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RESEARCH ARTICLE

EVALUATING ALTERNATIVE FISH FEED FOR SUSTAINABLE SPINACH AND TILAPIA PRODUCTION IN URBAN AQUAPONIC SYSTEM

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ABSTRACT

Aquaponics offers a promising solution for food security in urban areas where agricultural land is rapidly being repurposed. However, its wider use is limited by the high cost of commercial fish feed. Consequently, many aquaponic operators are exploring alternative and less expensive feed options. The major challenge in aquaponics is identifying fish feeds that not only promote healthy fish growth but also enrich the water with nutrients essential for plant development. Since fish feed is the main source of nutrients for both fish and plants in this system, it is important to understand how different feeds affect the whole systems performance. This study addresses this need by comprising the effect of two fish feed sources- biogas slurry and commercial market feed on the growth of Tilapia (*Oreochromis mossambicus*) and the nutrient quality of water in aquaponic system. The experiment was conducted over a period of two months from 01 August 2024 to 30 September 2024, using a controlled aquaponic setup. Two groups of Tilapia were maintained: one fed with biogas slurry-based feed and the other with standard commercial feed. Growth performance, water quality parameters, and nutrient levels were regularly monitored. Result showed that fish fed with biogas slurry exhibited slower growth (0.14 g/day) compared to those given market feed (0.43 g/day), indicating that biogas slurry in its current form does not sufficiently meet the nutritional needs of fish. Beside the reduced growth, water quality parameters, including temperature (24-27°C) pH (6.8-7.5), dissolved oxygen (>5 mg/L), and ammonia (<0.2 mg/L), nitrite (0.25-0.50 ppm), nitrate (5.0 ppm) remained within acceptable limits in both systems, confirming that biogas slurry does not negatively impact the aquatic environment. This finding emphasizes a critical need for the development of alternative fish feeds in aquaponics that are nutrient rich and balanced to support optimal health and productivity of both fish and plants. Further research is essential to formulate such feeds, which would enhance the sustainability and efficiency of aquaponic systems.

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INTRODUCTION

Aquaponics, an integrated food production system that combines aquaculture and hydroponics, has gained significant attention as a sustainable solution to urban food insecurity and resource conservation (Goddek *et al.*, 2015). By recycling fish waste as a nutrient source for plants, this closed-loop system offers an environmentally friendly alternative to conventional agriculture, especially in space-limited urban environments (Yep & Zheng, 2019). However, a major bottleneck in scaling aquaponic operations is the high cost and environmental footprint of commercial fish feeds, which can account for over 60% of total operational costs in aquaculture (Tacon & Metian, 2008). Given that fish feed directly influences both fish growth and the nutrient availability for plants, identifying affordable, eco-friendly, and nutritionally balanced feed alternatives is critical for the long-term viability of aquaponic systems (Rakocy *et al.*, 2006).

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Biogas slurry, a by-product of anaerobic digestion, has emerged as a potential low-cost alternative due to its rich organic and mineral content (Ghosh *et al.*, 2021). However, its efficacy in supporting optimal fish growth and maintaining water quality parameters within acceptable limits remains underexplored. This study evaluates the comparative effects of biogas slurry and commercial fish feed on the growth of *Oreochromis mossambicus* (Tilapia) and the quality of aquaponic water used for spinach cultivation. The findings aim to inform sustainable feed development and promote resource-efficient aquaponic practices in urban settings.

MATERIAL AND METHODOLOGY

Experimental Design: The experiment was conducted over a period of 45 days, from March 1 to April 14, 2025, in a well-ventilated room located at Sakharkherda, Maharashtra, India. Two identical aquaponic units were utilized for the study. Each unit comprised a 200 liter capacity fish tank, used for rearing Tilapia (*Oreochromis mossambicus*). Above each fish tank, two vertically positioned, half-cylinder-shaped plant-growing compartments were attached to an iron

stand, employing the floating raft technique for plant cultivation. Each raft measured 18 inches by 40 inches, containing 18 planting holes arranged in three rows, covering a total planting area of 5 square feet. To maintain adequate dissolved oxygen levels, each fish tank was equipped with an air diffusion stone connected to an air pump. To maintain optimal water quality for both fish and plants, an efficient biofilter was assembled.

Selection of Fish and Plants: The experiment utilized Tilapia (*Oreochromis mossambicus*) and spinach (*Spinacia oleracea*) as the test species for aquaponic integration. Fingerlings of Tilapia, with an average weight of 7.55 ± 0.31 g, were procured from the Government Fish Hatchery Centre, Paithan, Maharashtra, India, and transported to the experimental site in oxygenated packaging at a density of 100 fingerlings per pack. Upon arrival, the fingerlings were acclimatized in a 200-liter capacity aerated tank for 15 days. During acclimatization, daily water exchange and removal of fecal matter were carried out to maintain optimal water quality. Following acclimatization, the fingerlings were transferred to the experimental aquaponic units and both group fed at a rate of 5% of their body weight, twice daily, with commercial feed and biogas slurry-based feed throughout the experimental period. Total 80 number of *Oreochromis mossambicus* fingerlings were stocked at a density of 3kg/m^3 . For the plant component, spinach (*Spinacia oleracea*) seeds were sourced from a local commercial supplier. The seeds were initially sown in seed trays and allowed to germinate under daily watering for 15 days. Once germinated, the seedlings were transplanted into plastic containers for early establishment before being transferred to the floating raft grow beds in the aquaponic system for further growth and development.

Fish feed preparation: Fish feed was prepared using biogas slurry as the primary base, supplemented with nutrient-rich ingredients such as groundnut cake, soybean meal, maize, and wheat flour to enhance its protein and energy content. The biogas slurry was first sun-dried to reduce moisture content and potential pathogens. It was then finely mixed with powdered forms of the other components in appropriate proportions to achieve a balanced nutrient profile suitable for fish growth. The mixture was pelleted using a manual feed pelletizer and subsequently air-dried before storage.

Water quality study: various physico-chemical parameters of water such as temperature, dissolved oxygen, pH, ammonia, nitrite and nitrate were analysed after every 10 days intervals during the experiment.

Table 1. Water quality parameters were assessed using the following instruments

Sr.No.	Parameter	Instrument
1	Temperature	Digital thermometer
2	pH level	Digital pH meter
3	Dissolved Oxygen	Aquasol test kit
4	Ammonia	API freshwater master test kit
5	Nitrite	API freshwater master test kit
6	Nitrate	API freshwater master test kit

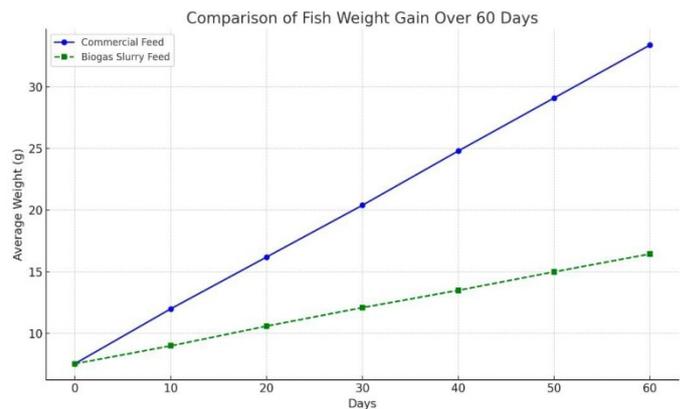
RESULT AND DISCUSSION

Fish growth:

Table 1. Growth performance of Tilapia (*Oreochromis mossambicus*) in commercial and home-made biogas slurry feed

Sr.No.	Parameters	Commercial feed	Biogas slurry feed
1	Initial body weight (g)	7.55	7.55
2	Final body weight (g)	33.39	16.45
3	Body weight gain (g)	25.84	8.9
4	Daily increase (g day^{-1})	0.43	0.14

The growth performance of Tilapia (*Oreochromis mossambicus*) varied significantly between the two feed treatment. Fish fed with commercial market feed demonstrated superior growth compared to those fed with homemade biogas slurry feed. Specifically, the market feed group showed a body weight gain of 25.84 g over the two month period, with an average daily growth rate of 0.43 g/day. In contrast, the biogas slurry fed group exhibited a body weight gain of only 8.9 g, with a daily growth rate of 0.14 g/day, indicating that biogas slurry while rich in organic matter, generally lacks the digestible protein and lipid concentrations required for efficient somatic growth in fish (FAO, 2016; Naylor *et al.*, 2009). Moreover, the nutritional composition of biogas slurry can be inconsistent and may contain indigestible or inhibitory compounds that limit its effectiveness as a standalone feed (Azim and Little, 2008). For the optimal growth in *O. mossambicus* typically requires a protein level of 28-32%, along with essential amino acids, fats, and micronutrients (EI-Sayed, 2006). The superior growth performance of market feed group is attributed to its well-balanced nutritional profile, formulated to meet the species-specific dietary requirements of tilapia.



Plant growth

Table 2. Plant growth parameters

Sr.No.	Parameters	Commercial feed	Biogas slurry feed
1	Initial plant height (cm)	5.20	5.13
2	Final plant height (cm)	25.28	23.03
3	Height gain (cm)	20.08	17.09
4	Plant growth rate (cm day^{-1})	0.33	0.28

The growth performance of spinach (*Spinacia oleracea*) in the aquaponic system was evaluated by measuring plant height over a two-month of experimental period. The result shows a notable difference in spinach growth between systems fed with biogas slurry and those with commercial market feed. Spinach grown in the biogas slurry-fed system recorded a final average plant height of 25.28 cm, compared to 23.03 cm in the commercial feed system. The net weight gain was 20.08 cm (0.33 cm/day) for biogas slurry and 17.09 cm (0.28 cm/day) for the commercial feed treatment. These findings indicate that the biogas slurry contributed more effectively to spinach growth despite its limited support for optimal fish growth. This result aligns with research conducted by Maucieri *et al.*, 2018; Pant *et al.*, 2023 indicating that organic nutrient sources, such as biogas slurry, enhance nutrient cycling and increase nutrient bioavailability for plant uptake. Also, according to Moller and Muller, 2012; Ronga *et al.*, 2020, biogas slurry is rich in essential plant nutrients including nitrogen, phosphorous, potassium, calcium, magnesium, sulfur and several micronutrients like iron and zinc. Recent studies by Eck *et al.*, 2020 and Kledal *et al.*, 2022 also support the concept that organic nutrient supplementation in aquaponic systems can improve plant productivity compared to conventional systems.

Water quality: Maintaining optimal water quality is a cornerstone for the success of aquaponic systems, as it affects fish health, microbial activity, and plant nutrient availability. In this study, water quality parameters including pH, dissolved oxygen (DO), ammonia, nitrite,

and nitrate were consistently monitored across systems fed with biogas slurry and commercial feed. All parameters remained within acceptable limits for tilapia culture and hydroponic spinach growth, regardless of the feed source, suggesting that biogas slurry, while less efficient in promoting fish growth, does not compromise water quality.

Table 3. Water quality parameters

Sr.No.	Parameters	Average value
1	Temperature °C	24-27
2	pH	6.8-7.5
3	Ammonia (ppm)	>5
4	Nitrite (ppm)	0.25-0.50
5	Nitrate (ppm)	5.0
6	DO (mg/L)	<5

pH: The pH levels recorded ranged from 6.8 to 7.5, which falls within the ideal range for aquaponic systems. A balanced pH is essential for multiple reasons: it affects the solubility and availability of nutrients to plants, the toxicity of ammonia to fish, and the efficiency of nitrifying bacteria. Rakocy *et al.* (2006) and Goddek *et al.* (2015) recommend a pH range of 6.5 to 7.5 as optimal for aquaponics, balancing the needs of fish, plants, and microbes. Nitrifying bacteria, especially Nitrosomonas and Nitrobacter, which convert ammonia to nitrate, operate most efficiently within this pH window. The stability of pH in both experimental systems confirms that biogas slurry does not significantly disrupt the system's acid–base balance.

Dissolved Oxygen (DO): Dissolved oxygen concentrations remained above 5 mg/L in both systems. This level is adequate for the metabolic needs of *Oreochromis mossambicus*, a species known to tolerate low DO but grow optimally above 5 mg/L (Boyd & Tucker, 2012). DO is also vital for aerobic microbial activity, particularly nitrification, which is oxygen-intensive. Tyson *et al.* (2004) highlighted that low DO levels can impair nitrification, leading to ammonia and nitrite accumulation. The maintained DO levels indicate efficient aeration and a healthy microbial community, even with the higher organic load introduced by biogas slurry.

Ammonia: Ammonia concentrations remained below 0.25 ppm (mg/L) in both systems, staying under the toxicity threshold for tilapia. Un-ionized ammonia (NH₃), which is highly toxic to fish, becomes prevalent at higher pH and temperature levels. According to Francis-Floyd *et al.* (2009), safe levels for total ammonia nitrogen (TAN) in aquaponic systems should be below 0.5 mg/L, with un-ionized ammonia below 0.05 mg/L. The values in this study suggest effective ammonia assimilation through microbial nitrification and plant uptake. Even with biogas slurry, which can introduce a higher organic nitrogen load, ammonia levels did not spike, indicating the biofilters capacity to handle the input efficiently (Yildiz *et al.*, 2017).

Nitrite (NO₂⁻): Nitrite levels ranged from 0.25 to 0.50 ppm, which are considered safe for tilapia. Nitrite is an intermediate product of ammonia oxidation and can be toxic at higher levels by interfering with the fish's oxygen transport (i.e., causing methemoglobinemia or “brown blood disease”). However, levels below 1.0 ppm are generally tolerated by tilapia (Timmons & Ebeling, 2021). The presence of nitrite at moderate levels suggests that while ammonia oxidation is occurring, the conversion to nitrate might be slightly delayed, possibly due to temperature or minor fluctuations in DO or pH. Still, the range observed indicates that the system was functioning well without signs of nitrite toxicity.

Nitrate (NO₃⁻): Nitrate levels were reported to be around 5.0 ppm, which is within the optimal range for leafy vegetable crops like spinach. Nitrate is the end product of nitrification and serves as the primary nitrogen source for plants in aquaponic systems. For effective plant growth, especially in leafy greens, nitrate levels between 5–60 ppm are desirable (Rakocy *et al.*, 2006; Somerville *et al.*, 2014). The measured nitrate concentration suggests moderate nitrification activity and nutrient availability. The fact that nitrate remained at

appropriate levels, even in the biogas slurry-fed system, further indicates the viability of using such alternative feeds from a nutrient cycling perspective.

CONCLUSION

This study highlights the potential and limitations of using biogas slurry as an alternative fish feed in urban aquaponic systems. While the use of biogas slurry resulted in slower fish growth compared to commercial feed, it maintained water quality parameters—such as pH, dissolved oxygen, ammonia, nitrite, and nitrate—within optimal and acceptable limits for both fish and plant cultivation. These findings suggest that although biogas slurry, in its current form, may not fully meet the nutritional needs of *Oreochromis mossambicus*, it does not negatively affect the aquatic environment or compromise water quality. Therefore, biogas slurry presents a sustainable and environmentally friendly feed option, provided its nutritional content is improved. Further research and feed formulation efforts are needed to develop a balanced, low-cost, and efficient alternative that supports both fish growth and plant productivity, ultimately enhancing the sustainability and economic viability of aquaponic systems in urban areas.

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