6,985

*Hatchling of public sector is distributed for fry production in private sector

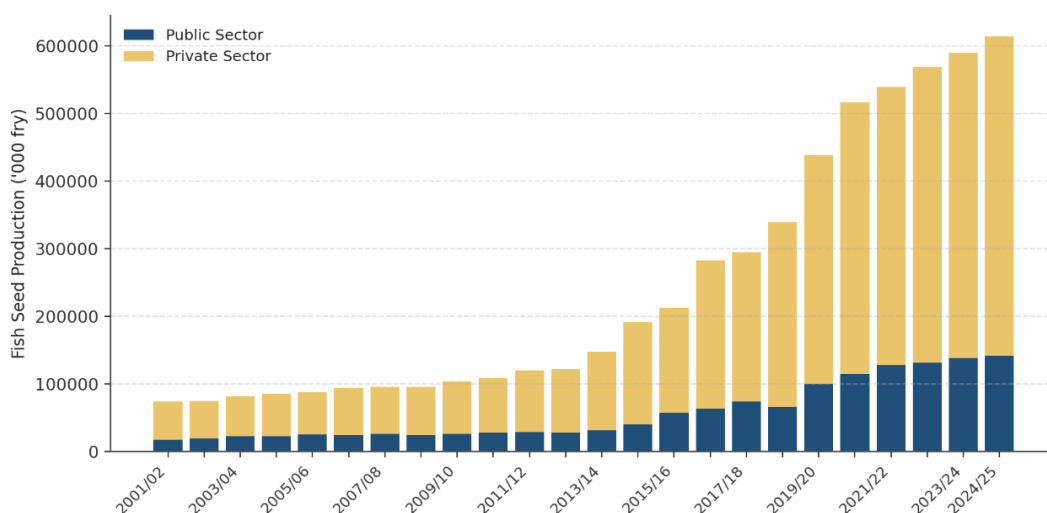


Figure 5: Fish seed production trend by public and private sector, FY 2001/02–2024/25.

KEY CHALLENGES IN NEPAL'S AQUACULTURE AND FISHERIES SECTOR

The following constraints are categorized by theme; within each theme, items are broadly ordered from most to least structurally significant for sector-wide productivity and sustainability.

Institutional and human-resource challenges

- Absence of a dedicated national Fisheries Act, and weak three-tier (federal-provincial-local) coordination on technical matters.

- Absence of a dedicated fish-health laboratory and referral fish-health laboratory at the national level.
- No Fisheries Development Center or Fisheries Research Station in Karnali Province; no Fisheries Development Center in Koshi Province; no dedicated institution for aquarium/ornamental fisheries.
- Very low filled-post ratio in the extension system; shortage of specialized expertise in fish nutrition, fish disease, and taxonomy.

Seed and feed constraints

- Inconsistent quality and year-round availability of carps and pangasius seed; inadequate nursery infrastructure.
- High feed costs, with carp and trout feeds costing approximately NRs 80-90/kg and NRs 140-160/kg, respectively, compounded by substantial dependence on imported feeds and raw materials and limited availability of alternative protein sources for feed formulation.

Market and post-harvest constraints

- Lack of collection centers, insulated transport and post-harvest infrastructure (sorting, grading, packing, cold storage/ice plants).
- Persistent price competition from imported Indian and Vietnamese fish, particularly pangasius; limited processed-product range and high post-harvest losses.

Aquatic biodiversity and environmental pressures (medium priority)

- Illegal fishing, dam and infrastructure construction, and climate change threaten aquatic biodiversity and natural capture-fisheries productivity.
- Limited alternative livelihood options for fisher communities and low public awareness of conservation needs.

Farmer-level operational issues (low priority)

- Veterinary certification costs add materially to per-kilogram costs for both table fish and seed; quarantine procedures are perceived by farmers as burdensome.
- High ice-plant/cold-storage costs, unreliable/expensive electricity, and shortage of field-level technicians for farm visits and technical guidance.

WAY FORWARD: POLICY AND RESEARCH PRIORITIES

- Enact a dedicated national Fisheries Act, formalize fishery-officer roles in quarantine, and set national standards for fish feed and hatchery operation.
- Address institutional gaps by establishing dedicated fish-health and diagnostic laboratories and completing the network of Fisheries Development Centers and Research Stations in Karnali and Koshi Provinces.
- Strengthen human resources within NARC, the Ministry and provincial fisheries directorates, including filling vacant technical posts and building expertise in nutrition, disease diagnostics and genetics.
- Strengthen the marketing system through private-sector investment in ice plants, collection centers, insulated transport and post-harvest facilities, and promote cooperative marketing models.

- Promote nursery infrastructure and continued productivity gains in carp and pangasius culture as the core productivity-enhancement strategy, alongside area expansion into under-utilized swamps and cage-culture-suitable reservoirs.
- Invest in research on species diversification and promote economically important native fish (e.g., Asala/snow trout, Katle, Sahar) alongside exotic species.
- For pangasius specifically, strengthen domestic hatchery and seed-quality systems, develop winter-management and good aquaculture practice (GAP) protocols, and establish basic processing capacity to support import substitution.
- Build farmer cooperatives and strengthen collaboration between NAMP, NARC, universities, and provincial and local governments; prioritize aquatic biodiversity conservation through habitat protection and co-management with fisher communities.

CONCLUSION

Aquaculture and fisheries sector in Nepal have grown from a small capture-based activity into a diversified, rapidly expanding sub-sector that now supplies more than four-fifths of national fish production and supports the livelihoods of more than half a million people. Three major findings stand out from this review. First, sectoral growth has been driven almost entirely by aquaculture, particularly intensive pond systems, whereas capture fisheries production has remained largely stagnant for two decades, a structural trend likely to persist and guide future investment priorities. Second, increases in pond productivity, from 0.8 to 5.62 t/ha nationally, have contributed substantially to production growth as area expansion, highlighting the importance of continued investment in feed, seed quality, and management practices. Third, species diversification, exemplified by pangasius, which has achieved productivity several times the national pond average within less than a decade of formal promotion, offers a promising, although still import-dependent, pathway for further sectoral growth.

These findings point to clear policy priorities: completing the institutional network (dedicated fish-health laboratories and Fisheries Development Centers in under-served provinces), enacting a dedicated national Fisheries Act, strengthening domestic seed and feed systems, and investing in basic post-harvest and processing infrastructure so diversified species can compete with imports on more even terms. Priority areas for future research include Nepal-specific management protocols for newly introduced species (particularly winter-season management for pangasius), farm-level cost-benchmarking against imported product, and systematic monitoring of still-nascent alternative systems (biofloc, RAS, aquaponics, integrated aquaculture) to establish whether they merit wider promotion. With coordinated institutional strengthening and continued private-sector investment, Nepal's aquaculture and fisheries sector is well positioned to keep closing the gap between domestic potential and domestic consumption, contributing further to national food security, rural income and, eventually, export diversification.

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TILAPIA AQUACULTURE IN NEPAL: A REVIEW

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ABSTRACT

Tilapia aquaculture has gained global prominence due to its rapid growth, environmental tolerance, and high production efficiency. In Nepal, tilapia farming is an emerging sector with considerable potential for diversification and intensification of aquaculture. This review provides an integrated overview of tilapia aquaculture in Nepal, covering its history, recent scientific and technological developments, production status, input and seed supply systems, key constraints, and prospective directions for future growth. The species was first introduced in 1985, with subsequent research and dissemination led by national institutions and universities. Recent studies demonstrate that monosex culture, improved feeding strategies, and integrated systems such as polyculture and cage-pond integration significantly enhance productivity and profitability. Despite these advances, the sector faces key challenges, including limited availability of quality monosex seed, inadequate extension services, low market penetration, and ecological risks associated with escape and establishment in natural water bodies. Emerging hatchery developments and value chain initiatives suggest a favorable trend toward the commercialization of the sector. Given Nepal's favorable climatic conditions, strategic expansion of tilapia farming, supported by strong policy frameworks, biosecurity measures, and capacity building can substantially contribute to sustainable aquaculture development, rural livelihoods, and national food and nutritional security.

Keywords: Nile tilapia, Aquaculture development, Monosex culture, Tilapia farming, Aquaculture diversification

INTRODUCTION

Tilapia, especially Nile tilapia (*Oreochromis niloticus*), is one of the most important aquaculture species globally due to its rapid growth, high environmental tolerance, efficient feed utilization, and strong consumer acceptance. Global production has surpassed 6 million metric tons annually, led by major producers such as China, Egypt, Indonesia, Brazil, and the Philippines (FAO 2024). In South Asia, countries like India, Pakistan and Bangladesh have rapidly expanded tilapia farming through improved seed systems, monosex culture, and intensified production practices (Belton et al. 2018; El-Sayed and Fitzsimmons 2023).

Biological traits of Nile tilapia, including omnivorous feeding behavior and tolerance to wide environmental fluctuations, enable its culture across diverse systems ranging from extensive ponds to intensive recirculating aquaculture and biofloc systems. These attributes make it highly suitable for both small-scale farmers and commercial aquaculture development in developing countries. However, tilapia culture is constrained by early sexual maturity and prolific reproduction under mixed-sex conditions, leading to excessive recruitment, high stocking densities, and stunted growth. To overcome this limitation, monosex male culture has been widely adopted, typically through hormonal sex reversal using 17 α -methyltestosterone or alternative approaches such as genetic and environmental manipulation (Bhujel 2012; Pandit et al. 2015). This practice has been shown to

enhance growth performance and increase productivity by 50-70% compared to mixed-sex populations in Nepalese condition (Shrestha et al. 2018; Pandit et al. 2023).

In Nepal, tilapia aquaculture is still in an emerging stage but shows considerable potential for expansion (Shrestha et al. 2022). Nile tilapia was first introduced in 1985 from Thailand as a royal gift and was initially maintained in government research stations with limited dissemination (Pantha 1993). For several decades, its culture remained restricted due to concerns regarding ecological impacts and lack of policy support. Recently, however, the Government of Nepal has recognized tilapia as a promising species and has initiated policies to promote its controlled cultivation (CFPCC 2022). On-station and on-farm experiments conducted by research institutions and universities over the past decades have demonstrated that tilapia performs well under Nepalese agro-climatic conditions, exhibiting satisfactory growth and productivity in pond and cage systems (Shrestha 2002; Pandit et al. 2023). These findings have also demonstrated its suitability for both smallholder and commercial aquaculture systems. Nevertheless, concerns regarding uncontrolled reproduction and potential biodiversity risks necessitate strict adoption of monosex culture systems.

This review aims to provide a comprehensive overview of the current status and practices of tilapia aquaculture in Nepal, with particular emphasis on its introduction history, research advancements, and developments in seed and feed technologies, as well as the key challenges constraining its expansion. Furthermore, it evaluates future prospects for sustainable development of tilapia farming in the country.

HISTORY OF TILAPIA INTRODUCTION IN NEPAL

The introduction and subsequent dissemination of tilapia in Nepal have occurred through a series of institutional initiatives and farmer-led interventions, reflecting both formal and informal pathways of species transfer. Nile tilapia (*Oreochromis niloticus*), particularly the “Chitralada” strain, was first introduced into Nepal in 1985 from Thailand under government auspices (Pantha 1993). However, its early utilization remained largely confined within government fish farms, with minimal research and limited dissemination to the farming community. Systematic scientific investigation on tilapia culture began later, in 1996, at the Institute of Agriculture and Animal Science (IAAS), Tribhuvan University, marking the initiation of organized research and development efforts (Shrestha and Bhujel 1999).

Prior to this formal introduction, *Oreochromis mossambicus* had already entered Nepal through informal cross-border movement from India, particularly in the southeastern Terai region, where it was adopted by local farmers (Pantha 1993; Karki 1998). Recognizing the potential of tilapia for aquaculture diversification, the Fisheries Research Center at Tarahara under the Nepal Agricultural Research Council (NARC) reintroduced Nile tilapia (Chitralada strain) along with Genetically Improved Farmed Tilapia (GIFT) from the Asian Institute of Technology (AIT), Thailand, in 2001 (Gautam 2005), followed by an additional import of GIFT in 2003 (KC 2003). These introductions facilitated the initiation of structured breeding and performance evaluation programs at Tarahara and Begnas (Pokhara) research stations.

Further strengthening of genetic resources occurred in 2009, when IAAS Rampur imported GIFT tilapia from WorldFish, Bangladesh. Subsequently, in 2012, private sector involvement expanded with the introduction of Nile tilapia (Chitralada) and red tilapia hybrids (*O. niloticus* ♂ × *O. mossambicus* ♀) from Thailand by Himalayan Aqua Agritech Pvt. Ltd, Rupandehi. These stocks were disseminated to key institutions, including the Agriculture and Forestry University (AFU) and NARC research stations, enhancing research and seed production capacity (Shrestha and Pandit

2017). Currently, red tilapia stocks are maintained at AFU Aquaculture farm, NARC research station - Parwanipur, and at a private farm in Kathar, Chitwan, Center for Aquaculture-Agriculture Research and Production (CAARP).

At present, Nile tilapia is widely maintained in government farms, research stations, and academic institutions across Nepal. Its culture has gradually expanded among farmers in the Terai region, specifically in districts such as Chitwan, Nawalparasi, Rupandehi, Dhanusha, Sunsari, Morang and Jhapa. Additionally, tilapia populations have become established in several natural water bodies, including lakes of the Pokhara valley and selected rivers and reservoirs, indicating both successful adaptation and emerging ecological considerations (Hussain et al. 2016; Manandhar et al. 2023; Khadka et al. 2025; Sah 2025).

RESEARCH ADVANCES IN TILAPIA AQUACULTURE IN NEPAL

Tilapia research in Nepal has extensively focused on system integration within carp-based polyculture, including cage-pond systems, as well as optimization of stocking density, growth performance, nutrition, and feeding strategies. Significant advances have also been made in seed production, sex reversal technologies, and recruitment control to enhance productivity and sustainability.

Polyculture systems

Polyculture systems integrating Nile tilapia with other compatible species have been a central focus of aquaculture research in Nepal, primarily due to their potential to enhance productivity, optimize resource utilization, and improve farm profitability. Given the country's long-standing tradition of carp-based aquaculture, most studies have explored the incorporation of Nile tilapia into existing carp-based polyculture systems, assessing production performance, ecological interactions, and economic feasibility under diverse production systems and agro-ecological conditions.

Early experimental work demonstrated the feasibility of integrating mixed-sex Nile tilapia with common carp (*Cyprinus carpio*) under subtropical pond conditions (Shrestha and Bhujel 1999). In a 108-day trial conducted in cement ponds (72 m²), both species were stocked at equal densities (1 fish/m²) and fed locally available duckweed (*Spirodela* sp.). Tilapia exhibited substantial growth, increasing from 39.6 g to 145 g with a survival rate of 90%, while common carp grew from 2.8 g to 63.2 g with 97% survival. The extrapolated annual yield reached approximately 2.5 t/ha, indicating moderate productivity under low-input conditions. However, a key observation was the prolific reproduction of tilapia, resulting in large numbers of recruits (1690 per pond) whose biomass exceeded that of the stocked population. This finding highlighted a major challenge in mixed-sex tilapia culture due to uncontrolled breeding, and suggested that common carp alone is insufficient to control tilapia recruitment in polyculture systems.

The integration of Nile tilapia with other cyprinids has also shown promising results. Chaudhary et al. (2008) compared the production performance of polyculture systems comprising all-male Nile tilapia and silver barb (*Barbonymus gonionotus*) with silver barb monoculture in outdoor concrete tanks over a 190-day culture period. While silver barb was stocked at 1.5 fish/m² in both treatments, tilapia was introduced at 0.3 fish/m² in the polyculture system. Only silver barb received supplemental feeding (23% CP diet), yet the inclusion of tilapia significantly increased overall productivity. The extrapolated net yield in tilapia-silver barb polyculture reached 4.4 t/ha/year, compared to 2.5 t/ha/year in silver barb monoculture. Water quality parameters remained stable across treatments, and both systems generated positive economic returns, with higher profitability in

polyculture. These results demonstrate the complementary ecological roles of tilapia and silver barb, where tilapia likely utilized unconsumed feed and natural planktons, thereby improving system efficiency.

Similarly, the polyculture of Nile tilapia with indigenous high-value species such as sahar (*Tor putitora*) has been investigated. Rai et al. (2007) reported that tilapia exhibited superior growth performance in polyculture compared to monoculture, with a daily weight gain of 1.15 g/day and 100% survival. The polyculture system yielded the highest net production (6.0 t/ha/year) and demonstrated improved feed conversion efficiency (FCR 1.3). Notably, while tilapia reproduction was higher in monoculture, the presence of sahar in polyculture appeared to regulate recruitment, possibly through predation. This interaction not only enhanced overall productivity but also addressed one of the major constraints of tilapia farming, reinforcing the value of species diversification.

The use of herbivorous species such as grass carp (*Ctenopharyngodon idella*) in combination with Nile tilapia represents another important advancement in low-cost aquaculture systems. Experiments conducted at the Institute of Agriculture and Animal Science (IAAS), Rampur demonstrated that feeding chopped Napier grass in grass carp-tilapia polyculture can yield substantial production without reliance on commercial feeds (Pandit et al. 2004)). Among the tested stocking combinations, a 1:1 ratio (0.5 fish/m² each) resulted in the highest gross (4.4 t/ha/crop) and net yields (4.1 t/ha/crop). Tilapia exhibited 100% survival, and although individual growth declined at higher stocking densities, total yield increased due to higher biomass accumulation. The study highlighted the synergistic interaction between the two species, where tilapia utilized organic wastes generated by grass carp feeding, thereby enhancing nutrient recycling and overall system productivity.

Further innovations in species combinations have demonstrated the potential for multi-species polyculture to maximize productivity and profitability. Studies incorporating Nile tilapia and sahar into carp-based polyculture systems revealed significant increases in net yield and gross margin in both on-station and on-farm settings (Shrestha et al. 2018). For instance, the inclusion of both species (carp+tilapia+sahar) resulted in net yields of up to 2.78 t/ha/crop and gross margins exceeding USD 3000/ha, compared to substantially lower values in carp-only systems. These results highlight the economic benefits of diversification and the role of trophic interactions in enhancing system performance.

Recent on-station and on-farm trials by Pandit et al. (2018, 2023) further substantiate the contribution of tilapia integration to improving carp-based polyculture systems in Nepal. The on-station experiment conducted at Agriculture and Forestry University, Chitwan, utilized 12 earthen ponds (150 m²) over 185 days, while the on-farm trial in Kathar, Chitwan, involved 12 ponds (200 m²) over 150 days. Both studies employed four treatments with three replications: (T₁) existing carp polyculture with mixed-sex Nile tilapia and sahar (*Tor putitora*); (T₂) carp polyculture with monosex Nile tilapia; (T₃) monosex Nile tilapia with fertilization only; and (T₄) monosex Nile tilapia with both fertilization and supplementary feeding.

In the on-station trial, total net fish yield was significantly lower in T₃, whereas T₁ (2.82), T₂ (3.20), and T₄ (3.77 t/ha/crop) produced comparable yields. Monosex tilapia in T₄ exhibited the highest harvest weight, daily growth rate, and overall productivity. Similarly, in the on-farm trial, T₃ resulted in the lowest production, while T₁ (2.49), T₂ (2.57), and T₄ (2.54 t/ha/crop) showed no significant differences. Growth performance of monosex tilapia remained superior in T₄. Economic analysis revealed that gross profit margins were lowest in T₃, whereas T₁, T₂, and T₄ generated comparable

and higher returns. These findings indicate that carp-tilapia-sahar polyculture, carp-monosex tilapia polyculture, and fed monosex tilapia monoculture are productive and economically viable alternatives to traditional carp polyculture, contributing to enhanced pond productivity and species diversification in Nepalese aquaculture. Consistent with these observations, Pandey (2002) reported that all-male Nile tilapia monoculture outperformed carp-based polyculture systems in an on-farm trial, achieving an extrapolated net fish yield of 5.6 t/ha/year.

Similarly, Neupane et al. (2022) reported that Nile tilapia monoculture outperformed both common carp monoculture and carp polyculture in terms of productivity and economic returns during the dry season, achieving net yields of up to 9.57 t/ha/year. These findings indicate that while polyculture systems are advantageous under certain conditions, tilapia monoculture may be more suitable in environments where water availability and temperature regimes favor rapid growth and high survival.

Environmental factors, mainly altitude, have also been shown to influence the performance of tilapia in polyculture systems. Shrestha et al. (2015) evaluated growth and survival across three altitude gradients (1870 m, 700 m, and 350 m) and found that lower altitudes significantly enhanced both parameters. Daily growth rates increased from 0.2 g/day at high altitude to 0.9 g/day at low altitude, while survival rates improved from 45% to 67%. These results underscore the importance of site selection in aquaculture planning, as sub-optimal temperatures at higher elevations can limit the effectiveness of polyculture systems involving tilapia.

The use of predatory species to control tilapia overpopulation resulting from self-recruitment has also gained attention. In a study conducted at the CAARP farm in Kathar, Chitwan, the polyculture of Nile tilapia with pangas catfish (*Pangasianodon hypophthalmus*) significantly improved production outcomes. Stocking tilapia at 1 fish/m² and pangas at 0.5 fish/m² in earthen ponds for 150 days resulted in net yields of 7.2 t/ha/year, more than double that of tilapia monoculture (3.1 t/ha/year) (Shrestha et al. 2015). Additionally, feed conversion efficiency improved (FCR 2.1), and tilapia recruitment was effectively controlled. The presence of a predatory species likely reduced the density of juvenile tilapia, minimizing competition for resources and allowing stocked fish to achieve better growth. This approach offers a practical solution to one of the major challenges in tilapia aquaculture and is particularly relevant for small-scale farmers seeking to optimize production.

Overall, research on Nile tilapia-based polyculture systems in Nepal demonstrates significant progress in identifying optimal species combinations, stocking densities, and feeding strategies. The integration of tilapia with carps, indigenous species, and predatory species has consistently shown improvements in productivity, resource use efficiency, and economic returns. However, challenges such as uncontrolled reproduction, environmental constraints, and the need for locally adapted management practices remain. Future research should focus on refining polyculture models through the use of monosex tilapia, improved feed formulations, and climate-resilient production strategies. Moreover, scaling up successful experimental models to farm-level applications will be critical for realizing the full potential of tilapia aquaculture in Nepal.

Cage-pond integrated systems

Cage-pond integrated systems have emerged as a promising innovation in tilapia aquaculture in Nepal, addressing key constraints such as low productivity, inefficient resource utilization, uncontrolled reproduction, and limited availability of quality seed. Early experimental work conducted at the Institute of Agriculture and Animal Science (IAAS), Chitwan demonstrated the

feasibility and productivity of this system under subtropical conditions (Shrestha 2002). In this model, larger Nile tilapia (100-150 g) are stocked in cages at the rate of 30 fish/m² and provided with supplemental feeding, attaining harvest sizes of 250-300 g within a 5-month production cycle. Concurrently, smaller fingerlings (20-30 g) are reared in the surrounding pond without direct feeding, reaching 100-150 g over the same period. This functional differentiation allows cages to serve as intensive grow-out units, while ponds act as both nursery and secondary production systems. The integration of these components facilitates efficient nutrient recycling and optimizes overall system productivity.

This system supports two production cycles annually, achieving yields of 3.5-4.0 t/ha/cycle and 7-8 t/ha/year, which is approximately two-fold higher than the national average fish productivity (Gautam and Sapkota 2023). An additional advantage is the generation of surplus recruits within the pond component, which can be utilized as a supplementary protein source in formulated feeds. This internal resource recycling enhances feed efficiency and reduces production costs, making the system particularly suitable for smallholder farmers with limited access to commercial inputs.

Subsequent refinement of the cage-pond concept was undertaken by Rai et al. (2005), who developed a “cage-cum-pond” system designed to optimize fish production under conditions of limited seed availability. In this approach, size grading is employed to separate larger and smaller fish between cages and ponds, respectively, thereby minimizing intra-specific competition and promoting uniform growth. Experimental results from IAAS, Rampur indicated that caged Nile tilapia with feeding achieved growth rates of up to 1.20 g/day with survival rates exceeding 94%, while pond-reared fish exhibited satisfactory growth supported by natural productivity. The system yielded a total production of approximately 7.9 t/ha/year with a feed conversion ratio of 1.3. Validation trials conducted under farmer-managed conditions reported slightly lower yields due to sub-optimal management practices, particularly in feeding and husbandry. Nevertheless, production levels remained substantially higher than conventional systems, demonstrating the robustness and adaptability of the technology.

The incorporation of biological control agents within cage-pond systems has further enhanced their performance. Yadav et al. (2008) evaluated the integration of sahar, an indigenous predatory species, to regulate excessive recruitment of tilapia in cage-pond system for 158 days. The study demonstrated that increasing the density of sahar significantly reduced the number of tilapia recruits in pond without adversely affecting the growth, survival, or yield of the stocked tilapia population. The highest extrapolated net fish yield (7.73 t/ha/year) was recorded in treatments with the highest predator density. However, sahar growth performance was inversely related to stocking density, suggesting the need for optimization of predator-prey ratios. These findings highlight the ecological compatibility of incorporating native predatory species to control reproduction and improve production efficiency in integrated systems.

Further advancements in cage-pond integration were demonstrated by Mandal et al. (2014), who evaluated multi-species systems combining Nile tilapia, African catfish (*Clarias gariepinus*), and carps. In this study, cages occupying approximately 3% of the pond surface area were used to culture tilapia and catfish at densities of 30 and 100 fish/m³, respectively, while carps were stocked in the open pond area at 1 fish/m². Caged fish were provided with a 24% crude protein pellet diet, whereas pond productivity was maintained through fertilization. The integrated tilapia-catfish-carp system achieved significantly higher combined net yields (9.4 t/ha/year) compared to the control carp monoculture (3.3 t/ha/year). The tilapia-carp system also produced substantial yields (7.5 t/ha/year), although not significantly different from the combined system. Economic analysis revealed

significantly higher net returns for integrated systems compared to monoculture, underscoring their economic viability.

Collectively, these studies demonstrate that cage-pond integrated systems significantly enhance fish production, resource efficiency, and profitability. The inclusion of indigenous predatory species such as *Tor putitora* provides a sustainable solution to the problem of uncontrolled tilapia reproduction. Future research should focus on optimizing stocking densities, feed strategies, and species combinations, as well as strengthening farmer training and extension services to maximize the benefits of this technology.

Stocking density and growth optimization

Optimization of stocking density is a critical determinant of growth performance, survival, and overall productivity in Nile tilapia aquaculture systems. Recent studies in Nepal have focused on identifying density thresholds that balance individual growth with biomass yield, particularly under mono-sex culture conditions.

A study conducted by Mandal et al. (2019/2020) evaluated the optimum stocking density of sex-reversed male tilapia produced using 17 α -methyltestosterone in hapa-based systems installed in concrete tanks. Fish with an initial weight of 4.3 g were stocked at densities of 2, 3, and 4 fish/m² and fed a commercial diet containing 23% crude protein at 4% body weight per day. At harvest, final weights ranged from 176.7 to 192.7 g, with high survival rates (95.8-100%) and no significant differences in individual growth among treatments. However, gross yield increased significantly with stocking density, reaching a maximum of 7.41 t/ha over 150 days at 4 fish/m². Economic analysis further indicated the highest gross margin (USD 7015/ha), identifying 4 fish/m² as the optimal density within the tested range.

Similarly, Sapkota et al. (2022) assessed the effects of stocking density on mono-sex tilapia cultured in hapas within earthen ponds. Fingerlings (8.5 g average initial weight) were stocked at densities of 5, 10, 15, and 20 fish/m³ and fed a 30% crude protein diet. Results indicated a clear density-dependent response, with individual growth and survival (84-95%) declining at higher stocking densities due to increased competition and resource limitation. The highest individual growth was observed at the lowest density (5 fish/m³), whereas maximum total production was achieved at the highest density (20 fish/m³).

In another experiment, Rijal et al. (2025) evaluated stocking densities of 10, 20, 30, and 40 fish/m³ in cage culture systems. Fish were fed a 35% crude protein diet at variable feeding rates, and results demonstrated that intermediate density (20 fish/m³) yielded the best growth performance, with significantly higher weight gain (76.32 g), daily growth rate (0.84 g), and survival (90%). Although maximum total production and gross revenue were achieved at the highest density (40 fish/m³), net profit was significantly higher at 20 fish/m³, indicating superior economic efficiency at moderate stocking levels. Sah et al. (2019) evaluated the comparative growth performance of monosex and mixed-sex Nile tilapia cultured under pond conditions in Nepal over a 150-day period. The study demonstrated that monosex tilapia exhibited significantly higher growth, achieving a greater final weight (133.7 g) compared to mixed-sex populations (101.5 g). Improved length, size uniformity, and growth rate in monosex fish were attributed to the absence of uncontrolled reproduction, which commonly leads to stunted growth in mixed-sex systems. The findings confirm that monosex culture is a more efficient and productive strategy for tilapia farming.

These studies demonstrate that optimal stocking density in tilapia culture is context-specific and depends on the balance between biological performance and economic returns. Higher densities increase total yield but often reducing individual fish growth due to competition for resources. As stocking density rises, growth performance typically declines, although overall biomass output improves. Moderate stocking densities provide a balance by optimizing growth rate, survival, and economic returns.

Nutrition and feeding strategies

Nutritional strategies play a crucial role in enhancing growth performance, feed utilization efficiency, and the economic viability of Nile tilapia aquaculture. In Nepal, recent research has increasingly emphasized the development of cost-effective, locally adapted feeding regimes, alongside the incorporation of functional additives and alternative feed ingredients and feeding frequency.

A key area of advancement in Nepal is the improvement of locally formulated feeds through functional supplementation. Jha et al. (2019/2020) evaluated the effects of molasses-fortified diets combined with probiotic pond treatment on the growth performance of monosex Nile tilapia over a 120-day culture period. The basal diet, composed of mustard oil cake, rice bran, and soybean flour (1:1:0.5), was either used alone or supplemented with molasses and a commercial probiotic (Everfresh Pro; Product of Blue Weight, India). Results demonstrated a substantial increase in productivity in the supplemented group, with extrapolated net fish yield reaching 43.2 ± 1.2 t/ha/year compared to 23.0 ± 1.0 t/ha/year in the control, assuming three production cycles per year. Growth indicators, including daily weight gain and total weight gain, were significantly improved, suggesting enhanced nutrient assimilation and gut microbial activity. This study underscores the potential of integrating probiotics with low-cost feed formulations to substantially increase production efficiency under semi-intensive culture systems.

The application of probiotics has been further validated by Chaudhary et al. (2022), who investigated graded levels of dietary probiotic inclusion (0.5-2.0%) in tilapia diets containing 30% crude protein. The results revealed significant improvements in growth performance and feed utilization across all probiotic treatments compared to the control. Notably, optimal outcomes were observed at moderate inclusion levels (0.5-1.5%), which yielded the highest weight gain, specific growth rate, and lowest feed conversion ratio (FCR). These findings indicate that probiotics play a critical role in enhancing digestive efficiency, possibly through modulation of intestinal microbiota and enzyme activity. However, diminishing returns at higher inclusion levels highlight the importance of dosage optimization in feed formulation.

Functional feed additives have also been explored to improve fish health and performance. Shrestha (2015) reported that supplementation with Lapsi (*Choerospondias axillaris*) fruit powder significantly improved growth, feed conversion, and immune parameters in Nile tilapia. The observed increase in liver protein and globulin levels indicates enhanced immune function, likely due to the high vitamin C content of Lapsi fruit. Optimal results were achieved at 200 mg/kg inclusion, demonstrating its potential as a natural growth promoter and immunostimulant.

In addition to functional additives, the exploration of alternative protein sources has gained considerable attention as a strategy to reduce feed costs and improve sustainability. Ahir et al. (2025) evaluated the use of earthworm-enriched diets as a protein supplement in Nile tilapia culture over a 62-day period. Fish fed the earthworm-based diet exhibited superior growth performance, achieving the highest weight and length gains among treatments, along with the lowest FCR (1.65) and 100%

survival. These results demonstrate the high nutritional quality and digestibility of earthworm protein, making it a promising alternative to conventional protein sources. Nevertheless, large-scale adoption will require further assessment of production costs and availability under local farming conditions.

Plant-based feed ingredients have also been investigated as sustainable substitutes for conventional protein sources. Pokharel (Bhattarai) et al. (2017) evaluated the effects of conventional feed (composed of wheat flour, soybean meal, and fishmeal) and greater duckweed (*Spirodela polyrrhiza*) on Nile tilapia fingerlings under controlled conditions. Results indicated that fish fed conventional feed achieved significantly higher weight gain (65%) compared to those fed mixed diets (37%) or duckweed alone (9%). However, the mixed diet improved protein deposition (50.3%), while conventional feed enhanced mineral content, including calcium and phosphorus. These findings suggest that while duckweed alone may not support optimal growth, its inclusion in feeding regimes can improve nutritional quality and reduce feed costs, thereby enhancing the sustainability of polyculture systems.

Bhatta et al. (2025) examined the effects of incorporating moringa (*Moringa oleifera*) leaf meal as a partial replacement for soybean meal in tilapia diets. The study demonstrated that inclusion levels of 5-10% moringa leaf meal improved feed acceptance, total harvest weight, and survival rates, without significantly affecting specific growth rate or FCR. Higher inclusion levels (15-20%) did not confer additional benefits, likely due to the presence of anti-nutritional factors at elevated concentrations. These findings suggest that moringa leaf meal can be effectively utilized at moderate inclusion levels as a cost-efficient and locally available protein source in tilapia aquafeeds. Similarly, Gahatraj et al. (2025) reported enhanced growth and feed utilization with soybean- and moringa-enriched diets, with improved daily weight gain and reduced FCR compared to control diets. These findings underscore the importance of integrating locally available plant resources into feed formulations. Kandel et al. (2023) reported that replacing fish meal with soybean meal at a 75% substitution level yielded the highest benefit-cost ratio compared to diets containing fish meal exclusively, without adversely affecting fish growth performance during the early growth stage of Nile tilapia.

Beyond protein sources, lipid substitution represents another important dimension of feed optimization. Bhatta et al. (2025) investigated the replacement of fish oil with palm oil in Nile tilapia diets under cage culture conditions. The study found no significant differences in growth performance, feed conversion efficiency, or survival across treatments with varying levels of fish oil substitution. Notably, up to 50% replacement of fish oil with palm oil was achieved without adverse effects, indicating that palm oil can serve as a viable and economically sustainable alternative lipid source. This is mostly relevant in the context of increasing costs and limited availability of fish oil in developing aquaculture systems.

The use of unconventional protein sources has also been explored. Prasad and Chaudhary (2019) demonstrated that *Achatina fulica* (giant African snail) can effectively replace soybean meal partially or completely in tilapia diets without affecting growth performance or feed efficiency. This approach not only reduces feed costs but also contributes to the management of invasive species, offering both economic and ecological benefits. In addition, Ghimire and Ranjan (2017) reported that linseed oilcake can fully replace mustard oilcake in tilapia diets without adverse effects on growth, further expanding the range of viable plant-based feed ingredients.

Feeding strategies, including feeding frequency and fertilization regimes, play a crucial role in optimizing nutrient utilization and production efficiency. B.C. (2023) demonstrated that daily

feeding (once or twice) significantly improved growth performance and yield in hybrid red tilapia compared to alternate-day feeding. Net fish yields were highest under daily feeding regimes (7.21-7.29 t/ha/year), highlighting the importance of consistent nutrient supply for maximizing growth. Integrated fertilization and feeding strategies have also been shown to enhance productivity. Pokharel (2012) and Manyala et al. (2015) reported that combining full fertilization with partial feeding resulted in higher yields and lower production costs compared to either fertilization or feeding alone. This approach promotes natural food production while supplementing with formulated feed, thereby improving nutrient efficiency and economic returns.

Collectively, these studies highlight a clear trend toward the development of nutritionally efficient and economically viable feeding strategies tailored to Nepalese aquaculture conditions. The integration of probiotics and functional feed additives enhances nutrient utilization and growth performance, while the use of alternative protein and lipid sources reduces dependency on costly conventional ingredients. These innovations not only improve production efficiency but also contribute to the environmental sustainability of aquaculture systems by promoting resource recycling and reducing feed-related inputs.

Seed production and sex reversal technologies

The development of efficient seed production and sex reversal technologies is fundamental to the success of Nile tilapia aquaculture in Nepal. Tilapia is characterized by early sexual maturity and prolific breeding, which often leads to uncontrolled reproduction, overpopulation, and stunted growth under culture conditions (Shrestha et al. 2011). Consequently, the production of monosex (all-male) populations has become a standard practice to enhance growth performance, improve feed conversion efficiency, and maximize yield. In Nepal, significant research efforts have focused on refining hormonal sex reversal techniques and exploring alternative, environmentally sustainable approaches for masculinization.

The most widely adopted method for producing all-male tilapia populations is the administration of 17 α -methyltestosterone (MT) through hormone-treated feed during the critical period of sex differentiation, typically within 1-21 days post-hatch (Bhujel 2012). This approach has consistently demonstrated high efficacy, often achieving masculinization rates exceeding 90%. For instance, studies conducted under Nepalese conditions have reported male proportions as high as 98-100% when fry are fed MT-treated diets for 28-35 days (Khanal et al. 2014; Mandal 2019/20; Pandey et al. 2021/2022). The effectiveness of MT is further supported by its application in improved strains such as Genetically Improved Farmed Tilapia (GIFT). Thapa et al. (2011) reported that feeding day-old larvae with MT-treated feed for 35 days resulted in approximately 95% male fry. Subsequent grow-out trials showed that all-male populations achieved significantly higher productivity (6.5 t/ha) compared to mixed-sex populations (3.0 t/ha), without significant differences in survival rates. These findings clearly demonstrate the critical role of sex reversal in enhancing tilapia production efficiency.

Despite its effectiveness, the use of synthetic hormones such as MT has raised concerns related to cost, regulatory restrictions, environmental contamination, and potential human health risks (Ruksana et al. 2010); however, no confirmed risks have been reported under regulated application levels. Considerable research in Nepal has also been directed toward identifying alternative methods of sex control that are both effective and eco-friendly. One such approach involves the use of natural androgen sources derived from animal tissues. Khanal et al. (2014) investigated the use of carp testis as a natural substitute for MT in Nile tilapia sex reversal. The study demonstrated that while MT achieved a higher masculinization rate (up to 98.5%), carp testis also produced a substantial

proportion of males (up to 91.4%), with effectiveness increasing with feeding duration. Similarly, Ranjan et al. (2015) reported that feeding diets containing common carp (*Cyprinus carpio*) testis induced masculinization in a dose-dependent manner, with male proportions reaching $95.8 \pm 7.2\%$ at higher inclusion levels. These findings were further corroborated by Shrivastav et al. (2017), who observed masculinization rates of up to $88.29 \pm 4.2\%$ using dried carp testis, along with improved growth performance and no adverse effects on survival. Collectively, these studies indicate that carp testis represents a viable, low-cost, and eco-friendly alternative to synthetic androgens, although further standardization is required to achieve consistently high masculinization rates.

In addition to natural androgen sources, plant-based reproductive inhibitors have been explored as a means of controlling tilapia reproduction. Yadav et al. (2021) evaluated the effects of papaya (*Carica papaya*) seed powder on the reproductive performance of Nile tilapia. While the inclusion of papaya seed (up to 15%) in the diet did not significantly affect growth or survival, it resulted in a marked reduction in reproductive parameters, including gonadosomatic index, fecundity, fertilization rate, and hatching success. Although complete sterility was not achieved, the suppression of reproductive activity suggests that papaya seed powder could be used as a cost-effective and environmentally friendly strategy to control unwanted breeding in grow-out systems.

Another promising alternative to MT is the use of non-steroidal aromatase inhibitors, which block the conversion of androgens to estrogens, thereby promoting male differentiation. Tamoxifen, a widely studied aromatase inhibitor, has shown considerable potential in this regard. Pandit et al. (2017) reported that feeding tilapia fry with tamoxifen at doses of 150-250 mg/kg diet resulted in masculinization rates of approximately 84-85%, with no significant effects on survival. Subsequent studies demonstrated that increasing the dosage to 1000 mg/kg improved masculinization rates to $96.7 \pm 1.2\%$, approaching the effectiveness of MT (Pandit et al., 2018). Importantly, treatment duration (30 vs. 40 days) did not significantly influence outcomes, suggesting flexibility in management practices. These findings indicate that tamoxifen is a promising alternative for monosex tilapia production, although further research is needed to optimize dosage and achieve complete masculinization.

The potential for combining MT with alternative agents has also been explored to reduce reliance on synthetic hormones. Pandey et al. (2021/2022) evaluated the combined use of MT and tamoxifen in varying proportions. The study found that both 100% MT and a 50:50 combination of MT and tamoxifen achieved 100% male populations, while survival rates remained unaffected across treatments. These results suggest that tamoxifen can partially replace MT without compromising masculinization efficiency, offering a practical approach to reducing hormone usage while maintaining production performance.

In addition to hormonal and alternative masculinization strategies, research has also addressed feed formulation for cost-effective seed production. Adhikari et al. (2021/2022) investigated the replacement of fish meal with soybean meal in hormone-treated diets used for sex reversal. The study demonstrated that up to 75% replacement of fish meal with soybean meal did not adversely affect masculinization rates, which remained consistently high (99.8-100%), nor did it compromise growth performance. However, complete replacement (100% soybean meal) resulted in reduced survival, indicating the need for balanced formulations. Mahatara et al. (2023) also reported a similar result. These findings highlight the potential for reducing feed costs in hatchery operations while maintaining high-quality seed production.

Beyond early-stage sex reversal, hormonal manipulation has also been applied to regulate gonadal development and improve growth in later life stages. Pandit and Nakamura (2015) investigated the effects of the aromatase inhibitor exemestane on sub-adult female tilapia. The study found that treated fish exhibited significantly higher body weight and reduced gonadosomatic index, accompanied by suppressed gonadal development and altered hormone profiles (reduced estradiol and increased 11-ketotestosterone). These results suggest that reproductive suppression through aromatase inhibition can redirect energy toward somatic growth, offering additional opportunities for enhancing productivity in tilapia culture.

As an eco-friendly, non-hormonal approach to sex control, Pandit et al. (2015) evaluated the effects of elevated temperature on germ cell development in Nile tilapia. Exposure of fish to 37 °C for 45-60 days resulted in complete and irreversible depletion of germ cells, leading to permanent sterility throughout all life stages. This condition was accompanied by significantly reduced levels of key sex steroids, including testosterone, 11-ketotestosterone, and 17 β -estradiol. Notably, thermally treated fish exhibited improved growth performance and higher body weight compared to untreated controls. These findings highlight thermal manipulation as a promising, environmentally sustainable strategy for inducing sterility while simultaneously enhancing growth in tilapia aquaculture.

In summary, research on seed production and sex reversal technologies in Nepal has made substantial progress, encompassing both conventional hormonal approaches and innovative alternatives. While MT remains the most effective and widely used method for producing all-male populations, growing concerns over its environmental and health implications have accelerated the search for safer and more sustainable alternatives. Natural androgen sources, plant-based reproductive inhibitors, and aromatase inhibitors such as tamoxifen and exemestane, and high-temperature treatment have all demonstrated considerable potential, although further refinement and standardization are required for large-scale application.

Recruitment control

In Nepal, considerable research efforts have focused on the development of biological control strategies, primarily through predator-based polyculture systems, to regulate tilapia recruitment while enhancing overall productivity and economic returns. Early studies investigated the use of African catfish as a biological control agent in tilapia culture. Mishra (2002) reported successful suppression of tilapia recruitment through the inclusion of African catfish (*Clarias gariepinus*), where predation on fry and juveniles reduced excessive recruitment and minimized intraspecific competition, resulting in improved growth performance and biomass production.

The integration of indigenous predatory species such as sahar (*T. putitora*) has emerged as one of the most effective and ecologically compatible approaches. Acharya (2007) demonstrated the effectiveness of sahar-based polyculture, reporting a dramatic reduction in tilapia recruits in sahar-integrated ponds (2.7 recruits per pond) compared with monoculture ponds (1745 recruits per pond). The higher mean weight of tilapia recruits in polyculture systems indicated reduced competition and improved growth conditions. Similarly, Yadav et al. (2008) evaluated the incorporation of varying densities of sahar in a cage-cum-pond system and observed a progressive decline in tilapia recruitment with increasing predator density. While tilapia growth and survival were not significantly affected, the highest extrapolated net fish yield (2.9 t/ha over 158 days) was achieved at the highest predator density, confirming the effectiveness of sahar as a biological control agent. Sharma et al. (2009) also reported a similar result with sahar in Nile tilapia ponds.

Supporting these findings, Shrestha et al. (2011) demonstrated that the inclusion of sahar in mixed-sex Nile tilapia culture significantly reduced recruitment and improved growth performance and yield compared to monoculture systems. Optimal results were achieved at stocking ratios of 1:16 (sahar:tilapia) under on-station conditions and 1:33 under on-farm conditions. These systems not only controlled excessive recruitment but also enhanced net fish yield and profitability, although excessively high predator densities slightly suppressed overall growth, indicating the importance of optimizing stocking ratios.

Beyond indigenous species, the use of exotic predatory fish has also shown promising results. A study conducted by Shrestha et al. (2015) at the Center for Aquaculture-Agriculture Research and Production (CAARP), Chitwan, demonstrated that polyculture of tilapia with pangas catfish (*Pangasianodon hypophthalmus*) effectively controlled tilapia recruitment, likely through predation on fry and juveniles, thereby reducing intra-specific competition. Consequently, improved growth performance and overall production efficiency were observed. Consistent findings by Shrestha et al. (2018) and other studies indicate that predator inclusion significantly reduces tilapia fry abundance while improving growth and biomass yield.

These studies highlight that predator-based polyculture systems represent a sustainable and efficient strategy for managing tilapia recruitment in Nepal. The use of indigenous species such as sahar offers additional ecological advantages, including conservation of this species and compatibility with local ecosystems. However, careful optimization of predator species, stocking density, and management practices is essential to balance predation pressure and fish growth.

Integrated system

Although integrated fish farming has long been practiced by farmers in Nepal, its scientific evaluation remains limited and is still at a relatively preliminary experimental stage. One of the earliest systematic evaluations of integrated aquaculture in Nepal was the rice-fish farming study conducted by Gurung and Wagle (2005) across four mid-hill districts. Their experiments demonstrated that common carp (*Cyprinus carpio*) can be successfully cultured in rice fields under Nepalese conditions, with productivity strongly influenced by stocking density, initial fingerling size, and nutrient management. Fish stocked at 4000-6000 fingerlings per hectare with initial body weights of 5-20 g attained mean harvest weights of approximately 90 g within 88-95 days. The highest gross and net fish yields reached 529 and 339 kg/ha, respectively, under higher stocking density combined with larger fingerlings. Feeding and fertilization interventions further improved system performance, with yields increasing to 514 kg/ha gross and 354 kg/ha net under 4% supplementary feeding with organic manure. These findings confirm that rice-fish integration can enhance paddy-field productivity while providing an additional source of aquatic protein and income. Similarly, we demonstrated the technical feasibility of decentralized Nile tilapia seed production in rice fields in Chitwan and Nawalparasi districts (Shrestha et al. 2010; unpublished data). In this study, fingerling productivity varied substantially among farmer groups, with densities ranging from 0.8 to 10.7 fingerlings/m² of rice plot area and average size of 10 g. Commercial application of this technology may be limited due to ecological concerns associated with tilapia self-recruitment in water bodies, thereby constraining its scalability.

Beyond rice-fish integration, livestock-based integrated aquaculture has also shown considerable potential. Kathayat et al. (2021) evaluated a pig-fish farming model in Nepal using a carp-tilapia polyculture system stocked at 10,000 fish/ha in association with two pigs over a 120-day production cycle. The integrated system yielded an extrapolated gross fish production of 4.2 t/ha/year and a net yield of 3.4 t/ha/year, with a survival rate of 62.93% and a feed conversion ratio of 2.72. Importantly,

pig integration improved pond fertility through manure inputs, thereby enhancing natural productivity and lowering feed costs. The benefit-cost ratio of 1.65 underscores the strong economic feasibility of this system for smallholder farmers.

Similarly, Banmali et al. (2021) reported favorable outcomes from integrated duck-fish farming at AFU Fish Farm, Rampur. In a 120-day trial, carp-tilapia polyculture stocked at 13,000 fingerlings/ha produced extrapolated gross and net fish yields of 4.0 and 2.9 t/ha/year, respectively, with a survival rate of 66% and a low FCR of 1.4. Concurrently, ducks exhibited satisfactory growth and contributed additional farm revenue, with benefit-cost ratios of 1.65 for fish and 1.24 for ducks.

Collectively, these studies indicate that integrated fish farming in Nepal represents a scientifically robust and economically viable strategy for sustainable aquaculture intensification. Future research should focus on system optimization, environmental carrying capacity, and region-specific integration models involving tilapia to maximize productivity and climate resilience.

Other systems

Beyond conventional pond- and cage-based production systems, recent research in Nepal has increasingly explored alternative and innovative aquaculture approaches to enhance productivity, resource-use efficiency, and environmental sustainability in Nile tilapia farming. These include biofloc technology, recirculating aquaculture systems (RAS), and improved hatchery incubation techniques.

Biofloc technology has emerged as a promising approach for intensifying tilapia production while minimizing water exchange and improving nutrient utilization. Gurung et al. (2024) investigated the influence of different carbon sources on biofloc performance under a fixed C:N ratio of 10:1. The study revealed significant variation in growth performance among treatments, with molasses-based systems producing the highest daily weight gain and overall fish yield. In contrast, the control group exhibited the lowest growth performance, confirming the benefits of biofloc systems over conventional culture. Interestingly, feed conversion ratio was most efficient in the rice bran treatment, suggesting that carbon source selection influences not only microbial productivity but also feed utilization efficiency. Overall, molasses emerged as a superior carbon source for enhancing growth and production under Nepalese conditions, likely due to its rapid fermentability and support for heterotrophic bacterial proliferation.

Complementing this, Gurung et al. (2025) evaluated the effect of different carbon-to-nitrogen (C:N) ratios on the growth performance of mono-sex tilapia in a 150-day trial using 500-L tanks. The study demonstrated that a C:N ratio of 25:1 produced the highest growth performance and biomass yield, significantly outperforming lower ratios (10:1-20:1) and the control (no biofloc). Enhanced growth under higher C:N ratios can be attributed to increased microbial biomass, which serves as a supplementary protein source and improves nutrient recycling within the system. These findings highlight the importance of optimizing the C:N ratio to maximize the efficiency of biofloc-based tilapia culture.

Recirculating aquaculture systems (RAS) represent another significant advancement, particularly in areas with limited water availability or high land pressure. Prajapati (2022) evaluated the performance of Nile tilapia in a controlled RAS environment using fiberglass-reinforced plastic (FRP) tanks over a six-month period. Fish exhibited substantial growth, reaching final weights of 227-244 g from initial weights of approximately 5 g, with average daily gains of 1.26-1.32 g/day and survival rates of 85-90%. The stable water quality conditions maintained in RAS contributed to

consistent growth and high survival, demonstrating the system's potential for intensive and environmentally controlled aquaculture. Although initial investment costs may be relatively high, RAS offers significant advantages in terms of water conservation, biosecurity, and year-round production.

Advances in hatchery technologies have also contributed to improved seed production efficiency in Nepal. Pandit et al. (2017) compared different incubation systems (jar, atkin and aquarium) for Nile tilapia fry production. The jar system achieved the highest hatching rate (95.5%) and larval survival (96.9%), indicating its effectiveness for large-scale operations. However, it required substantially higher water consumption compared to the aquarium system, which used only 0.05 m³ of water while maintaining a comparable hatching rate (95%) when incubating up to 5000 eggs in a 50-L unit. The aquarium system also maintained higher dissolved oxygen levels, suggesting better environmental control. These findings indicate that while jar incubation is suitable for maximizing production, aquarium systems provide a cost-effective, water-efficient alternative for small-scale hatcheries, particularly in water-scarce regions.

These studies demonstrate that alternative aquaculture systems offer significant opportunities to enhance tilapia production in Nepal. Biofloc systems improve nutrient utilization and reduce water dependency, RAS enables high-density and controlled production, and improved incubation technologies enhance seed availability. Future research should focus on scaling up these technologies, optimizing system design under local conditions, and conducting comprehensive economic and environmental assessments.

PRODUCTION STATUS

Tilapia farming in Nepal remains at a developmental stage; however, it has exhibited notable expansion in recent years, driven by increasing demand for fish protein, diversification of aquaculture systems, and supportive government policies (Gautam and Sapkota 2021/2022). Historically, Nepalese aquaculture has been dominated by low-input carp polyculture systems, but the introduction of Nile tilapia has initiated a gradual transition toward more intensive and commercially oriented production models. Recognizing its potential, the Government of Nepal has recently formulated policies to promote tilapia farming as a means to enhance national fish production, improve food security, and reduce dependency on imports (Gautam and Sapkota 2023).

At the farm level, tilapia production is expanding across the Terai and inner Terai regions. Small-scale farmers in areas such as Kathar (Chitwan), Kawasoti (Nawalparasi), Dhangadhi (Kailali), Kanchanpur have initiated tilapia culture, primarily for local markets. Concurrently, commercial-scale operations are emerging in districts including Rupandehi, Sunsari, and Morang, where farmers are integrating tilapia into existing aquaculture systems. While monoculture of tilapia is practiced in some locations, polyculture with carps remains the predominant system, reflecting farmers' preference for risk diversification and resource optimization. Institutions such as the Agriculture and Forestry University (AFU) and the Fisheries Research Center, Tarahara (NARC), play a crucial role in seed supply and technical support, facilitating the adoption of monosex tilapia farming among farmers.

Production performance has improved significantly with the adoption of monosex culture systems. The use of hormonally or otherwise masculinized fingerlings has enabled farmers to achieve yields of 7-8 t/ha/year in subtropical regions, which is considerably higher than traditional carp-based systems under similar management conditions. Seed production has also advanced, with facilities such as the Center for Aquaculture-Agriculture Research and Production (CAARP) in Chitwan

producing over 0.1 million monosex fry annually, addressing the growing demand for quality seed and supporting the expansion of tilapia farming (Shrestha et al. 2025).

Despite these advancements, the overall contribution of tilapia to national aquaculture production has historically been limited. Earlier estimates indicated that only about 4% of fish farmers were engaged in tilapia farming, contributing approximately 1.5% of total aquaculture production in 2014-2015 (Mishra 2015). However, recent data suggest a substantial increase, with tilapia contributing around 10% of total aquaculture production by 2022/23 (Gautam and Sapkota 2023). This growth reflects improved awareness, enhanced seed availability, and the development of emerging value chains.

In addition to aquaculture production, tilapia has become an important component of capture fisheries in certain regions. In the Pokhara Valley, specifically in Phewa and Begnas lakes, Nile tilapia, which though not intentionally introduced, has established self-sustaining populations and now contributes significantly to total fish catch. Recent catch data indicate a marked increase in tilapia harvests alongside a decline in catch of small native species, resulting in improved livelihoods for local fishing communities but raising concerns regarding biodiversity conservation.

Market development is also progressing, with tilapia increasingly available in local and urban markets, including Kathmandu. Initiatives such as aquaponics and bioflocs systems in urban areas have further promoted monosex tilapia culture. Moreover, the development of a structured tilapia value chain, encompassing hatcheries, nurseries, farmer clusters, and market networks, is gaining momentum. These efforts position tilapia as a promising species for scaling up aquaculture production, generating rural employment, and contributing to sustainable economic development in Nepal.

INPUT SUPPLY: SEED AND FEED SYSTEMS

The availability and quality of key inputs, particularly seed and feed, play a critical role in the expansion and intensification of tilapia aquaculture. In the past, the lack of quality seed supply was one of the main factors restricting the growth of this sector. Farmers relied on the collection of mixed-sex fry from production ponds, which often resulted in poor growth performance due to uncontrolled reproduction and stunted populations. Such practices, although low-cost, were inefficient and unsuitable for commercial-scale production.

Institutional efforts have significantly improved seed systems over the past few years. The Fisheries Research Center at Tarahara under the Nepal Agricultural Research Council (NARC) established a tilapia hatchery more than 20 years ago, focusing on research, broodstock management, and seed production. Subsequently, the Institute of Agriculture and Animal Science (IAAS) developed a tilapia hatchery in 2008 in Rampur, Chitwan, which was later upgraded by the Agriculture and Forestry University (AFU) in 2013 to support research on monosex fry production. These institutions have played a pivotal role in generating technical knowledge and disseminating improved seed to farmers.

Recognizing the importance of high-quality seed, the Government of Nepal has recently initiated policies and financial support mechanisms to encourage private-sector participation in hatchery development. A notable example is the establishment of a tilapia hatchery at the Center for Aquaculture-Agriculture Research and Production (CAARP) in Chitwan, developed with partial government support. Two additional hatcheries were established in the Morang and Siraha districts with support from the Government. All of these hatcheries have begun producing monosex tilapia

fry, addressing a major bottleneck in the value chain. Recent estimates indicate that CAARP alone can produce over 0.1-0.3 million monosex fry annually, reflecting growing capacity to meet increasing demand (Shrestha et al. 2025). Similar trends in South Asia highlight the importance of decentralized hatchery systems in scaling tilapia production (Belton et al. 2018).

Feed resources for tilapia culture in Nepal are relatively diverse but remain largely semi-intensive in nature. Tilapia are commonly reared in green water systems, utilizing natural productivity supplemented with external feed inputs. Small-scale farmers predominantly rely on locally available feed ingredients such as rice bran and mustard oil cake, often prepared as farm-made mash feed. In semi-commercial and commercial operations, sinking and floating pellet feeds are more widely used, frequently adapted from carp feed formulations. Protein levels in these feeds typically range from 22-28%, which is adequate for grow-out under semi-intensive conditions (Meurer et al. 2025).

In recent years, a gradual shift toward the use of commercially manufactured floating pellet feeds has been observed among progressive farmers. These feeds improve feed conversion efficiency, reduce wastage, and allow better monitoring of feeding behavior. However, their higher cost remains a limiting factor for widespread adoption. Overall, strengthening seed supply systems and improving feed quality and accessibility are essential for enhancing productivity and ensuring the sustainable growth of tilapia aquaculture in Nepal.

SOCIAL, CULTURAL AND MARKET DIMENSIONS

Tilapia has gained significant social, cultural, and market acceptance in Nepal over the past two decades, reflecting changing consumer preferences and evolving market dynamics. In its early stages, the species was cultured primarily for household consumption, with little emphasis on commercial marketing. For example, during the Women in Aquaculture (WIA) Nepal project in Kathar, Chitwan and Kwasoti, Nawalparasi (2000-2007), tilapia was primarily retained for household consumption, due to its prolific breeding, whereas carp was marketed because of its higher economic value (Bhujel et al. 2008). However, tilapia has gained widespread consumer acceptance in recent years, supporting its commercialization.

The increasing popularity of tilapia can be attributed to several favorable characteristics, including its affordability, availability, mild flavor, suitable serving size, and ease of consumption due to the presence of fewer intramuscular Y-bones compared with many indigenous fish species and exotic carps. These characteristics have made tilapia particularly attractive to urban and peri-urban consumers, especially in the Terai region and the Pokhara Valley. Moreover, improvements in production systems and marketing networks have ensured a more consistent supply of fresh fish, further strengthening consumer confidence and demand (Shrestha and Pandit 2017; Shrestha et al. 2025).

Market dynamics have also shifted considerably. Tilapia currently fetches market prices comparable to those of major carp species in many regions of Nepal, indicating a substantial improvement in its commercial value and consumer acceptance. The expansion of restaurants specializing in grilled tilapia, particularly around Phewa and Begnas lakes in Pokhara, further illustrates its growing culinary significance. Rising demand in these tourism-oriented areas is increasingly met through regular fish supplies from major production hubs in Chitwan and other Terai districts. Collectively, these trends demonstrate the increasing socio-cultural acceptance of tilapia in Nepal and highlight its considerable potential for future expansion.

CONSTRAINTS AND CONCERNS

Despite its promising potential, the expansion of tilapia aquaculture in Nepal is constrained by a combination of ecological, technical, and institutional challenges. Among these, the most critical concern is the ecological risk associated with mixed-sex culture systems and the unintended escape of tilapia into natural water bodies. Due to their high adaptability, prolific breeding, and competitive behavior, escaped tilapia can establish their populations, potentially disrupting native aquatic biodiversity. Evidence from the Pokhara Valley indicates that tilapia has become a dominant component of fish catches in Phewa and Begnas lakes following unintentional introduction, accompanied by a decline in indigenous species (Hussain et al. 2016). Similar trends have been observed in some rivers and wetlands, raising concerns regarding habitat alteration and competition for resources (Manandhar et al. 2023; Khadka et al. 2025; Sah 2025).

Globally, the ecological risks of tilapia introduction are well documented. In countries such as the Philippines and Indonesia, uncontrolled spread of tilapia has contributed to the displacement of endemic fish species and alterations in aquatic ecosystems (De Silva et al. 2004; Canonico et al. 2005). In Africa, tilapia introductions outside their native range have led to hybridization with local cichlid species, resulting in genetic erosion (Shechonge et al. 2019). These examples highlight the need for strict management and regulatory frameworks and the use of high-quality monosex seed, in countries like Nepal, where aquatic biodiversity is both rich and vulnerable.

From a production perspective, the lack of reliable monosex seed remains a significant constraint. In many regions, farmers still depend on mixed-sex fry, which leads to uncontrolled reproduction, overcrowding, and reduced growth performance. Although hatchery development has improved in recent years, access to quality seed is still limited, particularly for small-scale farmers. In addition, inadequate technical knowledge, limited extension services, and insufficient training programs hinder the adoption of improved culture practices (Gautam and Sapkota 2023).

Market-related challenges also persist. Tilapia is not yet widely available in major market centers, and consumer awareness regarding its taste and nutritional value remains low. Consequently, demand is still developing, necessitating targeted promotion, fish exhibitions, and value chain development initiatives to enhance market acceptance.

To address these constraints, the development of standardized protocols for controlled culture, emphasizing monosex farming and biosecurity measures, is essential. Strengthening extension services, ensuring the availability of high-quality seed, and promoting responsible aquaculture practices will be crucial for minimizing ecological risks while supporting the sustainable expansion of tilapia aquaculture in Nepal.

FUTURE PROSPECTS

Tilapia aquaculture in Nepal exhibits strong potential for expansion, supported by favorable climatic conditions, increasing research advancements, growing market demand, and supportive policy initiatives. The tropical and subtropical regions of the Terai and inner valleys provide suitable thermal regimes for the growth of Nile tilapia, enabling its culture under a wide range of production systems (Gautam and Sapkota 2023). Studies conducted under local conditions have demonstrated that tilapia, when integrated into existing carp-based systems, significantly enhances pond productivity, with both monoculture and polyculture systems yielding higher outputs than traditional carp farming (Pandit et al. 2023).

Future development should prioritize the implementation of controlled aquaculture practices, with particular emphasis on the cultivation of monosex male populations to mitigate uncontrolled reproduction, reduce associated ecological risks, and facilitate the adaptation and optimization of established culture models derived from international contexts (Bhujel et al. 2025). The climatic diversity of Nepal offers a strategic advantage, as tilapia cannot survive below approximately 10°C for longer period and shows reduced reproductive activity at lower temperatures. This allows the design of region-specific production systems, where broodstock and seed production are concentrated in warmer Terai regions, while grow-out operations are conducted in cooler hill areas, minimizing the risk of escape and establishment in natural ecosystems.

Strengthening hatchery infrastructure is essential to support this expansion. Increased investment in both public and private hatcheries will ensure a consistent supply of high-quality monosex seed. Experiences from countries such as Bangladesh and Thailand highlight the importance of robust seed systems in scaling tilapia production (Belton et al. 2020). The future prospects of tilapia aquaculture in Nepal are promising, supported by government initiatives, increasing interest from international organizations such as WorldFish, and the emergence of collaborative programs aimed at strengthening research, commercialization, and sustainable production systems. With appropriate policy support, technical training, and biosecurity measures, tilapia aquaculture can become a sustainable and economically viable sector in Nepal.

CONCLUSION

Tilapia aquaculture in Nepal has emerged as a commercially important sector, driven by increasing research evidence, supportive policy initiatives, and growing adoption among fish farmers. The species has demonstrated strong adaptability and productivity under Nepalese agro-climatic conditions, particularly when cultured as monosex populations in both monoculture and polyculture systems. Advances in seed production, feeding strategies, and integrated farming approaches have significantly improved yield potential and economic returns. However, critical challenges remain, including limited availability of quality monosex seed, inadequate technical knowledge, weak extension services, and ecological concerns related to escape and establishment in natural water bodies. Addressing these constraints through strengthened hatchery systems, farmer training, and implementation of strict biosecurity measures is essential. With coordinated efforts in research, policy, and value chain development, tilapia aquaculture has significant potential to contribute to production intensification, product diversity, livelihood improvement, and long-term food and nutritional security in Nepal.

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EFFECT OF FEEDING FREQUENCY ON GROWTH AND PRODUCTION OF RED TILAPIA (*Oreochromis* spp.) IN A HAPA SYSTEM

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ABSTRACT

An experiment was conducted for 180 days at Fisheries Program, Agriculture and Forestry University, Rampur, to determine the effect of feeding frequency on growth and production of sex reversed male hybrid red tilapia (*Oreochromis niloticus* ♂ x *Oreochromis mossambicus* ♀). There were four treatments with three replications: i) feeding once daily - T₁, ii) feeding twice daily - T₂, iii) feeding once on alternate day - T₃, and iv) feeding twice on alternate day - T₄. Fries were stocked at a density of 4 fish/m² in 2 m² hapa fixed in concrete tanks. Fish were fed with 23.4% CP commercial floating pellet at the rate of 4%, 3% and 2% BW for first month, second month and for the remaining experimental period. Water quality parameters were monitored fortnightly. Final body weight, growth rate, gross yield, and net fish yield were significantly higher ($p < 0.05$) in fish fed daily (T₁ and T₂) than in those fed on alternate days (T₃ and T₄). Although apparent feed conversion ratio was higher in T₁ and T₂, indicating lower feed efficiency than alternate-day feeding, daily feeding produced greater overall yield and economic return. Therefore, daily feeding is recommended for maximizing the production and profitability of hybrid red tilapia culture.

Key words: Red tilapia, Feeding frequency, Growth performance, Feed conversion ratio, Profitability

INTRODUCTION

Tilapia is ranked second among fishes on global aquaculture production (FAO 2024). Red tilapia is the hybrid from cross between male Nile tilapia (*Oreochromis niloticus* ♂) and female Mozambique tilapia (*Oreochromis mossambicus* ♀). It has both food and ornamental value due to its red color. Due to its appealing color, improved marketability, and excellent salinity tolerance, red tilapia is quickly gaining popularity among growers. However, red tilapia is poorly studied and very limited information is available about their diet, habit, production and reproduction. In Nepal, tilapia farming has just begun and it has potential to establish as a major fish species. Nile tilapia was introduced in Nepal in 1985 (Shrestha 1994), its production expansion was hindered due to the fear of indigenous fish replacement by tilapia. After the government of Nepal has recently given approval for monosex tilapia culture, its scope for aquaculture has increased. It has tremendous scope for both semi-intensive and intensive farming due to its desirable characteristics for the growers.

Feed and feeding management are an important factor in aquaculture to minimize feed waste and water quality problems. Feeding frequency if done at optimum level can help in reducing overfeeding, the feed cost and also helps in maintaining the water quality (Huang et al. 2025). Therefore, it is very essential to create an effective feeding management strategy based on the

pattern of daily feeding or rhythms. (Wang et al. 1998). Identifying appropriate feeding frequency for red tilapia will help the resource poor farmers to reduce their feed cost and maximize their return. Determination of appropriate feeding frequency and culture practice will help to guide farmers for red tilapia culture. The objectives of the present study were to evaluate the effects of different feeding frequencies on the growth performance, feed utilization, and production of sex-reversed male hybrid red tilapia (*Oreochromis niloticus* ♂ × *Oreochromis mossambicus* ♀), and to determine the optimum feeding frequency for maximizing production and profitability.

MATERIALS AND METHODS

Experimental site

The experiment was carried out in 12 nylon hapas (2m x 1m x 1m) fixed in three cemented tanks (5m x 5m x 1.5m) at the Hatchery complex of Fisheries Program, Agriculture and Forestry University, Rampur, Chitwan. The experiment was conducted for 180 days, from 18 May to 19 November 2019.

Experimental design

The experiment was conducted using a randomized complete block design (RCBD) consisting of four feeding-frequency treatments with three replicates each. The treatments included feeding once daily (T_1), feeding twice daily (T_2), feeding once on alternate days (T_3), and feeding twice on alternate days (T_4). Each replicate consisted of a 2 m² hapa installed in a concrete tank, and fish were randomly allocated to the experimental units to minimize experimental bias. This design enabled the evaluation of the effects of different feeding frequencies on the growth performance, feed utilization, and production of sex-reversed male hybrid red tilapia.

Tank preparation

Three cemented tanks (5m x 5m x 1.5m) were cleaned before installing the hapa. Tanks were drained, sediments were removed and then left to dry for one day. Liming was done using agriculture lime at the rate of 500 kg/ha (Shrestha and Pandit 2007). After drying and cleaning, fresh water from underground boring was filled to the tank. After that, urea and DAP were applied at the rate of 4 g N/m²/day and 1 g P/m²/day (Knud-Hansen 1998). Tanks were cleaned two days before installing of hapa and stocking of fish. Four hapas consisting of four treatments were installed in each of three tanks. Hapas were installed in such a way that the bottom of hapa did not touch the bottom of tank. Hapas were tied on all sides to bamboo poles at the surface and to stones at the bottom corners so that they remained stretched in water column. Hapas were checked for any leaks before instalment and rectangular iron frames of the same size of hapa were kept inside of all the hapas to give them rigid shape inside the tank.

Stocking of fries

One-month old healthy all-male red tilapia fries were procured from Aquaculture farm of the Agriculture and Forestry University. Sex reversed male tilapia fries were obtained by feeding 17 α -MT for their sex reversal for 21 days prior to the experiment. Healthy male fries were stocked at the rate of 4 fish/m² (8 fish in each hapa). The initial mean weight of the fry was 1.63 $\pm$ 0.08, 1.69 $\pm$ 0.04, 1.63 $\pm$ 0.07 and 1.57 $\pm$ 0.04 g/fry in T_1 , T_2 , T_3 and T_4 , respectively. Stocking was done early at 8 am.

Feed and feeding

Fish were fed with floating pellet of 3 mm containing 23.4% CP from Machhapuchre Agro Product Company, Butwal, Nepal. Feeding was done at the rate of 4% of body weight for the first month followed by 3% of body weight for the second month and thereafter at the rate of 2% of the body

weight for the rest of experimental period. Feeding was done at 8 am and 4 pm in the treatments T₂ and T₄ while it was done at 8 am in the treatments T₁ and T₃.

Fertilization

Fertilization for the open pond area was done weekly in the beginning and later as per the need based on Secchi disk reading. Urea and DAP were used for fertilization. Fertilizer was applied at the rate of 4 g N/m²/day and 1 g P/m²/day.

Growth check and harvesting

All fish in each hapa were weighed monthly to check growth and adjust ration. Fish were harvested on 19 November 2019 by removing each hapa from the tank. The number of fish was counted, and the weight of each fish was taken. The fish production and related parameters were analyzed using the following equations:

$$\text{Daily weight gain (g/fish/day)} = \frac{\text{Average harvest weight (g)} - \text{Average stock weight (g)}}{\text{Culture period (days)}}$$

$$\text{Gross fish yield (t/ha/yr)} = \frac{(\text{Total harvest weight (g)}) * 365}{\text{Culture period (days)} * \text{Culture units (m}^2\text{)} * 100}$$

$$\text{Net fish yield (t/ha/yr)} = \frac{(\text{Total harvest weight (g)} - \text{Total stock weight (g)}) * 365}{\text{Culture period (days)} * \text{Culture units (m}^2\text{)} * 100}$$

$$\text{Survival rate (\%)} = \frac{\text{Total number of fish harvested}}{\text{Total number of fish stocked}} \times 100\%$$

$$\text{Apparent food conversion ratio (AFCR)} = \frac{\text{Quantity of feed fed (kg)}}{\text{Total weight gain (kg)}}$$

Water quality analysis

Water quality parameters such as temperature, dissolved oxygen and pH were recorded from each hapa weekly at 6 am using DO meter (DO-5519) and pH meter (pH-222) and transparency at 10 am using Secchi disk. Water samples for total ammonia nitrogen, soluble reactive phosphorus and chlorophyll-a analyses were collected from ponds fortnightly at 7 am by using a plastic column sampler and brought to the Fisheries Program laboratory for analysis. Total ammonia nitrogen and soluble reactive phosphorus was analyzed following APHA (2012) while chlorophyll-a was analyzed using spectrophotometer method (Boyd and Tucker 1992).

Proximate analysis of feed

Commercial pellet feed was used in the experiment. Crude protein, moisture, crude fiber, ether extract, total ash and nitrogen free extract were analyzed following procedures outlined in AOAC (1990).

Gross margin analysis

Gross margin analysis was used for the calculation of financial returns from each treatment (Upton 1964). The farm gate price for both stocked and harvested fish as well as the current local market price for the inputs were used for the gross margin analysis. The cost of each piece of sex-reversed male red tilapia fry was 1.00 NRs. Harvested red tilapia was sold at 300 NRs/kg. Feed, DAP, and urea was 55, 54, and 28 NRs/kg, respectively.

Gross margin (NRs) = Gross return (NRs) – Totalvariable costs (NRs)

Statistical analysis

Data were analyzed by one-way analysis of variance (ANOVA) using the SPSS software package (version 16.0; SPSS Inc., Chicago) as there was no block effect in the randomized complete block design. Duncan multiple range test was used to compare means. On percentage data, arcsine transformations were carried out. At the 95% confidence level, differences were deemed significant ($p < 0.05$). Standard error (S.E.) was provided for each mean.

RESULTS

Proximate analysis of feed

Proximate analysis of floating pellet feed used in the present experiment showed that it contained $89.1 \pm 0.8\%$ dry matter (DM), $23.4 \pm 0.5\%$ crude protein (CP), $0.7 \pm 0.1\%$ ether extract (EE), $11.9 \pm 1.0\%$ crude fiber (CF), $9.3 \pm 0.5\%$ total ash (TA) and $54.5 \pm 0.9\%$ nitrogen free extract (NFE) in dry weight basis (Table 1).

Table 1. Proximate composition of pellet feed used in the experiment.

Parameter	Sample 1	Sample 2	Sample 3	Mean $\pm$ SE
Dry matter (DM)	88.2	88.3	90.7	89.1 ± 0.8
Crude protein (CP)	24.4	23.5	22.5	23.4 ± 0.5
Ether extract (EE)	0.7	0.9	0.5	0.7 ± 0.1
Crude fiber (CF)	10.5	11.2	13.9	11.9 ± 1.0
Total ash (TA)	8.5	9.1	10.3	9.3 ± 0.5
Nitrogen free extract (NFE)*	55.7	55.2	52.6	54.5 ± 0.9

* NFE = $100 - (\text{CP} + \text{CF} + \text{EE} + \text{TA})$

Fish growth, survival and production

The stocking number, stocking weight, harvesting number, harvesting weight, daily weight gain, survival, gross and net fish yields of male red tilapia in the present experiment are presented in Table 2. The total harvesting weight of fish in T_1 and T_2 was significantly higher than in T_3 and T_4 ($p < 0.05$), whereas there was no significant difference between T_1 and T_2 , and between T_3 and T_4 ($p > 0.05$). The average harvesting weight of fish in T_1 and T_2 was significantly higher than in T_3 and T_4 ($p < 0.05$), whereas there was no significant difference between T_1 and T_2 , and between T_3 and T_4 ($p > 0.05$). The daily weight gain in T_1 and T_2 was significantly higher than in T_3 and T_4 ($p < 0.05$), whereas there was no significant difference between T_1 and T_2 , between T_3 and T_4 ($p > 0.05$). The total weight gain in T_1 and T_2 was significantly higher than in T_3 and T_4 ($p < 0.05$), whereas there was no significant difference between T_1 and T_2 , between T_3 and T_4 ($p > 0.05$). The gross yield in T_1 and T_2 was significantly higher than in T_3 and T_4 ($p < 0.05$), whereas there was no significant difference between T_1 and T_2 , between T_3 and T_4 ($p > 0.05$). The net fish yield in T_1 and T_2 was significantly higher than in T_3 and T_4 ($p < 0.05$), whereas there was no significant difference between T_1 and T_2 ,

between T₃ and T₄ ($P>0.05$). The AFCR was significantly lower in T₃ and T₄ than in T₁ and T₂ ($p<0.05$), whereas there was no significant difference between T₁ and T₂, and between T₃ and T₄ ($p>0.05$).

Table 2. Summary of growth performance (Mean $\pm$ SE) of hybrid all-male red tilapia in different treatments during the experimental period of 180 days.

Parameters	Treatments			
	T ₁	T ₂	T ₃	T ₄
Stocking				
Stocking number (no./2 m ²)	8.0 $\pm$ 0.00 ^a	8.0 $\pm$ 0.00 ^a	8.0 $\pm$ 0.00 ^a	8.0 $\pm$ 0.00 ^a
Initial total weight (g/2 m ²)	13.00 $\pm$ 0.60 ^a	13.50 $\pm$ 0.31 ^a	13.07 $\pm$ 0.52 ^a	12.57 $\pm$ 0.32 ^a
Initial mean weight (g/fish)	1.63 $\pm$ 0.08 ^a	1.69 $\pm$ 0.04 ^a	1.63 $\pm$ 0.07 ^a	1.57 $\pm$ 0.04 ^a
Harvesting				
Harvesting number (no./2 m ²)	7.33 $\pm$ 0.33 ^a	8.00 $\pm$ 0.00 ^a	8.00 $\pm$ 0.00 ^a	7.67 $\pm$ 0.33 ^a
Final total weight (g/2 m ²)	1443.33 $\pm$ 52.7 ^a	1459.33 $\pm$ 44.8 ^a	1082.67 $\pm$ 73.5 ^b	1041.33 $\pm$ 42.6 ^b
Final mean weight (g/2 m ²)	197.08 $\pm$ 5.19 ^a	182.42 $\pm$ 5.60 ^a	135.33 $\pm$ 9.18 ^b	136.23 $\pm$ 6.89 ^b
Total weight gain (kg/2 m ²)	1.44 $\pm$ 0.05 ^a	1.46 $\pm$ 0.04 ^a	1.08 $\pm$ 0.07 ^b	1.04 $\pm$ 0.04 ^b
DWG (g/fish/day)	1.09 $\pm$ 0.03 ^a	1.00 $\pm$ 0.03 ^a	0.74 $\pm$ 0.05 ^b	0.74 $\pm$ 0.04 ^b
Survival (%)	91.67 $\pm$ 4.17 ^a	100 $\pm$ 0.00 ^a	100 $\pm$ 0.00 ^a	95.83 $\pm$ 4.17 ^a
Gross fish yield (t/ha/cycle)	7.22 $\pm$ 0.26 ^a	7.30 $\pm$ 0.22 ^a	5.41 $\pm$ 0.37 ^b	5.21 $\pm$ 0.21 ^b
Net fish yield (t/ha/cycle)	7.21 $\pm$ 0.26 ^a	7.29 $\pm$ 0.22 ^a	5.41 $\pm$ 0.37 ^b	5.20 $\pm$ 0.21 ^b
AFCR	0.95 $\pm$ 0.11 ^a	1.01 $\pm$ 0.10 ^a	0.52 $\pm$ 0.06 ^b	0.56 $\pm$ 0.07 ^b

Mean ($\pm$ SE) values with different superscripts in the same row are significantly different ($p<0.05$). T₁ = Feeding once daily; T₂ = Feeding twice daily; T₃ = Feeding once on alternate day time; T₄ = Feeding twice on alternate day; AFCR = Apparent feed conversion ratio.

Water quality

Weekly and fortnightly analyzed mean and range of water quality parameters in different treatments during the experimental period are given in Table 3 and 4. Most water quality parameters were within the acceptable range of tilapia growth. There was no significant difference in all water quality parameters among treatments ($p>0.05$).

Table 3. Water quality parameters in different treatments (Mean $\pm$ SE). Values in the parenthesis indicate the average.

Parameters	Treatments			
	T ₁	T ₂	T ₃	T ₄
Temperature (°C)	29.6 $\pm$ 0.0 (23.8-33.6)	29.6 $\pm$ 0.0 (23.8-33.8)	29.6 $\pm$ 0.0 (23.8-33.9)	29.5 $\pm$ 0.0 (23.8-33.7)
Dissolved oxygen (mg/L)	7.2 $\pm$ 0.0 (5.7-10.9)	7.4 $\pm$ 0.0 (5.9-11.1)	7.5 $\pm$ 0.0 (6.0-11.2)	7.3 $\pm$ 0.0 (5.8-10.97)
pH	7.7 (7.2-8.9)	7.7 (7.1-8.9)	7.7 (7.2-8.9)	7.7 (7.1-9.0)
Secchi disk depth (cm)	61.5 $\pm$ 4.5 (52.3-72.6)	61.3 $\pm$ 4.5 (52.3-72.6)	61.6 $\pm$ 4.5 (52.3-72.6)	61.1 $\pm$ 4.7 (52.3-72.6)

T₁ = Feeding once daily; T₂ = Feeding twice daily; T₃ = Feeding once on alternate day time; T₄ = Feeding twice on alternate day.

Table 4. Water quality parameters in three ponds (Mean±SD).

Parameters	Mean and Range		
	Pond-1	Pond-2	Pond-3
Chlorophyll-a (µg/L)	49.05±9.75 (26.73-89.82)	49.85±7.09 (24.59-69.5)	38.18±4.61 (27.26-61.48)
Total ammonium nitrogen (NH ₃ -N, mg/L)	0.05±0.00 (0.04-0.07)	0.06±0.01 (0.02-0.09)	0.06±0.01 (0.03-0.98)
Soluble reactive phosphorous (PO ₄ -P, mg/L)	0.07±0.05 (0.00-0.41)	0.08±0.04 (0.00-0.32)	0.12±0.06 (0.01-0.47)

Gross margin analysis

Seed, feed, fertilizer, hapa, total variable cost, income from fish sale, gross margin, B:C ratio and cost per kilogram production of male red tilapia in the different treatments are presented in Table 5. Values of seed, feed, fertilizer, hapa, total variable cost, income from fish sale, gross margin were extrapolated to hectare (NRs/ha/180 days). Feed cost was significantly higher in T₁ and T₂ than in T₃ and T₄ (p<0.05), whereas there was no significant difference between T₁ and T₂, and between T₃ and T₄ (p>0.05). The total variable costs in T₁ and T₂ was significantly higher than in T₃ and T₄ (p<0.05), whereas there was no significant difference between T₁ and T₂, and between T₃ and T₄ (p>0.05). The gross income was significantly higher in T₁ and T₂ than in T₃ and T₄ (p<0.05; Table 5), whereas there was no significant difference between T₁ and T₂, and between T₃ and T₄ (p>0.05). The cost of fish production per kilogram were NRs 170, 175, 153 and 160 in T₁, T₂, T₃ and T₄, respectively however, the cost of fish production did not vary among treatments (p>0.05).

Table 5. Comparative gross margin analysis of hybrid red tilapia culture under different feeding frequency treatments (NRs thousand/ha for a 180-day culture period).

Parameters	Treatments			
	T ₁	T ₂	T ₃	T ₄
Variable costs				
Seed	40±0 ^a	40±0 ^a	40±0 ^a	40±0 ^a
Feed	693±101 ^a	742±84 ^a	285±45 ^b	294±47 ^b
Fertilizer	1±0 ^a	1±0 ^a	1±0 ^a	1±0 ^a
Hapa and other materials	500±0 ^a	500±0 ^a	500±0 ^a	500±0 ^a
Total variable cost	1234±101 ^a	1283±84 ^a	826±44 ^b	835±47 ^b
Return				
Gross income	2165±79 ^a	2189±67 ^a	1624±110 ^b	1562±64 ^b
Gross margin	931±40 ^a	906±68 ^a	798±92 ^a	727±36 ^a
B/C ratio	1.75±0.08 ^a	1.70±0.08 ^a	1.96±0.11 ^a	1.88±0.06 ^a
Fish production cost (NRs/kg)	170±9 ^a	175±7 ^a	153±6 ^a	160±5 ^a

Mean (±SE) values with different superscript in the same row are significantly different (p<0.05). T₁ = Feeding once daily; T₂ = Feeding twice daily; T₃ = Feeding once on alternate day time; T₄ = Feeding twice on alternate day.

DISCUSSION

Growth and yield

The research showed that daily feeding treatments T₁ and T₂ were significantly better than alternate day feeding treatments T₃ and T₄ based on daily weight gain, average harvest size, total weight gain, gross yield and net fish yield. The daily weight gain was 47% and 35% higher in T₁ and T₂,

respectively than T_3 and T_4 . This might be due to lower feed intake under alternate-day feeding as compared to daily feeding. The food intake probably could not provide sufficient nutrients required for growth in alternate day feeding because it was found that there was a favorable relationship between feed consumption and fish growth (Riche et al. 2004). Further, higher frequency of feeding might promote faster growth and size uniformity while reducing aggressive behavior (Zhou et al. 2003; Emranul 2009). Lower weight gain and growth rate in alternate day feeding might be due to the fact that fish fed on alternate days mobilized the energy stored to prolong its survival period than on weight gain (Yang et al. 2019). Previous studies on Arctic char (*Salvelinus alpinus*) and Gurami sago (*Osphronemus goramy*) also showed that increasing the feeding frequency per day enhanced growth (Jobling 1983; Azrita et al. 2020). The average harvest size of red tilapia in T_1 and T_2 was also significantly higher than T_3 and T_4 ($p < 0.05$). The average harvest size in T_1 was 45% higher than T_3 and 44% higher than T_4 . Similarly, average harvest size of T_2 was 34% higher than T_3 and T_4 . The total weight gain of red tilapia in T_1 and T_2 was significantly higher than T_3 and T_4 ($p < 0.05$). Feeding red tilapia on alternate days caused a significant decline in growth compared to daily feeding, which can be attributed to insufficient diet. The gross fish yields in T_1 , T_2 , T_3 and T_4 during the 180 days culture period were 7.22, 7.30, 5.41 and 5.21 t/ha/180 days, respectively. This means that assuming two production cycles per year, the yield would be 14.44, 14.60, 10.82 and 10.42 t/ha/y T_1 , T_2 , T_3 and T_4 , respectively. Gross fish yield was found significantly higher in T_1 and T_2 ($p < 0.05$) than T_3 and T_4 . The fish yield in the current study was higher compared to the 5.57 t/ha/y average fish productivity in Nepal (Gautam and Sapkota 2023).

The apparent feed conversion ratio in T_1 and T_2 was significantly higher than T_3 and T_4 ($p < 0.05$) which suggests better AFCR in feeding on alternate day treatments. According to Wang et al. (2006) when fish don't have enough food, their basic metabolism decreases. As a result, a significant part of the food they eat is used for growing their tissues rather than for basic bodily functions. This could explain why the alternate-day feeding method, as observed by Limbu and Jumanne (2014), led to better conversion of feed into energy. The findings of the present study align with the observations made by Ali et al. (2003), who reported that Nile tilapia can tolerate fasting well. They noted that during the re-feeding period, tilapia exhibited rapid growth rates and improved feed conversion ratios. This could be attributed to heightened activities of protease, lipase, and amylase, particularly during the re-feeding phase. Additionally, before fasting, the enzyme activity progressively returns to normal levels, stimulating hunger, food intake, olfaction, and visual perception, as mentioned by Zheng et al. (2015). The survival rate of red tilapia was higher in all treatments and were 92, 100, 100 and 96% in T_1 , T_2 , T_3 and T_4 , respectively. Diana et al. (1994) and Bolivar et al. (2006) reported that pond fertilization enhanced natural food to contribute significantly to tilapia growth and survival. This might be the reason survival and growth in tilapia fed on alternate days was not adversely affected.

Water quality

Water quality parameters remained comparable among the four feeding treatments throughout the experimental period, indicating that differences in feeding frequency did not adversely affect the pond environment. Dissolved oxygen concentrations ranged from 5.7 mg/L in T_1 (feeding once daily) to 11.5 mg/L in T_3 (feeding once on alternate days), remaining well above the minimum level of 1 mg/L recommended for tilapia culture (Boyd 2004). Similarly, pH values (7.1-9.8) and water temperatures (23-34 °C) were within the acceptable ranges for Nile tilapia as reported by DeWalle et al. (2011), although temperatures occasionally exceeded the optimum range of 25-27 °C. The absence of significant differences in water quality among treatments suggests that reducing feeding frequency, including alternate-day feeding, did not impair pond water quality. Consequently, the

observed differences in growth performance and feed utilization were most likely attributable to the feeding strategies rather than environmental variation.

Gross margin

All cost estimation was based on local market prices for fingerlings, fertilizers and feed. Feed cost was significantly higher in daily feeding treatments than in alternate day feeding treatments due to high feed intake by fish in daily feeding treatments. The feed cost in daily feeding significantly increased with increased weight gain in T_1 and T_2 because ration was adjusted monthly based on body weight. The significant difference in total variable cost between daily feeding and alternate day feeding was due to the difference in feed quantity and associated feed cost between daily feeding and alternate day feeding. The gross income in T_1 and T_2 was significantly higher than in T_3 and T_4 corresponding to higher fish production. Although there was higher gross income in daily feeding treatments than alternate day feeding treatments there was no significant difference between once and twice daily feeding treatments due to the same feed cost between treatments. The gross margins were NRs 931000, 906000, 798000 and 727000 in T_1 , T_2 , T_3 and T_4 , respectively but did not differ among treatments ($p>0.05$).

CONCLUSION

The present study demonstrated that daily feeding resulted in superior growth performance, production, and gross returns of all-male red tilapia cultured in a hapa-based system compared with alternate-day feeding. Although daily feeding requires more time and labor, feeding once daily offers a practical balance between production performance and operational efficiency. Therefore, once-daily feeding may be recommended as an appropriate feeding strategy for all-male red tilapia production in hapa systems, particularly where reducing labor inputs is an important consideration.

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QUALITY ENHANCEMENT AND SHELF-LIFE EXTENSION OF SOLAR-DRIED MRIGAL (*Cirrhinus mrigala*) THROUGH NATURAL PRESERVATIVES

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ABSTRACT

This study examined the effects of natural preservatives on the nutritional composition, microbial load, and sensory qualities of sun dried *Cirrhinus mrigala* stored at room temperature for 30 days during May to August 2024 at Chitwan. Thirty fish per group (average weight 30.01 g) were treated with salt (20%), turmeric (1%), moringa (3%), and neem (5%) before solar drying. Proximate composition, pH, bacterial counts (CFU/g), and defect-based sensory scores were measured at designated intervals. Solar drying required 72-96 hours at 45.5-77.4 °C, with stable pH across treatments. Turmeric-treated fish exhibited the lowest moisture content ($18.41 \pm 0.47\%$), while salt-treated samples had the highest value ($23.59 \pm 2.07\%$). Salt treatment reduced protein and fat. Turmeric treatment preserved protein ($66.97 \pm 0.34\%$) and fat ($7.66 \pm 0.18\%$). Neem and moringa demonstrated potent antimicrobial effects, yielding the lowest bacterial counts on day-30. Sensory evaluation ranked salt and turmeric the best for acceptability, though neem and moringa remained within the tolerable limits. The findings indicated that neem and moringa are highly effective for microbial control, turmeric for nutrients conservation, and salt for enhanced flavor despite affecting protein and fat. Therefore, it is concluded that rational use of these natural preservatives in solar drying can improve the safety and postharvest losses in *C. mrigala*.

Keywords: Solar drying, Natural preservatives, Microbial quality, Sensory evaluation

INTRODUCTION

Fish is an important source of high-quality protein, essential fatty acids (omega-3 fatty acid), and essential micronutrients like Vitamin D, Vitamin B12, iodine, and selenium (Noreen et al. 2025), making it vital for maintaining overall health. However, it is highly perishable due to rapid enzymatic breakdown, microbial growth, and lipid oxidation after harvest (Nie et al. 2022). Therefore, several techniques have been practiced to preserve fish to increase their shelf life and to maintain their quality, safety, texture, flavor, and nutritional value. Chilling, freezing, drying, salting, smoking, pickling, and canning are the common methods of preservation, with selection depending on fish species, storage requirements, processing, cost, and consumer demand (Ghaly et al. 2010).

Sun-drying is a traditional method of fish preservation common in south-east Asian countries. There are many problems associated with this method such as space availability, labor-intensive, contamination with dust, insect infestation, and predation by birds, animals and rodents. High moisture, insect infestations, and microbial contaminations are among the disadvantages that traditional methods of sun-drying have, resulting in an approximate loss of 20% in developing countries (Banna et al. 2022). The tropical climates increase the difficulties of sun-drying due to potential higher losses (about 30%) of the products in humid environments (Singh et al. 2018). Fat oxidation during storage can cause significant flesh degradation (up to 25%), compromising product value. Hence, solar dryer machines are the alternative for open-air sun drying. Solar drying is an

improved method of sun-drying which consists of closed-system minimizing some of the limitations of open sun-drying.

Preserved fish are preferentially used by different communities and are also culturally and religiously important (Kalita et al. 2020). Preserved fish are nutritionally rich, and they provide good quality protein compared to fresh fish (Thapa 2016). Because of their longer shelf-life and rich nutritional content with protein, healthy fats, minerals and vitamins, the preserved fish products like Budu (Malaysia), Patis (Philippines), Nam-pla (Thailand), and Nepal's Sukako machha and Sukuti are very important in diet (Bogard et al. 2015; Thapa 2016). Due to limitations in terms of aquaculture and transportation of fish, the traditional processes of fish preservation such as fermentation, salting, sun-drying and smoking have been effective protein sources in hilly regions of Nepal (Gautam and Sapkota 2023). Some traditionally preserved fish in Nepal include Gunchi (smoked fish), Sukako machha (sun-dried fish), Sidra, and Sukuti (Thapa 2016). The sun drying and smoking methods are used widely on *Tor putitora*, *Schizothorax* sp., *Bagarius* sp., and *Neolissocheilus hexagonolepis* (Pradhan et al. 2017). Despite having the largest shares of production in aquaculture, there is a lack of traditional methods for preserving indigenous major carps rohu (*Labeo rohita*), catla (*L. catla*), and mrigal (*C. mrigala*) presenting opportunities for value addition.

The fishery industry is always looking for noble preservation methods to extend the shelf life of fish (Rey et al. 2012). In this context, growing awareness of the potential negative effects of chemical preservatives had prompted the food industry to find natural alternatives. Therefore, use of natural preservatives could be instrumental for maintaining the quality of the product. Microbiome derived preservatives (e.g., bacteriocin) and plant derived preservatives (e.g., turmeric, pepper, ajwain, and chili powder) have promising antimicrobial and antioxidative effects for use as natural preservatives (Jahan et al. 2019). Curcumin found in turmeric, phenolic components in moringa, and azadirachtin contained in neem are capable of preventing the growth of microorganisms and keeping insects away (Haryanti et al. 2024).

Nevertheless, there is insufficient research on the use of these natural preservatives for the solar-drying of mrigal in Nepal. The objective of this study was to investigate whether the combined application of natural treatments (salt, turmeric, moringa leaf powder, and neem leaf powder) and solar drying could improve the quality and safety of dried mrigal.

MATERIALS AND METHODS

Experimental setup

This study was conducted in the Fisheries Laboratory of the Agriculture and Forestry University, Rampur, Chitwan, Nepal, over a 100-day period from 25 May to 31 August 2024.

Fresh *Cirrhinus mrigala* were purchased from the Hira Matsya Hatchery, Tandil, Chitwan. Approximately 200 active fish (20-30 g size) were caught early in the morning, packed in polyethylene bags with one-third water and two-third of oxygen, and transported to the Laboratory. The fishes were acclimatized using pond water for 15 minutes before being washed to remove the debris and slime from body; then, euthanized, eviscerated, washed, and graded according to size (20-30 g). The fishes were weighed before and after gutting and finally cut longitudinally and divided into following five treatments (n = 30 per group):

Treatment 1 (Control; T₁): Fish without any pre-treatment.

Treatment 2 (T₂): Fish pre-treated with a 20% (w/v) common salt solution

Treatment 3 (T₃): Fish pre-treated with 1% (w/w) turmeric (*Curcuma longa*) powder.

Treatment 4 (T₄): Fish pre-treated with 3% (w/w) moringa (*Moringa oleifera*) leaf powder.

Treatment 5 (T₅): Fish pre-treated with 5% (w/w) neem (*Azadirachta indica*) leaf powder.

Treatments T₂ - T₅ involved dipping fish in respective preservative solutions/powders for 20 minutes, followed by 30 minutes drainage. Fish (purchased in three lots as replicates) were graded uniformly, then transferred to solar dryer racks. Temperature was recorded thrice daily (9:00 am, 12:00 pm, 3:00 pm) until drying completion; fin brittleness (by light pressing) and weight loss were monitored. After drying, fish samples from each treatment were sealed in airtight polyethylene bags and stored under ambient laboratory conditions (room temperature) for 30 days to evaluate changes in quality and shelf stability. The samples were then brought to the laboratory for chemical and microbiological analysis.

Chemical analysis of fish sample

The pH and proximate composition of the fish in each treatment group were determined soon after drying in the beginning (Day 0) and after 30 days of preservation at the room temperature in polyethylene bags to compare the changes in chemical properties of pre-treated fish during storage.

pH analysis

Fish sample for each treatment was minced separately using mortar and pestle. The mince flesh was homogenized in distilled water (ratio 1:10) and pH value was determined by using digital pH meter (Mahmoud et al. 2004). The value was converted to H⁺ concentration, average, and then reconverted to pH value.

Proximate composition analysis

Proximate composition (moisture, ash, crude protein, and lipid) of fish muscle was analyzed at Day 0 and Day 30 following AOAC methods (Jena et al. 2018; Latimer 2023). Briefly, moisture content was determined by oven-drying 1 g homogenized muscle at 120 °C for 3 hours. Ash content was measured by incinerating dried samples at 600 °C for 6 hours. Protein was estimated via Kjeldahl method: digestion in H₂SO₄ with catalyst (350 - 400 °C), distillation with NaOH, absorption in boric acid, and titration with 0.1 N HCl; protein was calculated as N × 6.25. Lipid was extracted using Soxhlet apparatus with petroleum ether, solvent removed by rotary evaporator, and residue weighed. All analyses performed in triplicate.

Microbial analysis

Microbial analysis was performed on days 0, 15, and 30 of storage. Total plate count was assessed using the decimal dilution and pour plate method (Alikunhi et al. 2017). Fish mince (1 g) was homogenized in 9 mL of 0.1% sterile peptone water (10⁻¹ dilution) at 500 rpm for 10 min, followed by serial dilution to 10⁻⁶ with vortex mixing. Plate count agar (28 g/L, pH 7.0) was autoclaved at 121 °C for 15 min, cooled to 45-50 °C, and poured with 1 mL of each dilution in duplicate. Plates were incubated at 30 °C for 72 h; colonies between 10-300 were counted, and bacterial population was calculated.

Sensory evaluation

Sensory evaluation was conducted after 30 days of storage using the Quality Index Method (QIM) to assess organoleptic characteristics (color, odor, texture, flavor, insect infestation, general appearance, and overall acceptability) (Jaman et al. 2021). Untrained general consumer evaluated samples on a 1-5 defect scale. Average defect score was calculated as:

Average defect score = Total defect points/ Number of characteristics

Quality grades were assigned as:

Grade A (excellent/highly acceptable): Average defect score <2,

Grade B (good/acceptable): Average defect score 2 to <4,

Grade C (rejected): Average defect score ≥ 4

Statistical analysis

Data were analyzed using SPSS version 27.0 (IBM Inc., New York, USA). All data were tested for homogeneity and presented as mean $\pm$ standard error of the mean (SEM). One-way ANOVA or Kruskal-Wallis non-parametric test compared microbial loads between treatments at each time point (Day 0, 15 and 30), followed by Tukey's or Stepwise Step-down post-hoc tests. Friedman test (non-parametric repeated-measures ANOVA) evaluated temporal variations within treatments. One-way ANOVA or appropriate non-parametric tests were conducted for flesh composition, pH, and sensory data. Multiple comparisons were performed with suitable post-hoc tests. Figures were prepared using Microsoft Excel and Statistical significance was set at $p < 0.05$.

RESULTS

Drying temperature and biomass during storage

Drying parameters and their effects on the weight reduction of *C. mrigala* across three experimental lots, is shown in Table 1. Drying temperatures were similar for lots 1 and 2, both maintained for 72 h. Lot 3 experienced a wider and lower-starting temperature (45.5-75.5 °C) but was subjected to a prolonged drying duration of 96 hours. Despite minor variations in initial weights, the final weights decreased substantially, with lot 3 yielding the lowest mean final weight. In contrast, lots 1 and 2, dried for a shorter period, showed slightly higher final weights.

Table 1. Drying temperature, drying duration, and initial and final weights of *Cirrhinus mrigala* in different lots (mean $\pm$ SE; n = 10).

Lot	Drying temp. (°C)	Drying hours (h)	Initial weight (g)	Final weight (g)	Weight loss (%)
1	58.7–77.4	72	27.66 $\pm$ 1.44	5.79 $\pm$ 0.29	79.06 $\pm$ 0.63
2	61.3–76.5	72	27.64 $\pm$ 1.64	5.62 $\pm$ 0.30	79.68 $\pm$ 0.95
3	45.5–75.5	96	27.72 $\pm$ 1.93	5.52 $\pm$ 0.68	80.07 $\pm$ 0.90

Repeated measures ANOVA revealed a significant main effect of storage time on biomass ($F_{2, 40} = 5157.57$; $p < 0.001$, partial $\eta^2 = 0.996$) and a significant time $\times$ treatment interaction ($F_{8, 49} = 9.73$; $p < 0.001$, partial $\eta^2 = 0.661$). However, no significant main effect of treatment was observed ($F_{4, 20} = 0.638$; $p = 0.642$, partial $\eta^2 = 0.113$). Post-hoc analysis showed biomass increased significantly from Day 0 to Day 15 ($p < 0.05$) and Day 15 to Day 30 ($p < 0.05$) across all treatments (Figure 1). The salt-treated group consistently showed higher biomass values, though differences were not statistically significant.

pH analysis

Initial pH values ranged from 6.3 (5% neem leaf) to 6.5 (control) with non-significant differences among treatments ($p = 0.68$). After 30 days, slight decreases were observed across all treatments: control (6.5 to 6.4; $p = 0.06$), 20% salt (6.3 to 6.3; $p = 0.42$), 1% turmeric (6.4 to 6.3; $p = 0.18$), 3% moringa leaf (6.4 to 6.2; $p = 0.34$), and 5% neem leaf (6.3 to 6.3; $p = 0.76$), none of which were significant (Table 2). One-way ANOVA at Day 30 confirmed non-significant differences among treatments ($p = 0.89$).

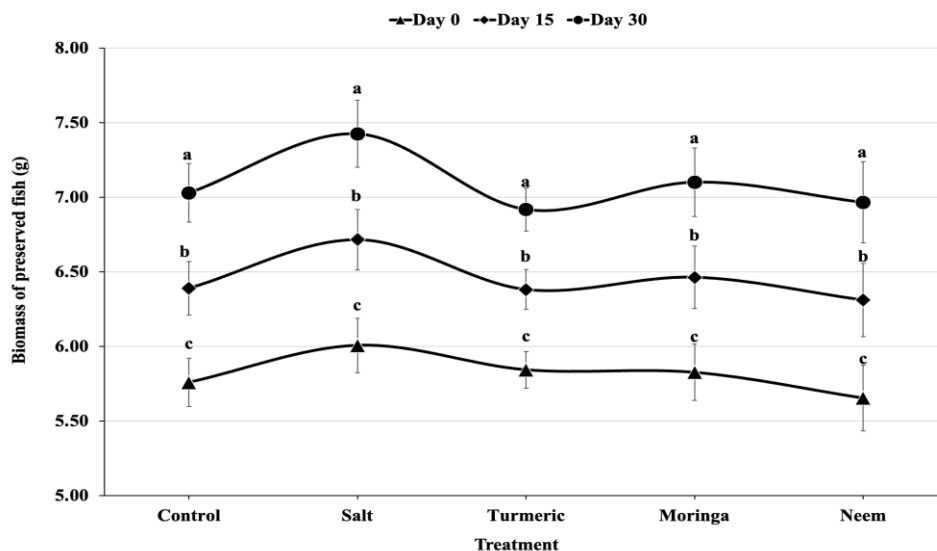


Figure 1: Weight changes of pre-treated dried mrigal (*Cirrhinus mrigala*) during the storage period under different storage conditions.

Table 2. The pH values of pretreated solar-dried *Cirrhinus mrigala* samples at the beginning and end of the storage period (Day 0 and Day 30).

Treatment	Day 0	Day 30
Control	6.5	6.4
20 % Salt	6.3	6.3
1 % Turmeric	6.4	6.3
3 % Moringa powder	6.4	6.3
5 % Neem leaf powder	6.3	6.3

Proximate composition

Significant differences were observed in percentage of protein, fat, and ash content among treatments ($p < 0.05$), but moisture showed non-significant variation ($p > 0.05$; Table 3).

Table 3. Muscle composition of pre-treated solar dried *C. mrigala* after 30 days of storage.

Treatment	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Control	22.05±2.05	67.32±2.03 ^a	6.81±0.14 ^b	3.85±0.21 ^d
20% Salt	23.59±2.07	45.02±0.74 ^b	1.60±0.04 ^d	29.81±1.85 ^a
1% Turmeric	18.41±0.47	66.97±0.34 ^a	7.66±0.18 ^a	6.98±0.4 ^c
3% Moringa	21.89±0.72	65.09±0.58 ^a	5.11±0.26 ^c	7.93±0.41 ^c
5% Neem	23.22±2.88	60.71±2.9 ^a	5.44±0.28 ^c	10.64±0.7 ^b
p-value	>0.05	<0.05	<0.05	<0.05

Different superscript letters within columns indicate significant differences between treatments at $p < 0.05$.

The muscle composition of pre-treated solar-dried *C. mrigala* following a 30-day storage period, revealing significant treatment-specific effects on nutritional quality is presented in Table 3. The moisture content across all samples ranged from 18.41% to 23.59%, with no significant differences among treatments, indicating that the drying and storage process consistently achieved a stable product regardless of the pre-treatment applied. In contrast, protein, fat, and ash contents were significantly influenced by the pre-treatment ($p < 0.05$). The control group retained the highest crude protein level (67.32%), closely followed by turmeric-treated (66.97%) and moringa-treated (65.09%) samples, while salt-treated fish exhibited a marked reduction in protein (45.02%), likely due to leaching or denaturation. Fat content was highest in the turmeric-treated group (7.66%) and lowest in salt-treated samples (1.60%), suggesting a protective antioxidant effect of turmeric against lipid oxidation, whereas salt might have promoted fat loss. Ash content, reflecting mineral retention, was exceptionally high in salt-treated fish (29.81%), attributable to salt absorption, with neem-treated samples (10.64%) also showing elevated ash levels compared to control (3.85%).

Microbial evaluation

Kruskal-Wallis test revealed significant differences in microbial loads among treatments at all time points: Day 0 ($\chi^2 = 25.03$; $p < 0.001$), Day 15 ($\chi^2 = 26.03$; $p < 0.001$), and Day 30 ($\chi^2 = 25.59$; $p < 0.001$; Table 4).

Table 4. Microbial load ($\times 10^3$ CFU/g) of solar dried *Cirrhinus mrigala* at day 0, 15, and 30.

Treatments	Day 0	Day 15	Day 30	p-value
	($\times 10^3$ CFU/g)			
Control	1.91 $\pm$ 0.004 ^{aZ}	2.63 $\pm$ 0.007 ^{aY}	3.89 $\pm$ 0.09 ^{aX}	<0.05
20% Salt	1.80 $\pm$ 0.008 ^{bZ}	2.18 $\pm$ 0.03 ^{bY}	2.46 $\pm$ 0.007 ^{dX}	<0.05
1% Turmeric	1.84 $\pm$ 0.06 ^{aZ}	2.38 $\pm$ 0.09 ^{bY}	3.42 $\pm$ 0.10 ^{bX}	<0.05
3% Moringa	1.53 $\pm$ 0.01 ^{cZ}	1.90 $\pm$ 0.006 ^{cY}	2.97 $\pm$ 0.02 ^{cX}	<0.05
5% Neem	0.94 $\pm$ 0.007 ^{dZ}	1.53 $\pm$ 0.04 ^{dY}	1.91 $\pm$ 0.006 ^{eX}	<0.05
p-value	<0.05	<0.05	<0.05	

Different lowercase superscripts within columns indicate significant differences between treatments at that time point; different uppercase superscripts within rows indicate significant differences within treatments across time ($p < 0.05$).

The microbial load, expressed as colony-forming units per gram ($\times 10^3$ CFU/g), in solar-dried *C. mrigala* over a 30-day storage period under various treatment conditions is presented in Table 4. At the Day 0, the control group exhibited the highest microbial count (1.91×10^3 CFU/g), which was statistically comparable to the 1% turmeric treatment (1.84×10^3 CFU/g). In contrast, all other treatments, 20% salt, 3% moringa, and 5% neem, showed significantly lower initial loads, with the neem-treated sample displaying the most pronounced reduction (0.94×10^3 CFU/g). Over the storage duration, a consistent and significant upward trend in microbial proliferation was observed across all treatments. By Day 30, the control group showed the highest bacterial count (3.89×10^3 CFU/g), while the 5% neem treatment remained the most effective in curbing microbial growth, with the lowest count (1.91×10^3 CFU/g). Notably, the 20% salt treatment also demonstrated strong preservative efficacy, maintaining counts substantially lower than the control and turmeric-treated samples throughout the storage period.

Sensory evaluation

Sensory evaluation revealed significant differences in organoleptic characteristics among treatments (Table 5). Control and salt treatments achieved Grade A (Highly acceptable) with defect scores of 1.61 and 1.66, respectively. Control showed whitish-shiny appearance and natural odor, while salt caused slight off-white to yellowish discoloration but maintained natural flavor. In natural preservatives treatments turmeric (defect score: 2.09), moringa (2.38), and neem (2.46) all achieved Grade B (Acceptable). Color alterations (yellowish-brown to brownish reddish) and bland or bitter flavors reduced consumer acceptability. No insect infestation was observed in any treatment. Brittle texture was consistent across all treatments, indicating uniform drying.

Table 5. Organoleptic characteristics and defect scores of solar-dried *Cirrhinus mrigala* after 30 days of storage.

Treatment	Color	Odor	Texture	Flavor	Insect infestation	General appearance	Taste	Overall acceptability	Defect score	Grade	Grade characteristics
Control	Whitish and shiny	Natural dried fishy	Brittle near to broken	Natural and slight salty	No infestation	Excellent	Moderately desirable	Highly acceptable	1.61 ^c	A	Highly acceptable
20% Salt	Off white to yellowish	Natural dried fishy	Brittle near to broken	Natural and slight salty	No infestation	Good	Moderately desirable	Highly acceptable	1.66 ^{bc}	A	Highly acceptable
1% Turmeric	Shining yellowish to brownish	Bland	Brittle near to broken	Slight to moderate	No infestation	Good	Moderately desirable	Slight to moderate acceptable	2.09 ^{ab}	B	Acceptable
3% Moringa	Brownish outer reddish in inner	Bland	Brittle near to broken	Slight to moderate flavor	No infestation	Good	Medium	Slight to moderate acceptable	2.38 ^a	B	Acceptable
5% Neem	Brownish outer reddish in inner	Natural dried fishy	Brittle near to broken	Slight to moderate	No infestation	Good	Medium	Slight to moderate acceptable	2.46 ^a	B	Acceptable

Different superscript letters in defect score column indicate significant differences between treatments at $p < 0.05$.

DISCUSSION

Mrigal is an important species of carps and locally known as Chhadi if raised in smaller sizes and sold as whole fish. According to Gupta et al. (2019), fish in the size range 31-50 g are the most preferred (51.4% of total production), followed by 50-100 g (35.3%), and 20-30 g (13.3%). The selection of about 30 g body weight in the present study agrees with Pradhan et al. (2018), who stated 20-100 g body weight as optimum for producing mrigal and their drying. Small sized fish are preferred since they are easily dried and marketed besides consuming less energy for drying process (Azizah et al. 2022).

Drying temperature and efficiency

Fish were dried for 72-96 hours, with longer drying time in the third lot as a result of low temperature and poor solar radiation. According to Obayopo and Alonge (2018), the performance of solar dryer is optimal during dry seasons with high solar radiation. Relative humidity plays a crucial role, as low humidity facilitates moisture migration while high humidity prolongs drying (Kituu et al. 2010).

Solar dryer gave the highest temperature of 77.4 °C, giving 80% weight reduction, which is 7% more than the 64 °C and 73% weight reduction obtained by Pradhan et al. (2020). This showed that high temperature increases the efficiency of removing moisture. Nevertheless, fluctuations in temperature

when the day was cloudy led to an increased drying period, calling for hybrid drying systems which utilize other energy sources (Regupathi and Balasubramanian 2018).

Biomass changes during storage

Repeating measures ANOVA showed a significant increase in biomass over time (partial $\eta^2 = 0.996$), with salt-treated group giving the highest values. This increase was likely caused by moisture accumulation from the surroundings due to poor sealing of the packing bags. The hygroscopic property of salt makes it hold moisture, as shown by Jahan et al. (2019) who reported that salt forms water complex with fish proteins. Moisture content in salt-treated fish (23.59%) was nearly the same as the 24.78% found by Imtiaz et al. (2017) in salt-dried ribbon fish.

According to Nooralabettu (2008), salted dried fish having moisture less than 25% could have extended shelf life. Fish samples treated with turmeric had low moisture (18.41%) due to hydrophobic nature of turmeric (Nath et al. 2021). Fish samples treated with neem and moringa had more moisture due to hydrophilic substances (Paramita et al. 2024; Pereira-Rojas et al. 2025). High-quality dried fish must have moisture below 20% for having shelf life of 9-10 months (Nath et al. 2021), indicating the need for further improvement in drying and packaging processes.

pH stability

The initial (6.3-6.5) and final (6.2-6.4) pH values remained within the acceptable range (6.0-6.9), indicating that the dried fish maintained good quality throughout the storage period (Nasreen and Abdulrahm 2021). Slight and non-significant decrease over 30 days agreed with Haryanti et al. (2024) who described the pH range of dried fish in their study. This is because pH is decreased due to hydrolysis of glycogen and accumulation of lactic acid in response to metabolic switch from aerobic to anaerobic metabolism (Chandra et al. 2020). Almost constant pH in all treatments confirmed that natural preservatives contributed towards pH stability. Further, low pH prevented bacterial growth (Gill & Gill 2005), in line with the data on microbial counts showing lower number of bacteria in those treatments where pH was decreased (moringa and neem). The pH range remained between 6.0-6.4 for dried mrigal (Pradhan et al. 2018), implying that solar drying with the use of natural preservatives can result in quality equal to the commercial products.

Proximate composition

The protein content usually increases in dried fishes because of protein nitrogen preservation as well as protein coagulation owing to drying (Kim et al. 2020). However, salted fish had significantly low protein content (45.0%) as compared to other treatments (60.7-67.3%) owing to the denaturation of proteins induced by salt (Kumar et al. 2017). The herbal treatments maintained the protein content close to control, implying the applicability of such preservatives to preserve the nutritional value of the product. The highest ash content (29.8%) was observed for salted fish because of the salt absorption, which is also confirmed by El-Bassir et al. (2015) who found 27.4% ash in salted sun-dried *Bagrus bayad*. The herbal treatments possessed higher ash content (neem: 10.6%, moringa: 7.9%, turmeric: 6.98%) as compared to the control (3.85%) because of the high mineral contents (calcium, magnesium, potassium, phosphorus) in such preservatives (Kumar et al. 2017; Penalver et al. 2022). However, the fat content was found to be low compared to the control (6.81%), with the lowest level seen in salt treatment (1.60%). Salt induced osmotic dehydration leading to removal of water along with lipids (Sinha and Khare 2014). Turmeric treated fishes had the maximum fat content (7.66%), as turmeric contains 2-4% essential oil and 2-3% fixed oil in it (Kumari et al. 2022). Neem and moringa might have helped reduce fat content because of their antimicrobial and antioxidant properties (Karim et al. 2018; Kumawat et al. 2020).

Microbial quality

No sample exceeded the acceptable limit of 10^6 CFU/g (Nahid et al. 2016). Control samples kept without preservative treatment exhibited the highest microbial load, increasing from 1.91×10^3 to 3.89×10^3 CFU/g after 30 days. This highlighted the need of using preservatives. Treated samples showed lower microbial counts, which indicates the efficacy of natural preservatives. The bacterial counts obtained (0.94×10^3 to 3.89×10^3 CFU/g) are mid-range compared with previous reports: lower than that of dried *C. mrigala* bought from the market (150×10^3 to $12,000 \times 10^3$ CFU/g; Pradhan et al. 2018), but higher than solar dried controlled samples (2.2×10^2 to 5.0×10^2 CFU/g; Pradhan et al. 2020). This disparity likely reflected differences in processing hygiene, environmental conditions, and storage practices.

Salt provides an unsuitable environment for bacterial growth because of the reduction in water activity (Nuwanthi et al. 2016). Phytochemicals (phenolic compounds, flavonoids) found in herbal preservatives have known antibacterial properties (Haryanti et al. 2024). The curcumin found in turmeric causes a marked reduction in bacterial load (Nath et al. 2021). Phenolic compounds in moringa prevent the growth of *S. aureus*, *E. coli*, and *Listeria monocytogenes* (Martinez Perez et al. 2024). Azadirachtin, nimbin, and nimbidin from neem are highly efficient in reducing the microbial load (Kumawat et al. 2020).

Sensory evaluation

Control (defect score of 1.61; Grade A) and salt-treatment (defect score of 1.66; Grade A) had extremely high acceptability as control had whitish-shiny appearance and natural odor while salt produced slight off-white to yellowish discoloration due to salt crystals deposition (Lestari et al. 2022).

Herbal treatments had relatively high defect scores; turmeric (defect score of 2.09; Grade B), moringa (defect score of 2.38; Grade B), and neem (defect score of 2.46; Grade B). Discoloration (yellowish-brown to brownish reddish) and bland odor led to low consumer acceptability. This was consistent with Haryanti et al. (2024) where turmeric and neem negatively affected sensory quality resulting in dark color and bitter taste, respectively. The bland odor of turmeric indicates that solar drying degrades volatile compounds. All treatments were effective in preventing insect infestation and similar brittle texture across all treatments indicated even drying and lower moisture content. However, natural preservatives affected organoleptic properties because the bitterness and earthy off flavor of neem and moringa (Ilesanmi and Gungula 2011) reduced flavor ratings and acceptability.

The salt was found to be the best preservative because it maintained both the process of preservation and sensory value, as it is traditionally used in fish preservation processes (Nahid et al. 2016). The turmeric could be considered the second-best treatment if the consumer is ready to accept any changes that may occur visually. Although the moringa and neem have good preservative properties, they need to undergo formulation modification.

CONCLUSION

The findings of the present study demonstrate that natural pre-treatments combined with solar drying can effectively enhance the quality, safety, and shelf-life of dried *C. mrigala* during storage. All pre-treatment methods maintained the physicochemical quality of the product within acceptable limits, indicating their suitability for fish preservation. Among the treatments, turmeric showed superior performance in preserving the nutritional quality of the dried fish, while neem exhibited the strongest antimicrobial activity. Salt treatment remained effective in controlling microbial growth and produced a highly acceptable product from a sensory perspective. Although the herbal treatments

resulted in slightly lower sensory acceptability than the control and salt-treated samples, they successfully maintained product quality and ensured microbial safety throughout the storage period. In overall, the results suggest that natural plant-based preservatives (turmeric and neem) represent promising alternatives to conventional preservation methods for improving the quality and safety of solar-dried fish. Further studies evaluating longer storage periods and optimizing treatment concentrations are recommended to facilitate their wider application in sustainable fish processing.

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EFFECTS OF 17 β -ESTRADIOL ON OXYGEN CONSUMPTION OF BLUEGILL SUNFISH (*Lepomis macrochirus*)

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ABSTRACT

Fish habitats are increasingly contaminated with estrogenic compounds, including 17 β -estradiol (E_2). E_2 causes adverse effects on the reproductive system of male fish; however, its effects on fish metabolism are less known. The objective of this study was to evaluate the effects of E_2 exposure on the basal and stressed metabolic rates in Bluegill sunfish (*Lepomis macrochirus*). In total, 45 Bluegill sunfish were included in the study in three cycles with 15 fish in each cycle. Fish were held individually in ten gallon tanks under two treatments with varying estradiol concentrations (40 and 80 ng/L) and one control group (no E_2). The duration of E_2 exposure was 21 days. Basal and maximum aerobic scopes were measured using a closed respirometer before and at the end of the exposure. The results showed that females had 19% higher basal metabolic rates than males before exposure but there were no significant differences after exposure, indicating convergence of basal metabolism among the male and female fish. For maximum metabolism, no significant differences were found between female and male fish both before and after exposure. In summary, the comparison between groups showed that sex was a significant predictor of difference in oxygen consumption during basal metabolism before exposure but there was no such difference between control, T_1 (40 ng/L) and T_2 (80 ng/L) treatments.

Key words: Aerobic scope, Bluegill sunfish, Estradiol, Metabolism, Oxygen consumption

INTRODUCTION

Various chemical substances found in natural waterways are deteriorating the water quality of rivers, lakes, and ponds, thereby making them increasingly less habitable to aquatic life (Shore and Shemesh 2003; Wright-Walters and Volz 2009). One of the several pollutant types found in surface waters that is of growing concern is estrogenic compounds (Kolpin et al. 2002; Shore and Shemesh 2003; Cargouet et al. 2004). There are several forms of estrogenic compounds that include estrone (E_1), 17 β estradiol (E_2), estriol (E_3), and 17 α ethinylestradiol (EE_2). Among them, E_2 is the most abundant in natural habitats and has the potential to cause negative effects on the fish reproductive system even at lower concentrations of 1 ng/L (Wright-Walters and Volz 2009). These compounds are found in contraceptives and other therapeutics that are commonly used to treat reproductive system pathologies, such as endometriosis (Wright-Walters and Volz 2009; Vandenberg et al. 2012). These compounds enter waterways via widespread human therapeutics use and excretion.

Another source of estrogenic compounds is intensive livestock production where it is used as a growth promoter in cattle feed (Adeel et al. 2017). As in humans, E_2 compounds are excreted in the livestock feces and urine (Kolpin et al. 2002; Jones-Lepp et al. 2009). Though processing at wastewater treatment facilities reduces the load of these compounds (Heffron et al. 2016), substantial amounts remain in effluents after processing enter the surface water system (Pessoa et al. 2014; Belhaj et al. 2015). The estrogenic compounds are found in different concentrations in the water effluents depending upon the site, ranging from 1 ng/L to 80 ng/L (Wright-Walters and Volz

2009), with 1-10 ng/L detected frequently (Bradley et al. 2009). At the wastewater treatment facility located in Charleston, IL, where this study is being conducted, an average of 3.6 ng/L (range 0 to 25.3 ng/L) of estrogenic compounds were detected after processing (Heffron et al. 2016).

Several studies found that E₂ compounds cause negative effects on the reproductive system of fish due to their endocrine disrupting properties (Olivereau and Olivereau 1979; Miles-Richardson et al. 1999; Brian et al. 2007; Wang et al. 2008). The most notable effects of E₂ are their ability to cause both sex reversal in male fish and feminization (Vajda et al. 2011; Tamschick et al. 2016). E₂ also causes reduced gonadosomatic index, which is the proportion of gonadal tissues compared to their total body weight in male fish and erosion of sexual dimorphic characters in exposed males (Pickering 1993; Brian et al. 2007). The adverse effects of E₂ on fish are not limited to male fish. In female fish, E₂ causes reduced fecundity and decreased reproductive performance (Olivereau and Olivereau 1979; Miles-Richardson et al. 1999). This indicates that the long-term exposure of fish species to E₂ is likely to alter the population structure of fish species, which will have serious consequences to fish biodiversity (Moyle and Leidy 1992). Though the effects of E₂ and other estrogenic compounds on the reproductive system of fish are well known, their effects on metabolic rate in fish are poorly understood. The physiological defense against E₂ requires energy redirection which can alter metabolic demands.

The metabolic rate in fish is estimated by measuring oxygen consumption in two physiological states: resting and exhausted conditions (Auer et al. 2015). Oxygen consumption during resting conditions measures basal or standard metabolic rate, which is the minimum amount of oxygen required to maintain life (MO_{2min}), while the maximum oxygen that a fish can consume under given temperature and ecological condition is used to measure maximum metabolic rate (MO_{2max}) (Norin and Malte 2011; Norin and Clark 2016). The metabolic rate in fish is increased when fish are subjected to stress.

We hypothesized that the exposure of fish to E₂ causes significant stress, which will lead to higher oxygen consumption. During stress, cortisol hormone will be secreted in the blood stream, which results in increased oxygen demand for osmoregulation and increased metabolism. To test this hypothesis, the objective of this study is to evaluate how E₂, a common environmental estrogen, alters the basal and stressed metabolic rate of Bluegill Sunfish. Experiment was designed with control group and two groups, exposed with E₂ at 40 ng/L and 80 ng/L concentrations.

MATERIALS AND METHODS

Experimental animals

Bluegill sunfish (*Lepomis macrochirus*) was selected as a model species because they are common in Illinois, USA and are easily found in the local streams, ponds, and lakes, and have commercial value as a sports fish. Moreover, they are more likely to be affected if surface water sources get contaminated due to their large local population, high site fidelity and wide availability. Sexually mature Bluegill sunfish were collected from the local impoundments near Charleston by electrofishing in early June to conduct the first cycle of an exposure experiment. The length of fish varied from 146 to 230 mm, while the weight varied from 47 to 203 g. The fish were collected in July and September for the second and third cycle of experiment, respectively. They were transported in well-aerated open buckets to the fish laboratory at EIU and acclimated in the tanks for a minimum of 10 days before dosing began. The sex of the fish was not identified a priori.

Experimental design and exposure protocol

A protocol to conduct this study was approved by the Eastern Illinois University (EIU) Institutional Animal Care and Use Committee (IACUC Protocol# 15-004). This study was conducted from May through December 2016 in three different experimental cycles with each cycle lasting 21 days. Experiments took place under controlled conditions in the fish laboratory at Eastern Illinois University, USA. A mesocosm experiment was conducted with fifteen 10-gallon tanks in each cycle to mimic the best possible natural environment for fish. The temperature of mesocosm was maintained at 21 ± 1 °C. Fish were fed soy-free pellet food daily. Light cycles were maintained at 12:12 hour (day: night). Tank water was replenished using deionized water to ensure no contamination with estrogen, and buffering salts were added to 1 ppt. Filtration was present, but carbon cartridges were removed to avoid E_2 sequestration. Water quality parameters, namely salinity, nitrates, nitrites, ammonia, and pH were regularly monitored. Salinity was kept at <1 ppt, pH was kept between 7.0 to 7.5, and nitrates, nitrites, and ammonia were kept at zero. The tanks were inspected daily to examine fish condition. A protocol to conduct this study was approved by Institutional Animal Care and Use Committees (IACUC Protocol approval number 15-004).

There were two treatment groups and one control group. Among the treatment groups, one group was exposed to 40 ng/L of E_2 (T_1) and another group was exposed to 80 ng/L of E_2 (T_2). These concentrations were chosen based on the highest concentration of E_2 detected in local wastewater effluents (Heffron et al. 2016). In each group, there were five fish and each of them was kept individually in a 10-gallon tank. The total sample size was 45 fish, with 15 fish in each experiment cycle. Experiments were run in three different cycles which lasted 21 days. Fish were exposed to E_2 by adding the premixed E_2 to the water in tanks to achieve 40 ng/L and 80 ng/L concentrations. A sham treatment of just water was delivered in the control tanks. The E_2 was replenished every week based on its half-life to maintain the desired concentration of E_2 throughout the experiment by replacing two-thirds of the water in the tank. Fish were gently and humanely handled to minimize pain and discomfort during the experiment.

Fish were fasted for 24 hours before measuring oxygen consumption to avoid any artifacts caused by digestive metabolism. The transportation of fish from the tanks to the experiment laboratory was performed gently and carefully to minimize handling stress. Weight and length of the fish were measured before placing the fish in a 3.9 L glass respirometry chamber. The chamber was fitted with an optical oxygen probe and sealed with a rubber stopper and parafilm to measure oxygen consumption. Water temperature in the respirometer chamber was measured and maintained at 21 ± 1 °C. To measure the oxygen consumption during resting (or basal metabolism), the fish was acclimatized for one hour in the chamber with the lid open before starting the trial. Fish were individually stocked and handled during the process. After acclimatization, the lid was sealed and a YSI ProODO optical oxygen probe was inserted (Figure 1). Trials lasted 30 minutes and the oxygen partial pressures were always above 75%. To measure the oxygen consumption under stressed conditions (or maximum metabolism), a chase protocol was followed. The fish were chased for five minutes intensively with a net to exhaust the fish (Ferguson et al. 1993). After that, the fish were immediately placed in the respirometry chamber to measure the oxygen consumption following the same procedure as in basal metabolism.



Figure 1: Experimental apparatus for measuring oxygen consumption in fish using a closed respirometer chamber (jar where fish is) fitted with an optical oxygen probe (horizontal object in front of the fish).

The oxygen consumption rate was calculated as a difference in dissolved oxygen concentration over time, taking into account the weight of the fish and the volume of the chamber, using the following formula:

$$MO_2 = \frac{(DO \text{ initial} - DO \text{ final}) * V}{(T * W)}, \text{ where,}$$

MO_2 is the mass corrected oxygen consumption rate ($\text{mg O}_2/\text{kg/h}$),

DO initial is the concentration of dissolved oxygen in the chamber at the beginning of measurement in $\text{mg O}_2/\text{L}$,

DO final is the concentration of dissolved oxygen in the chamber at the end of measurement in $\text{mg O}_2/\text{L}$,

V is the volume of respirometer chamber in liters,

T is the total time elapsed in hours, and

W is the weight of fish in kilograms.

Statistical analysis

First, descriptive statistics (mean and standard deviation) were calculated to evaluate the oxygen consumption pattern before and after E_2 exposure during different physiological stages (basal and maximum) and across sex. The variables considered were basal metabolic rate before exposure (basal before), basal metabolic rate after exposure (basal after), maximum metabolic rate before exposure (maximum before) and maximum metabolic rate after exposure (maximum after). The normality and homogeneity of variance of these four variables were tested by conducting Shapiro-Wilk W tests and Levene's tests, respectively. An independent sample t-test was used to compare the oxygen consumption rate between male and female separately for the four variables mentioned above. Paired t-tests were used to compare the before and after oxygen consumption for those four variables separately for male and female fish. Finally, two-way ANOVA tests were performed to compare the oxygen consumption rate between two treatment groups and control group accounting for sex for all those four variables. Post-hoc tests were conducted if there was a significant result in the ANOVA tests.

RESULTS

The effects of E_2 exposure by groups, namely control, lower E_2 exposure (T_1) and higher E_2 exposure (T_2) showed that the oxygen consumption was higher in female fish across all groups and physiological stages, but the magnitude of the difference was higher during basal metabolism compared to maximum metabolism (Figure 2). Sex was found as a significant predictor of differences in the oxygen consumption during basal metabolism before exposure but there was no such significant difference between control, T_1 and T_2 groups.

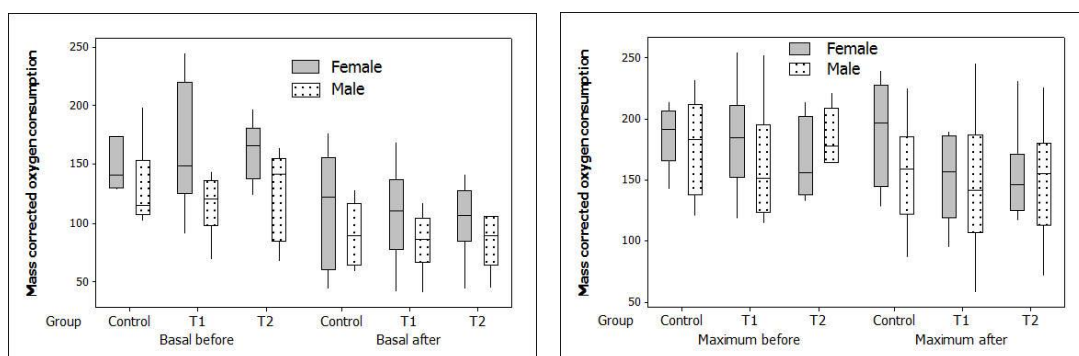


Figure 2: A Left: Oxygen consumption (mg O₂/kg/h) during basal metabolism before and after exposure in male and female fish in control and treatment groups. B. Right: Oxygen consumption (mg O₂/kg/h) during maximum metabolism before and after E_2 exposure in male and female fish in control ($N = 15$) and treatment groups. T_1 ($N = 15$) indicates treatment group 1 (40 ng/L E_2) and T_2 ($N = 15$) indicates treatment group 2 (80 ng/L E_2).

Distribution of oxygen consumption pattern during basal and maximum metabolism before and after exposure is shown in Figure 3. This shows visual representation of the differences in the basal and maximum metabolism before and after exposure but whether metabolism between male and female actually differs was tested using the t-tests. The comparisons between average oxygen consumption in all females and all male fish before exposure indicated that the basal metabolism in female fish was higher by 19% compared to male fish, which was statistically significant ($p < 0.05$). However, there was no such difference between female and male fish in the oxygen consumption after exposure ($p > 0.05$). For maximum metabolism, no significant differences were found between female and male fish both before and after exposure. When all treatments were combined in two groups based on sex, we found that basal and maximum metabolism decreased by 42% in males and 20% in females after exposure.

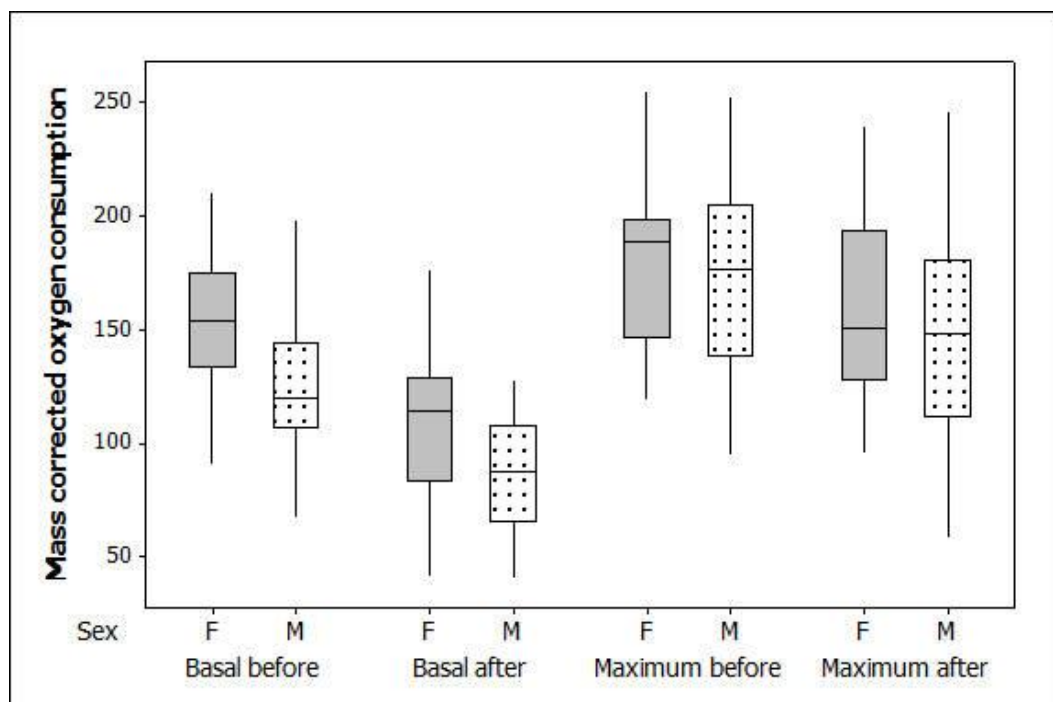


Figure 3: Oxygen consumption ($\text{mg O}_2/\text{kg/h}$) during basal metabolism before and after exposure in male ($N = 17$) and female fish ($N = 26$) in control and treatment groups.

Among all male fish, the average oxygen consumption during basal metabolism before and after E_2 exposure was $128.5 \text{ mg O}_2/\text{kg/h}$ (95% confidence interval, CI: $112.5 - 144.5 \text{ mg O}_2/\text{kg/h}$) and $93.2 \text{ mg O}_2/\text{kg/h}$ (95% CI: $77.5 - 108.9 \text{ mg O}_2/\text{kg/h}$), respectively (Table 1). There was a decrease in oxygen consumption by 27% ($p = 0.0006$). The oxygen consumption in male fish during maximum metabolism before and after exposure also decreased by 13% ($172.7 \text{ mg O}_2/\text{kg/h}$, 95% CI: $156.3 - 189.1 \text{ mg O}_2/\text{kg/h}$ versus $149.3 \text{ mg O}_2/\text{kg/h}$, 95% CI: $129.5 - 169.1 \text{ mg O}_2/\text{kg/h}$) ($p = 0.005$).

The average oxygen consumption among all female fish during basal metabolism before E_2 exposure was $158.6 \text{ mg O}_2/\text{kg/h}$ (95% (CI): $139.7 - 177.5 \text{ mg O}_2/\text{kg/h}$; Table 1). However, the average oxygen consumption among all female fish during basal metabolism after E_2 exposure was only $106.9 \text{ mg O}_2/\text{kg/h}$ (95% CI: $86.5 - 127.4 \text{ mg O}_2/\text{kg/h}$, Table 1), indicating 32% decrease in the average oxygen consumption after E_2 exposure. The difference in the oxygen consumption during basal metabolism among females before and after E_2 exposure was statistically significant ($p = 0.0004$). Though there was a significant drop in oxygen consumption during resting stage before and after exposure, no such difference was found for the maximum metabolism in female fish ($p = 0.24$). The average oxygen consumption during maximum metabolism among female fish before and after E_2 exposure was $178.9 \text{ mg O}_2/\text{kg/h}$ (95% CI: $160.8 - 197.0 \text{ mg O}_2/\text{kg/h}$) and $163.2 \text{ mg O}_2/\text{kg/h}$ (95% CI: $141.9 - 184.6 \text{ mg O}_2/\text{kg/h}$), respectively.

Table 1. Descriptive results of oxygen consumption in overall female and male Bluegill Sunfish.

Variable	N	Mean	SD	Q1	Q3	Minimum	Maximum
Female							
Basal before	17	158.6	36.8	136.6	174.0	90.5	245.4
Maximum before	17	178.9	35.3	150.9	198.9	118.8	255.8
Basal after	17	106.9	39.8	89.4	125.7	41.7	177.3
Maximum after	17	163.2	41.5	128.4	190.6	94.8	239.7
Male							
Basal before	26	128.5	39.6	107.3	143.4	67.4	229.9
Maximum before	26	172.7	40.6	138.9	204.5	94.3	252.5
Basal after	26	93.2	38.9	65.6	106.2	40.6	213.6
Maximum after	26	149.3	49.0	113.3	180.1	58.0	246.0

Unit = mg O₂/kg/h; N = Sample size; SD = Standard deviation; Q1 = First quartile; Q3 = Third quartile

DISCUSSION

This study evaluated the role of 17 β estradiol (E₂) on the oxygen consumption during basal and maximum metabolism in Bluegill Sunfish by continuously exposing them for 21 days at two ecologically relevant E₂ concentrations. We found that male and female fish are differently affected by E₂ exposure. The influence of E₂ exposure was also more pronounced on the basal metabolic rate compared to maximum metabolism.

The basal metabolic rate in female fish before exposure was higher than their male counterparts but there was no significant difference after E₂ exposure. This finding suggested that after the E₂ exposure, there was a gradual convergence between male and female fish resulting in similar oxygen basal consumption irrespective of their sex. 17 β estradiol exposure caused male dimorphic characters to change in Bluegill by becoming less prevalent. Specifically, caudal peduncle was bar, smaller nape protrusion, reduced opercular flap and pectoral fin, and a deeper body in the exposed groups compared with control fish under both concentrations (Karki et al. 2021). Several studies have shown that E₂ leads to feminization in male fish (Blázquez et al. 1998; Gorshkov et al. 2004; Filby et al. 2012; Heffron et al. 2016).

In this study, both the basal and maximum metabolism decreased after E₂ exposure. This finding was contrary to our hypothesis, as we had expected that E₂ would cause stress to the fish, which generally leads to increased oxygen consumption. Stress causes elevated cortisol levels in fish, which in turn results in increased oxygen consumption (Barton 2002; Jentoft et al. 2005). For example, higher cortisol levels and subsequently higher oxygen consumption were recorded in juvenile Steelhead (*Salmo gairdners*) after physical stress (Barton and Iwama 1991). Likewise, higher cortisol levels and increased oxygen consumption were found in subordinate fish compared to dominant aggressive fish in Brown trout (*Salmo trutta*) due to social stress (Sloman et al. 2001). The contrast findings in this study may indicate that the exposure duration of 21 days at the chosen concentration might not be sufficient to exert enough stress in fish to cause increased oxygen consumption. As cortisol level was not measured, stress level in fish could not be measured, which is recommended for future studies.

In this study, we did not find significant changes in the maximum metabolic rate and aerobic scope before and after exposure. This indicates that basal metabolism is more sensitive to the effects of E₂ exposure. Previous studies evaluating effects of the environmental contamination of E₂ compounds on fish focused mostly on the reproductive system of fish. Very few studies have so far evaluated the

effects of E₂ exposure on metabolic rates. The findings from this study provided additional evidence that E₂ is capable of affecting metabolic rates, primarily basal rate. As metabolic activity in fish is directly related to fish growth and reproduction, it can impact the health of fish populations. Additionally, the affected fish might be more prone to predation due to stunted growth. As this study was conducted in a mesocosm controlling several factors, such as water quality parameters, it would be interesting to evaluate how E₂ is impacting populations in natural settings.

In summary, we evaluated the effects of E₂ exposure on the basal and stressed metabolic rate in Bluegill Sunfish. The result indicated that after the E₂ exposure the basal metabolic rate in male and female fish became similar while it differed between sexes before the E₂ exposure. This indicates the convergence of male and female fish due to E₂ exposure. As metabolism of fish is affected, additional effects on other aspects of fish may be observed, such as growth and reproduction, due to shift in the energetic costs. This finding suggests that the effect of environmental contamination of E₂ on fish might be beyond the reproductive system and needs further investigation with larger sample sizes. The close monitoring of E₂ levels in natural water systems and stricter guidelines for E₂ removal in wastewater treatment plants may help curb the negative effects of E₂ compounds on fish and other aquatic fauna.

CONCLUSION

The findings of the present study demonstrate that exposure to 17β-estradiol (E₂) can alter energy metabolism in Bluegill sunfish. The sex-specific difference in basal metabolic rate observed prior to exposure was no longer evident following E₂ exposure, indicating a convergence of metabolic phenotypes between males and females. Such metabolic reorganization may have important ecological consequences because changes in energy expenditure can alter the allocation of resources among maintenance, growth, reproduction, and other physiological functions. These results therefore suggest that the biological impacts of environmentally relevant estrogenic contamination may be broader and more complex than reproductive disruption alone. Further studies with larger sample sizes are needed to clarify the underlying mechanisms and ecological significance of these metabolic changes. Given the widespread occurrence of endocrine-active contaminants in aquatic environments, monitoring E₂ contamination and improving its removal from wastewater are essential to minimize potential risks to aquatic ecosystems.

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PRODUCTION ECONOMICS AND PROFITABILITY ASSESSMENT OF CARP POLYCULTURE IN SUNSARI DISTRICT OF NEPAL: A COBB-DOUGLAS PRODUCTION FUNCTION AND SENSITIVITY APPROACH

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ABSTRACT

Carp polyculture has considerable potential to enhance rural livelihoods in Nepal by improving fish production and farm income. However, its economic efficiency, production performance, and profitability remain inadequately assessed. This study aimed to assess the production economics of carp polyculture in Sunsari district using field survey data and a Cobb- Douglas production function model. Cross-sectional survey of 60 fish farmers was conducted across four municipalities of Sunsari district between January and June 2025. Data were analyzed using descriptive statistics and economic performance indicators. Results revealed that gross revenue obtained from carp polyculture farming was NRs 1,578,157.64 per hectare, with net revenue of NRs 669,802.01, and a benefit-cost ratio of 1.74. Feed, fingerlings, and labor costs accounted for the largest share of variable costs. The Cobb-Douglas production function analysis showed that feed cost had significant negative effects on carp polyculture production. Sensitivity analysis showed that the sharpest profitability decline was observed under a 30% fall in fish price combined with a 5% increase in production. These findings highlight the viability of carp polyculture farming in the study area and underscore the need for technical support, input quality improvements, and policy interventions to enhance the sustainability and scalability of aquaculture in Nepal.

Keywords: Benefit-cost ratio, Carp polyculture, Cobb-Douglas, Sensitivity analysis, Nepal

INTRODUCTION

Aquaculture represents one of the fastest-expanding sectors on a global scale. It is estimated to account for 47% of the total global fish production (Khanal et al. 2020). The FAO reported that in 2022, world capture fisheries and aquaculture production reached 223.2 million tons with aquaculture contributing 130.9 million tons of which 94.4 million tons were fish (FAO 2024). The global demand of food fish is predicted to increase by 23 million by 2030 because of population growth and increased awareness of nutrition and healthy eating (Yazew et al. 2020). This trend presents significant opportunities for the expansion of fish farming worldwide (Rosiane et al. 2020). Fish farming represents a rapidly expanding sector within aquaculture, particularly in Nepal. A significant variety of fish species are cultivated globally. Nepal has a diverse variety of fish with more than 200 species recorded, among which around 190 are indigenous species, and the remaining are exotic (Shrestha et al. 2019). Among them, carps are the most recognized and widely cultivated freshwater fish species (Veerina et al. 1999). Nepal's pond aquaculture exhibits significant aquatic biodiversity, primarily featuring various carp species (Kunwar and Adhikari 2016/17). The 2023 Fishery statistics report indicates that Nepal's pond area covered 14,745 hectares, yielding 92,736 tons of fish in FY 2022/23, accounting for 81.5% of the total national production (MoALD 2025). The Terai region accounted for more than fifty percent of this output. Sunsari district, located in Koshi Province, is notable among Terai districts, featuring 11,047 fish ponds that span 2,019

hectares and yield approximately 9,919 tons of fish, resulting in a productivity rate of 4.91 t/ha (MoALD 2025).

Previous economic studies in Nepal have shown that aquaculture can yield considerable profits, however returns vary significantly depending on location, inputs, intensity, management practices, and market conditions. Sharma et al. (2018) reported that fish production in Chitwan district was highly profitable, with feed representing a substantial production cost. Poudel and Pandit (2020) found that the efficiency of resource utilization and net revenue of carp polyculture in Morang district were highly influenced by input management and variations in farm scale. Magar et al. (2022) emphasized the significance of farm characteristics, production costs, and farmer decision-making in influencing fish enterprise performance. Moreover, Neupane et al. (2024) revealed diversity in net revenue and socio-economic situations among fish farmers in Bara, Nepal. Together, these studies demonstrate that fish farming in Nepal can yield attractive returns, but profitability is highly sensitive to cost structure and local production factors. However, comprehensive studies on the economic analysis of carp polyculture have not been conducted in Sunsari district.

In aquaculture economics, production and profitability relationships have frequently been assessed using regression-based approaches, including Cobb-Douglas production functions. Veerina et al. (1999) in India and Siddiqa (2018) in Bangladesh showed that capital investment, input use, and management costs can significantly influence aquaculture returns. However, such type of study is still limited in Nepal, especially regarding carp polyculture systems at the district level. Despite the growing role fish farming in Nepal, there is little district-level information on the economics of carp polyculture. This study aims to fill that gap by analyzing economic performance, applying Cobb-Douglas regression, and conducting sensitivity analysis for carp polyculture farming in Sunsari district of Nepal.

METHODOLOGY

Study area

The study was conducted in Sunsari district of Nepal, which lies at a latitude of 26°38'29.76" N and a longitude of 87°07'44.76" E. Based on the potential for fish production, the study area was purposively selected, followed by the random selection of 60 respondents from four municipalities, i.e., Barahakshetra, Ramdhuni, Inaruwa and Duhabi municipalities. Data were collected from January 2025 to June 2025 using a structured questionnaire survey.

Economic analysis

All cost and return variables were standardized on a per-hectare basis by dividing each farmer's annual cost and return by the pond area used for carp production.

Total cost

Total cost was calculated as the sum of total variable cost and total fixed cost incurred in fish farming.

Total Cost (TC) = Total variable cost (TVC) + Total fixed cost (TFC)

Gross revenue and gross margin

Gross revenue was calculated by multiplying the quantity of fish produced (kg) by the average price of fish (NRs). The average farm-gate price of fish was NRs 305.77/kg.

Gross revenue = Quantity of fish produced x Average price of fish (NRs/kg)

Similarly, gross margin was calculated as the difference between gross revenue and total variable costs, following the method described by Olukosi et al. (2006), as follows:

Gross margin (NRs/ha) = Gross revenue (NRs/ha) – Total variable cost (NRs/ha)

Net revenue

Net revenue represents the profit remaining after deducting total costs from gross revenue.

Net revenue (NRs) = Gross revenue (NRs) - Total cost (NRs)

Benefit cost ratio (BCR)

It is a quantitative or qualitative representation of the relationship between a project's relative costs and benefits. A project must have a positive net present value for the company and its investors if its BCR is greater than 1.0. The BCR was calculated using the following formula:

BCR = Gross revenue (NRs)/ Total cost (NRs)

Cobb-Douglas production function

Cobb-Douglas production function model was used to identify how different input costs influence the total carp production from carp farming in Sunsari district of Nepal. This model enables the estimation of the contribution of major cost components to carp production and facilitates to identify the key factors influencing total production. In this study, Cobb-Douglas production function was estimated in ln-linear form to examine the effect of major cost components on total production. The dependent variable was total carp production, and the explanatory variables were logged cost components. Accordingly, the Cobb-Douglas production function was specified as follows:

$$\ln Y_i = A + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \dots \beta_6 \ln X_6 + \beta_7 \ln X_7 + \mu$$

Where, Y_i = Production, A = Constant, X_1 = Excavation cost (NRs/ha), X_2 = Electronic motor pump set cost (NRs/ha), X_3 = Fishing net cost (NRs/ha), X_4 = Water pipe cost (NRs/ha), X_5 = Feed cost (NRs/ha), X_6 = Labour cost (NRs/ha), X_7 = Fertilizer cost (NRs/ha), μ = Random error term, β_i = Coefficients of respective variables, $\ln$ = Natural logarithm.

Sensitivity analysis

Sensitivity analysis is used to determine how fluctuations in one variable can affect the profitability of the carp fish farming. Sensitivity analysis is a group of assumptions that can be used to examine the degree of uncertainty in a cost-benefit analysis. The scenarios examined changes in total variable cost, fish production, feed cost, and fish price. Profitability percentage was estimated using following formula in sensitivity analysis.

Profitability % = (Net revenue/total cost) x 100 %

Data analysis

Microsoft Excel and SPSS Statistics were used for data entry, processing, statistical analysis, and interpretation of the results. MS Excel was primarily used for data organization, coding, tabulation, calculation of economic and production indicators, and preparation of tables. SPSS was used for

statistical analysis of the quantitative data, including descriptive statistics and relevant inferential analyses. Qualitative information obtained from the survey was systematically coded, categorized, and summarized to identify major patterns and themes relevant to the study objectives. Statistical significance was assessed at the 1% and 5% significance levels ($p < 0.01$ and $p < 0.05$, respectively).

RESULTS

Economic and profitability analysis

Total production and productivity

Study revealed that the average total carp polyculture production was 5,161.34 kg/ha/year. The minimum recorded production was 203.18 kg from a pond area of 0.03 ha, while the maximum was 37,249.46 kg from 6.77 ha. Likewise, the average productivity was calculated to be 5.2 t/ha as presented in Table 1.

Table 1. Economic performance and cost structure of carp polyculture production in Sunsari district, Nepal.

Parameters	Value (NRs/ha)	Percentage of cost
Fixed cost		
Pond excavation	240,136.06	26.44
Electronic motor pump set	30,107.93	3.31
Fishing net	20,225.34	2.23
Water pipe	12,867.24	1.42
Total fixed cost (A)	303,336.58	33.39
Variable cost		
Feed	516,292.53	56.84
Fingerlings	45,194.10	4.98
Fuel and energy	10,341.60	1.14
Lime	5,975.81	0.66
Electricity	7,750.11	0.85
Labour	13,143.50	1.45
Manure and Fertilizer	6,321.41	0.70
Total variable cost (B)	605,019.06	66.61
Total cost (A+B)	908,355.63	
Production (kg/ha)	5,161.34	
Productivity(t/ha)	5.2	
Gross Revenue (C)	1,578,157.64	
Gross Margin (C-B)	973,138.59	
Net Revenue [C-(A+B)]	669,802.01	
B: C Ratio	1.74	

Fixed cost

The results revealed that the average fixed cost of carp polyculture production was NRs 303,336.58/ha. The fixed cost components included pond excavation, electric motor pump sets, fishing nets, and water pipes. Among these, pond excavation represented the largest component (NRs 240,136.06/ha; 26.44%) of total cost, followed by the electronic motor pump set (NRs 30,107.93/ha; 3.31%), fishing net (NRs 20,225.34/ha; 2.23%), and water pipe (NRs 12,867.24/ha; 1.42%; Table 1).

Variable cost

The total variable cost was NRs 605,019.06/ha. Feed constituted the largest share of production costs, accounting for NRs 516,292.53/ha (56.84% of total cost), followed by fingerlings at NRs 45,194.10/ha (4.98%). Other variable costs included labour (NRs 13,143.50/ha; 1.45%), fuel and energy (NRs 10,341.60/ha; 1.14%), electricity (NRs 7,750.11/ha; 0.85%), manure and fertilizer (NRs 6,321.41/ha; 0.70%), and lime (NRs 5,975.81/ha; 0.66%).

Total cost

The total cost of production comprised 33.39% fixed costs and 66.61% variable costs. The average total cost of carp production per hectare was found NRs 908,355.63.

Gross revenue, gross margin, and net revenue

Survey data revealed that the per-hectare gross revenue, gross margin, and net revenue were estimated as NRs 1,578,157.64, NRs 973,138.59, and NRs 669,802.01, respectively, as presented in Table 1.

Benefit-cost ratio

The profitability analysis revealed that the benefit-cost ratio of carp polyculture in Sunsari district, Nepal, were greater than one. This result indicates that carp polyculture is feasible and profitable, with a benefit-cost ratio of 1.74 (Table 1).

Factors affecting carp production

A log-linear Cobb-Douglas production function was estimated to identify the factors affecting carp production in Sunsari district of Nepal. All variables were transformed into natural logarithms prior to estimation. The results showed that excavation cost, fishing net cost, and water pipe cost had positive and statistically significant effects on carp production. This implies that a 1% increase in excavation cost, fishing net cost, and water pipe cost would increase carp production by approximately 0.622%, 0.498%, and 0.177%, respectively, holding other factors constant. Conversely, feed cost had a negative and statistically significant effect on carp production, indicating that a 1% increase in feed cost was associated with a 0.816% decrease in production. The coefficients of electric motor pump set cost, labour cost, and manure and fertilizer cost were statistically insignificant, suggesting that these variables did not have a significant influence on carp production within the study area. The estimated constant term was 3.179. The results of the Cobb-Douglas production function are presented in Table 2 and 3.

Multicollinearity diagnostics indicated moderate to high correlations among some explanatory variables. The variance inflation factor (VIF) values ranged from 5.22 to 20.56. The highest VIF values were observed for electronic motor pump set cost, fishing net cost, and water pipe cost, suggesting the presence of multicollinearity among these variables. However, the VIF values for

excavation cost, feed cost, labour cost, and organic manure cost remained below the commonly accepted critical threshold of 10 as presented in Table 2.

Table 2. Estimated production function coefficients and multicollinearity diagnostics for carp polyculture in Sunsari district, Nepal.

Variables	Coefficient	Standard error	t- value	p- value	Variance inflation factor (VIF)
Constant	3.179	1.944	1.635	0.108	
ln(Excavation cost)	0.622	0.258	2.408	0.020**	5.65
ln(Pump set cost)	0.172	0.104	1.648	0.105	20.56
ln(Fishing net)	0.498	0.101	4.931	<0.001***	15.5
ln(Water pipes)	0.177	0.086	2.054	0.045**	14.78
ln(Feed cost)	-0.816	0.291	-2.804	0.007***	6.08
ln(Labour cost)	0.009	0.071	0.127	0.899	8.93
ln(Fertilizer cost)	-0.012	0.052	-0.221	0.826	5.22

Note: *** Significant at 1%, ** Significant at 5%.

Table 3. Regression diagnostics for the Cobb-Douglas production function model of carp polyculture.

Statistic	Value
Total observations	60
R ²	0.96
Adjusted R ²	0.955
F-statistic	179.20***
Prob > F	<0.001
RMSE	0.227
Durbin-Watson	1.767

The estimated Cobb-Douglas production function showed a strong goodness of fit, explaining 96.0% of the variation in carp production ($R^2 = 0.960$; Table 3). The adjusted R^2 value of 0.955 indicates that the model retained high explanatory power after accounting for the number of explanatory variables included. The overall regression model was highly significant confirming that the explanatory variables jointly influenced carp production. The root mean square error was 0.227, indicating a relatively low prediction error. The Durbin-Watson statistic of 1.767 indicated no serious autocorrelation among the residuals.

Sensitivity analysis

The findings of the sensitivity assessment for carp production under alternative cost and output conditions are presented in Table 4. In the baseline case, gross revenue was NRs 1,578,157.64 and the total variable cost was NRs 605,019.06, yielding a net revenue of NRs 669,802.01 and a profitability of 73.74%.

Table 4. Sensitivity analysis of the economic performance of carp polyculture in Sunsari district, Nepal.

Scenario	Gross revenue	Total variable cost	Net revenue (Profit)	Profitability (%)
Original value	1,578,157.6	605,019.1	669,802.0	73.74
All variable costs increase by 20% without a revenue change	1,578,157.6	726,022.9	548,798.2	53.31
Production increases by 5% and the others remain constant	1,657,065.5	605,019.1	748,709.9	82.42
Production increases by 10% and variable cost increases by 10%	1,735,973.4	665,521.0	767,115.9	79.18
Feed cost increase by 10% and others remain constant	1,578,157.6	656,648.3	618,172.	64.39
Price decreases by 30% and Production increases by 5%	1,159,945.9	605,019.1	251,590.23	27.70

When all variable costs were increased by 20% while the gross revenue remained unchanged, the variable cost rose to NRs 726,022.87, and net revenue declined to NRs 548,798.20, resulting in a profitability of 53.31%. A 5% increase in production, with other parameters unchanged, produced a gross revenue of NRs 1,657,065.52 and a net revenue of NRs 7,48,709.88, corresponding to a profitability of 82.42%. Under the scenario of a 10% increase in production accompanied by a 10% rise in variable cost, gross revenue reached NRs 1,735,973.41 and net revenue stood at NRs 767,115.87, with a 79.18% profit margin. An increase of 10% in feed cost, keeping other costs constant, raised the total variable cost to NRs 656,648.31 and resulted in a profitability of 64.39%. When the price of fish was reduced by 30% while production increased by 5%, gross revenue declined to NRs 1,159,945.87, and net revenue decreased to NRs 251,590.23, reducing the profitability to 27.70%.

DISCUSSION

Our analysis showed that carp polyculture in Sunsari district was economically viable, with an average benefit-cost ratio of 1.74 and positive net returns. These results are broadly aligned with other Nepalese carp polyculture studies (Sharma et al. 2018; Poudel and Pandit 2020). An economic assessment conducted across three sites in Chitwan District reported an average benefit-cost ratio (BCR) of 1.63 for carp polyculture, with an average net revenue of NRs 480,135/ha (Sharma et al. 2018). Neupane et al. (2024) reported a higher BCR of 2.20 in the Bara district, compared with the BCR of 1.74 observed in the present study. Differences among districts may arise from contrasts in farm size, access to water, pond construction quality, market distance, input prices, and farmer management skills. Such differences matter for commercial aquaculture development because profitability is not determined only by biological production but also by infrastructure, input markets, and risk exposure. Notably, feed was the largest component of the variable cost, accounting for 56.8% in the present study, compared with only 28% reported by Sharma et al. (2018). The higher proportion for the feed cost was mainly due to frequent and intensive operating input in carp

farming. Feed was purchased and applied repeatedly throughout the production cycle, so even small changes in feed price or feeding rate can substantially increase total cost. The consistently large feed share across studies confirms that feed is the major expense, and our higher percentage may indicate more intensive feeding or higher feed prices in Sunsari district.

The Cobb-Douglas regression identified excavation, fishing net, water pipes and feed costs as the significant determinants of total carp production in Sunsari district. Feed cost significantly reduced the total production. The notable negative coefficient of feed cost suggests that higher feed spending correlated with reduced carp production. This could result from poor feed management, low feed conversion rates, or the use of expensive feed that failed to produce corresponding increases in fish growth and production. Similar finding had been attributed to poor feed management, feed wastage, and low feed conversion efficiency, which increase feed expenditure without generating proportional gains in fish production (Hasan and New 2013).

Sensitivity analysis confirms that profitability is highly vulnerable to changes in feed costs. In the present study, a 20% rise in all variable costs decreased the profitability from 73.7% to 53.3%, and a 30% drop in fish price even with a 5% higher production reduced the margin to only 27.7%. These results aligned with Siddiqua (2018) who reported similar conditions and profitability decreased in a similar pattern. Both of these studies showed that aquaculture profitability is highly sensitive to fluctuations in major cost components leading to similarly sharp reductions in profit margins when the variables change.

Overall, the present findings suggest that carp polyculture farming has strong commercial potential in the terai districts of Nepal, but profitability depends on efficient input use and sound infrastructure. Commercial expansion should therefore focus on improving management, and reducing cost inefficiencies.

CONCLUSION

This study provides an assessment of the production economics and profitability of carp polyculture in Sunsari district. Carp polyculture in the study area appears economically viable, with a benefit-cost ratio above one and positive net returns, indicating that the enterprise is profitable and offers considerable scope for enhanced economic gains through improved management interventions. The regression results help to identify which production costs most strongly influence total production, enabling farmers and policymakers to prioritize investments that gives the highest yield. Similarly, sensitivity analysis supports farmers and planners in developing strategies that minimize financial vulnerability and improve economic resilience. These economic outcomes of carp polyculture suggest considerable scope for improvement in productivity, and efficiency of carp farming.

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Short communication

FIRST PHOTOGRAPHIC RECORD OF NON-NATIVE ALLIGATOR GAR *Atractosteus spatula* (LEPISOSTEIFORMES: LEPISOSTEIDAE) FROM IRRIGATION CANAL CONNECTED TO THE TINAU RIVER, NEPAL

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ABSTRACT

The present study reports the first documented photographic record of non-native gar fish *Atractosteus spatula* (Lacepède, 1803) from the Tinau River irrigation canal system in Western Nepal. The species is native to the North America and is not a part of natural ichthyofauna of Nepal. A single individual was observed in human-modified irrigation channel locally known as “36 Khulo” which is diverted from main Tinau River system for agricultural irrigation purposes and water management. This record highlights the increasing vulnerability of modified river-canal systems to biological invasions and may pose a risk to native fish communities, emphasizes the need for regular monitoring of non-native aquatic species in Nepal.

Keywords: Alligator gar, Exotic species, First record, Irrigation canal, Habitat fragmentation

INTRODUCTION

Freshwater ecosystems in South Asia supports high biodiversity and provide critical ecosystem services, yet they are increasingly impacted by anthropogenic pressures such as habitat modification, pollution, and biological invasions (Sharma 2008; Sarkar et al. 2012). River systems in Nepal are highly influenced by anthropogenic activities including irrigation networks and artificial channels that alter the natural habitat connectivity (WECS 2011; Grill et al. 2019).

Non-native fishes can negatively affect native communities through predation, competition, and habitat alteration (Singh and Lakra 2006). In south Asia, the introduction of exotic fishes is primarily associated with aquaculture practices, ornamental fish trade, accidental or intentional releases (Sarkar et al. 2012; Sandilyan 2021). Several exotic fish species are reported from different aquatic river systems of Nepal, including riverine, lakes, and pond habitats (Budha 2015; Khatri et al. 2020).

The Alligator gar *Atractosteus spatula* (Lacepède, 1803) is a large predatory fish native to the North America (Raz-Guzman et al. 2018). Due to its popularity in the ornamental trade, the species has been recorded outside its native range including several habitats of India (Manna et al. 2021; Magloo et al. 2024). A search of published literature, national fish inventories, and available biodiversity databases found no previous verifiable record of *A. spatula* from Nepal. Therefore, this study reports the first record of *A. spatula* from a diverted irrigation canal connected to the Tinau River system, Western Nepal.

MATERIALS AND METHODS

A single individual of *A. spatula* was captured from irrigation canal locally known as “36 Khulo” connected with Tinau River system in Butwal, Western, Nepal on 2 December 2025. The

observation site is located at 27°41'14" N, 83°27'37" E, at an elevation of approximately 170 m above sea level (Figure 1). The canal is used for agricultural irrigation and represent a semi-natural aquatic habitat characterized reduced water flow and high anthropogenic influence.

The specimen was not collected due to its large size; instead, photographic documentation was performed in situ and the specimen was released. Identification was carried out based on external morphological characters using standard taxonomic references (Nelson et al. 2016; Page & Burr 2011). No voucher specimen was collected.

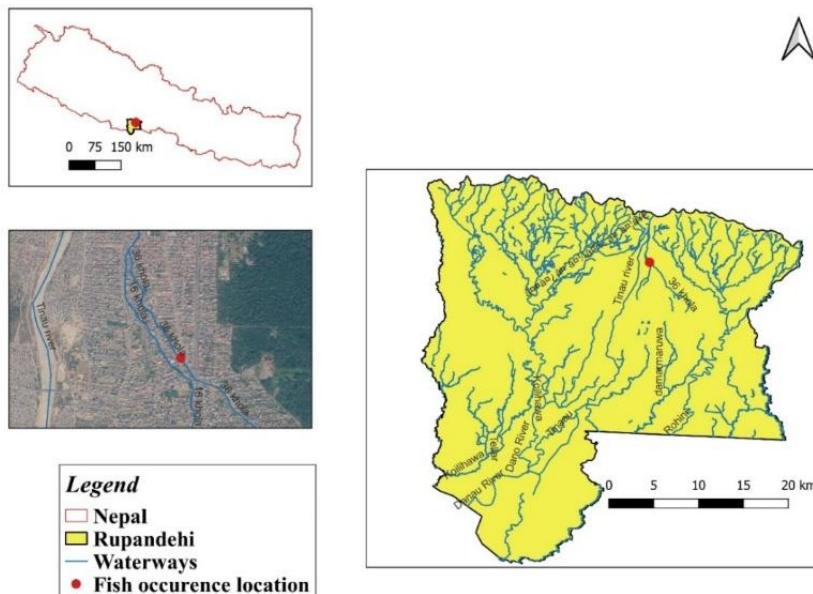


Figure 1: Map of study area showing the location of irrigation canal (36 Khulo) in Butwal, Western Nepal, where *A. spatula* was recorded.

RESULTS

Species identification

Based on the available photographic evidence and external morphological characteristics, the observed individual was identified as *Atractosteus spatula*. The identification was based on its cylindrical body, broad and dorsoventrally flattened (alligator-like) snout, heavily armoured ganoid scales, two rows of large teeth in the upper jaw, the posterior position of the dorsal and anal fins and the overall silvery-olive body colouration, all of which are diagnostic characteristics of *A. spatula* (Figure 2).

Habitat description

The individual was observed in semi-natural irrigation canal (36 Khulo) connected to the Tinau River system. The habitat was characterized by slow moving water, shallow depth, muddy, gravels and pebbles, sparse aquatic vegetations, noticeable anthropogenic disturbance associated with agricultural activities. The substrate consisted mainly mud, fine sand, gravel and scattered pebbles (Figure 3).



Figure 2: Photographic record of single individual of *Atractosteus spatula* captured from irrigation canal in the Tinau River system, Western Nepal.



Figure 3: Sampling location within the irrigation canal system (36 Khulo), showing habitat conditions at the sites where the specimen was observed.

DISCUSSION

This observation represents the first documented photographic record of *Atractosteus spatula* from Nepal, based on available evidence. Since the species is not native to Nepal, its presence most likely resulted from human-mediated introduction. The ornamental fish trade represents a plausible pathway of introduction; however, the specific pathway responsible for this observation could not be determined.

Reports indicate that alligator gar is available in Nepal's ornamental fish market (Bashyal 2025), while previous studies have shown that juvenile alligator gars are commonly traded as ornamental fishes, and release after rapid growth is considered an important pathway of freshwater fish introductions (Nelson et al. 2016; Raz-Guzman et al. 2018). The species has already been reported from several Indian states and freshwater habitats, indicating its introduction into South Asia mainly through anthropogenic pathways such as ornamental fish trade and accidental or released aquarium specimens rather than natural dispersal (Asbjornsen et al. 2015; Chan et al. 2019; Magloo et al. 2024). The present observation extends the known distribution of *Atractosteus spatula* into Nepal.

The species has been reported from several regions of India, including an open wetland of the Ganga River system in West Bengal, freshwater wells in Maharashtra, Dal Lake of Kashmir, Kurumali river in Kerala (Kumar et al. 2019; Patil et al. 2019; Manna et al. 2021; Sandilyan 2021). These records from South Asia indicate repeated occurrences of the species outside its native range, with human mediated introduction representing a plausible explanation for these records (Singh and Lakra 2006; Gul et al. 2024).

The fish was captured from the 36 Khulo, an artificial irrigation canal supplied by the water diverted directly from the Tinau River. Such artificial waterways with slow flow condition may facilitate the survival and movement of non-native species and act as a secondary corridor into natural ecosystems (Rahel 2002; Cucherousset and Olden 2011). Although the exact pathway of introduction cannot be confirmed, the ornamental aquarium trade is considered a plausible source for the introduction of *Atractosteus spatula*. Similar concerns have been reported from Indian freshwater ecosystem following its introduction through the ornamental fish trade (Manna et al. 2021; Gul et al. 2024; Magloo et al. 2024).

Although only a single individual species was recorded, however there is currently no evidence of an established population in Nepal. This observation highlights the need for monitoring of irrigation canal and river systems, regulation of ornamental fish trade, implementing awareness programs to prevent aquarium release and future establishment of invasive aquatic species. Future surveys of aquarium shops and consultations with aquarium keepers could verify the occurrence of *Atractosteus spatula* in the ornamental fish trade in Nepal and improve understanding of its introduction pathway.

CONCLUSION

This study documents the first occurrence of *Atractosteus spatula* in Nepal and establishes a reference point for future assessments of non-native fishes. Continued monitoring will be essential to evaluate its status, and improve understanding of its occurrence so that timely evidence-based preventive management will be supported if any changes detected and minimize the risk of species establishment in Nepalese freshwater ecosystems.

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