

Portable Aquaponic Model for Household and Agricultural Applications

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ABSTRACT

Food and water shortages, pesticide contamination, and limited agricultural land pose significant challenges to organic food production. A small-scale aquaponic system offers a sustainable solution by integrating fish and vegetable farming in a closed-loop, water-efficient system. However, existing models often require high investment, technical expertise, and large space, making them less accessible. This study develops a cost-effective, portable aquaponic model using locally available materials. Over 45 days, the system maintained stable water quality, supporting fish and plant growth. Tilapia (*Oreochromis mossambicus*) grew to an average of 31.5 g (0.5 g/day), while spinach (*Spinacia oleracea*) yielded 1960 g in 10 sq. ft., demonstrating its potential for sustainable food production. Future research should focus on optimizing feeding strategies and water quality management to enhance fish growth rates, exploring alternative, locally sourced fish feed options for better sustainability, and integrating renewable energy sources, automation, and advanced nutrient recycling to improve efficiency.

Keywords- Aquaponic system, water shortage, limited agricultural land, cost-effective, portable.

I. INTRODUCTION

The most prevailing issues of the modern world are food and water crises. It is neither possible to consume the pesticide affected food nor grow one's own plants due to scarcity of water and fertile agricultural land. The rapid expansion of urbanization is reducing agricultural farmland, making it harder for countries to increase their agricultural production (Bovas *et al.*, 2019). In Kerala the average land holding of farmers is 0.2 hectares, but due to high population density and

limited farmland, it consumes more than it produces (Shinoj 2015). The FAO (2022a, 2022b) predicts that farmland will keep shrinking due to urban growth, industrial expansion, and melting icebergs. Traditional farming faces many challenges, such as poor soil fertility, less help from soil microbes due to constant farming, frequent droughts, unpredictable weather, rising temperatures, polluted rivers, poor water management, water wastage, and dropping groundwater levels. This issue highlights the need for developing countries to focus on improving

agricultural practices and technologies to enhance productivity (Swetha et al., 2016). Aquaponic system has a potential to overcome all these problems. Aquaponics has attracted considerable attention for its capacity to preserve water quality, decrease freshwater usage, and produce commercially viable vegetable crops (Adler *et al.*, 2000a; Lennard & Leonard, 2005; Graber & Junge, 2009; Pantanella *et al.*, 2015). While aquaponics has emerged as a sustainable solution for integrated fish and vegetables farming current models face significant challenges that limit their accessibility and practicality for widespread use. Existing systems often require high initial investment, extensive technical knowledge, and large surface areas, making them unsuitable for small-scale farmers and urban households. Additionally, reliance on imported materials and sophisticated technology increases operational costs, while high water and energy consumption further restricts adoption in regions with limited resources. These limitations hinder the potential of aquaponics to contribute effectively to organic food production and the improvement of farmers livelihoods. To overcome these challenges, there is a critical need for a portable aquaponics model constructed from locally available materials and integrated with user friendly technology.

II. MATERIAL AND METHODOLOGY

Research location: The experiment was conducted over a period of 45 days from 04 December 2024 to 17 January 2025 in a net house located at Sakharkherda village in Buldhana district of Maharashtra state.

Structural framework: A custom iron stand was constructed using 3 cm hollow square pipes to support the system.

Fish tank: A 200 L capacity fibre loft tank, measuring 4 feet × 2 feet × 2 feet was utilized for fish rearing. An aerator was installed to ensure adequate oxygenation. Tilapia (*Oreochromis mossambicus*) was taken for the study. Fingerlings were fed with

commercial feed at a rate of 5% of their body weight, two times in a day throughout the experimental period.

Hydroponic Unit: Two vertically positioned, half-cylinder-shaped compartments were attached to the iron stand to grow plants using the floating raft technique. Each raft measure 18 inches × 40 inches, erected with 18 holes arranged in three rows, covering a total area of 5 sq ft. Spinach (*Spinacia oleracea*) is used in the study, as it is a widely favoured green vegetable for aquaponics system due to its quick growth rate with minimal nutritional requirements, favourable market acceptability, and exceptional adaptation to a wide range of environmental circumstances (Petrea, S.M. *et al.*, 2014).

Filtration system: The efficiency of an aquaponics system relies heavily on the proper functioning of beneficial bacteria, which play a crucial role in converting fish waste into bioavailable nutrients for plant growth (Goddek *et al.*, 2019). To maintain optimal water quality for both fish and plants, an efficient biofilter was assembled. Components included PVC pipes, elbows, reducers, ceramic filtration media, sponge pad, gravels, and an 18-inch PVC pipe perforated with 0.1 cm holes spaced 3 cm apart across 8 rows over 8 inches length. API biofilter media was added to the biofilter to initiate the growth of nitrification bacteria. Nitrifying bacteria play a crucial role in aquaponics by converting toxic ammonia from fish waste into less harmful nitrate, which serves as a vital nutrient for plants (Rakocy *et al.*, 2006). The pipe was fix in a 20L capacity container in which a filtration media is arranged in a specific manner. An 18-watt submersible water pump is attached at the end of perforated pipe for pumping a nutrient rich water to the hydroponic units.



Fig.1. Model design



Fig.2. Biofilter



Fig.3. Spinach plants

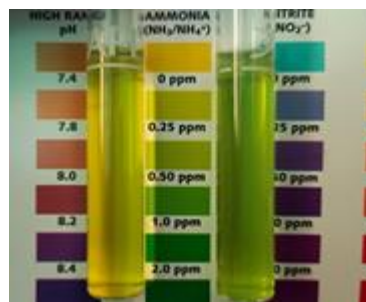


Fig.4. Test kit



Fig.5. Fish feed



Fig.6. Fish tank

Water Quality Monitoring:

Water quality parameters were assessed weekly 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

III.RESULT AND DISCUSSION

Working of the Model: An 18-watt submersible pump served as the primary mechanism for water movement throughout the system. Maintaining an optimal water flow rate is crucial for the removal of nutrients such as inorganic nitrogen and phosphate to ensure water quality and prevent the accumulation of toxic nitrogen compounds like ammonia and nitrate. This process is essential for sustaining the health and growth of both fish and plants in an aquaponic system (Rakocy *et al.*, 2006). A submersible water pump fixed at the end of perforated pipe in biofilter pump water to the hydroponic units. In a biofilter ceramic media blocks, sponges' pad and gravels are used in biofilter for effective filtration. Similarly, Estim *et al.*, (2019) utilized two types of filtration media in aquaponics, where sponge pads functioned as mechanical filters, and gravel served as a substrate for biological filtration in the filtration tank. water flow is adjusted through a valve fixed at the inlet pipe of hydroponic units. Excess water exited through outlets situated at the base of the hydroponic units, returning to the fish tank. As the water level of fish tank increases overflow entered the biofilter where nitrification process enriched the water with nutrients before recirculating it back to the hydroponic units.

Fish Growth Performance:

In a 45-day experiment, conducted to assess the effectiveness of a newly designed aquaponic system, a total 70 number of *Oreochromis mossambicus* fingerlings were stocked at a density of 3kg/m³ with initial average weight of 8.58 gm per fish. At the end of the study, the fish reached an average weight of 31.5 g. with 100% survival rate. Rahmatullah *et al.*, (2010) examined the effects of different stocking densities (53, 106, and 159 fish/m³) on tilapia growth, feed conversion ratio (FCR), survival, and production in an aquaponic system. Their findings revealed that survival rate was inversely proportional to stocking density, with higher densities leading to reduced survival. The fish grew at an average rate of 0.5 g per

day, showing moderate growth under the given conditions. The result shows similarity with the research conducted by Al-Zahrani *et al.*, (2023), in their research they investigated the impact of different stocking densities (3, 6, and 9 kg/m³) on water quality parameters and the growth performance of Nile tilapia and spinach in a Nutrient Film Technique (NFT) aquaponic system. Their findings indicated that a stocking density of 3 kg/m³ resulted in a faster growth rate of fish compared to those stocked at 6 and 9 kg/m³, suggesting that lower stocking densities may be more favourable for fish growth in NFT aquaponic systems. These results suggest that the system can support fish growth, but further improvements in feeding methods and water quality management could help to achieve better performance.

Plant Productivity:

To evaluate plant productivity, the *Spinacia oleracea* seed were obtained from a commercial market were sowed and allowed to develop in seed tray for 8-10 days. Daily watering was given to the seedling until they began to germinate. The germinated spinach was then transferred to the plastic container. The 15 days old seedling stage spinach then moved to hydroponic unit. A total 36 spinach plants were grown in two hydroponic units within the system. At the end of the experiment, the total weight of harvested spinach was 1960 g grown within 10 square feet (9290 cm²) area. The lower plant production may be due to the lower stocking density. According to Goddek *et al.*, (2017), higher fish stocking density in aquaponic systems leads to an increased production of organic matter, which enhances nutrient availability for plant growth. Al-Zahrani *et al.*, (2023) found that higher tilapia stocking densities in an NFT aquaponic system led to increased spinach yields. The highest yield (2.58 kg/m²) was recorded at 9 kg/m³ stocking density, while the lowest (0.88 kg/m²) occurred at 3 kg/m³, highlighting the positive correlation between fish biomass and plant growth.

Water Quality Parameters:

The results align with existing research, confirming the effectiveness of the designed portable aquaponics system in sustaining a balanced aquatic environment.

Temperature

Water temperature remained within the optimal range for aquaponic systems, ensuring efficient fish metabolism and microbial activity. Regular monitoring of water temperature and maintaining a thermograph are essential to ensure optimal conditions for fish and plant growth in aquaponic systems (Resh, 2012). The observed temperature range of 24–27°C falls within the optimal range for aquaponic systems, as reported by Somerville *et al.*, (2014) and Endut *et al.*, (2010), ensuring favourable conditions for fish and plant growth.

pH

Somerville *et al.*, (2014) demonstrated that maintaining a pH between 6.0 and 8.5 is critical for aquaponic system efficiency, as this range optimizes the activity of nitrifying bacteria responsible for converting fish waste into essential nutrients for plants. The pH levels of 6.5–7.4 recorded during the experiment were within the ideal range for aquaponics, ensuring a suitable balance for fish health, microbial activity, and plant nutrient absorption. Deswati *et al.*, (2022) reported that maintaining a stable pH level within the optimal range is crucial for water quality management in aquaponic systems. In their study on bio floc technology in a flood and drain aquaponic system they demonstrated that pH fluctuations influence key parameters such as dissolved oxygen (DO), chemical oxygen demand (COD), and biological oxygen demand (BOD), which are essential for maintaining a balanced ecosystem for fish and plants. A pH range of 6–7 helps maintain ammonia in the ionized form (NH_4^+), thereby minimizing the accumulation of toxic un-ionized ammonia (NH_3) in the system (Rakocy, 2007).

Dissolved Oxygen

According to Somerville *et al.*, (2014), maintaining a dissolved oxygen (DO) concentration between 4 and 6

mg/L is essential for aquaponic systems. This DO range not only supports the respiratory needs of fish but also facilitates the optimal performance of nitrifying bacteria, thereby ensuring effective waste conversion and overall system health. The results of the dissolved oxygen level during the study were in the recommended range, ranged from 4–6 mg L⁻¹. According to, Mahfouz M.E. *et al.*, (2015) and Zaki M A *et al.*, (2020) dissolved oxygen level was inversely proportional to stocking density of fishes.

Ammonia

During the experiment ammonia levels remained below 0.25 ppm, which is considered safe for fish and plants by Shafeena T. (2016). Ideally, ammonia concentrations should be kept below 0.25 parts per million (ppm) to prevent toxicity to fish and ensure efficient nutrient conversion for plant growth. Che Deer B. *et al.*, (2021), the obtained result shows similarity with this finding. Low ammonia concentrations indicate effective biological filtration, where nitrifying bacteria converted ammonia into nitrite and nitrate efficiently. The controlled ammonia levels suggest that waste generated by tilapia was adequately processed by the system, minimizing toxicity risks, and preventing adverse effects on fish health and spinach growth.

Nitrite

In aquaponic system nitrite level above 1 ppm can be harmful to fish Sallenave R., (2016). Nitrite concentrations were within the acceptable range for aquaponic systems. The presence of nitrite concentration between 0.25–0.50 ppm indicates active nitrification, where ammonia was successfully converted into nitrite. Although nitrite can be toxic at higher concentrations, the recorded levels were within tolerable limits, ensuring no significant impact on fish health. The steady nitrite levels demonstrate that the biofilter was functioning effectively, preventing excessive accumulation.

Nitrate

Nitrate levels stabilized around 5.0 ppm, providing essential nutrients for plant growth. In aquaponics,

nitrate serves as the primary nitrogen source for spinach (Canali S *et al.*, 2008) and its presence at moderate levels indicates efficient nutrient cycling. The uptake of nitrate by spinach plants helped maintain a balanced nutrient load in the system, preventing excessive buildup that could compromise water quality. The recorded nitrate levels suggest that plant absorption was effectively synchronized with fish waste production, supporting sustainable vegetable growth.

IV. CONCLUSION

The newly designed portable aquaponic system demonstrated its potential as an efficient and space-saving approach for integrated fish and vegetable production. The system's structural framework, incorporating a fish tank, biofiltration unit, and vertical hydroponic compartments, successfully maintained a recirculating water environment that supported both *Oreochromis mossambicus* growth and *Spinacia oleracea* cultivation. Overall, the experiment confirmed that the integrated system is capable of sustaining both fish and plant growth while maintaining a balanced aquatic environment. Future research can focus on refining feed formulations, optimizing biofiltration efficiency, and expanding crop diversity to enhance system productivity and sustainability.

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REFERENCES

- [1]. Adler, P. R., Harper, J. K., Wade, E. M., Takeda, F., & Summerfelt, S. T. (2000). Economic analysis of an aquaponic system for the integrated production of rainbow trout and plants. *International Journal of Recirculating Aquaculture*, 1, 15–34.
- [2]. Al-Zahrani, M. S., Hassanien, H. A., Alsaade, F. W., & Wahsheh, H. A. M. (2023). Effect of stocking density on sustainable growth performance and water quality of Nile tilapia–spinach in an NFT aquaponic system. *Sustainability*, 15, 6935.
- [3]. Bovas, J. J. L., Tesfit, A. M., Temesgen, B. T., Temesgen, G. H., & James, S. P. (2019). Development of a microcontroller-based drip irrigation control system in Eritrea. *Trends in Biosciences*, 12(3), 3–6.
- [4]. Canali, S., Montemurro, F., Tittarelli, F., & Masetti, O. (2008). Effect of nitrogen fertilization on yield, quality, and nitrogen utilization of processing spinach. *Journal of Food, Agriculture & Environment*, 6, 242–247.
- [5]. Che Deer, B., Hu, B., Dunn, B., & Dusci, J. (2021). Nitrification and maintenance in media bed aquaponics. Oklahoma State University.
- [6]. Deswati, D., Safni, S., Khairiyah, K., Yani, E., Yusuf, Y., & Pardi, H. (2022). Biofloc technology: Water quality (pH, temperature, DO, COD, BOD) in a flood and drain aquaponic system. *International Journal of Environmental Analytical Chemistry*, 102, 6835–6844.
- [7]. Endut, A., Jusoh, A., Ali, N., Wan Nik, W. B., & Hassan, A. (2010). A study on the optimal hydraulic loading rate and plant ratios in recirculating aquaponic systems. *Bioresource Technology*, 101(5), 1511–1517.
- [8]. Estim, A., Saufie, S., & Mustafa, S. (2019). Water quality remediation using aquaponic subsystems as biological and mechanical filters in aquaculture. *Journal of Water Process Engineering*, 30, 100566.
- [9]. FAO. (2022a). News article: 2050: A third more mouths to feed, May 2022. Retrieved from <https://www.fao.org/news/story/en/item/35571/i/code/>
- [10]. FAO. (2022b). Food and agriculture projections to 2050 | Global Perspectives Studies | Food and Agriculture Organization of the United Nations,

- May 2022. Retrieved from <https://www.fao.org/global-perspectives-studies/food-agriculture-projections-to-2050/en/>
- [11]. Goddek, S. (2017). Opportunities and challenges of multi-loop aquaponics systems (Doctoral dissertation). PQDT-Global, 28232804.
- [12]. Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K. V., Jijakli, M. H., & Thorarinsdottir, R. (2019). Challenges of sustainable and commercial aquaponics. *Sustainability*, 11(7), 4193.
- [13]. Graber, A., & Junge, R. (2009). Aquaponic systems: Nutrient recycling from fish wastewater by vegetable production. *Desalination*, 246, 147–156.
- [14]. Lennard, W. A., & Leonard, B. V. (2005). A comparison of reciprocating flow versus constant flow in an integrated, gravel-bed aquaponic test system. *Aquaculture International*, 12, 539–553.
- [15]. Mahfouz, M. E., Hegazi, M. M., El-Magd, M. A., & Kasem, E. A. (2015). Metabolic and molecular responses in Nile tilapia (*Oreochromis niloticus*) during short and prolonged hypoxia. *Marine and Freshwater Behaviour and Physiology*, 48, 319–340.
- [16]. Pantanella, E., Cardarelli, M., Di Mattia, E., & Colla, G. (2015). Aquaponics and food safety: Effects of UV sterilization on total coliforms and lettuce production. *Acta Horticulturae*, 1062, 71–76.
- [17]. Rahmatullah, R., Das, M., & Rahmatullah, S. M. (2010). Suitable stocking density of tilapia in an aquaponic system. *Bangladesh Journal of Fisheries Research*, 14(1–2), 29–35.
- [18]. Rakocy, J. (2007). Ten guidelines for aquaponic systems. *Aquaponics Journal*, 46, 14–17.
- [19]. Rakocy, J. E., Masser, M. P., & Losordo, T. M. (2006). Recirculating aquaculture tank production systems: Aquaponics—Integrating fish and plant culture. Southern Regional Aquaculture Center (SRAC) Publication No. 454, 1–16.
- [20]. Sallenave, R. (2016). Important water quality parameters in aquaponics systems. Circular 680, College of Agricultural, Consumer and Environmental Sciences, New Mexico State University.
- [21]. Shafeena, T. (2016). Smart aquaponics system: Challenges and opportunities. *European Journal of Advances in Engineering and Technology*, 3(9), 52–55.
- [22]. Shinoj, P. (2015). Agriculture performance and future outlook on food commodities in Kerala. *Agricultural Economics Research Review*, 24(5), 247–258.
- [23]. Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). Small-scale aquaponic food production: Integrated fish and plant farming. FAO Fisheries and Aquaculture Technical Paper No. 589.
- [24]. Swetha, S., Nirmalraj, A. A., & Shanbough, G. R. (2016). Autonomous VTOL agro-drone. *International Journal of Research in Engineering and Applied Sciences*, 10(10), 26–34.
- [25]. Zaki, M. A., Alabssawy, A. N., Nour, A. E.-A. M., El Basuini, M. F., Dawood, M. A., Alkahtani, S., & Abdel-Daim, M. M. (2020). The impact of stocking density and dietary carbon sources on the growth, oxidative status, and stress markers of Nile tilapia (*Oreochromis niloticus*) reared under biofloc conditions. *Aquaculture Reports*, 16, 100282.