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Design and Performance Analysis of a Double Rotary Table Aquaponic System for Integrated Fish and Plant Cultivation

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Abstract

Aquaponics integrates aquaculture and hydroponics into an efficient closed-loop system for urban food production. This study examines the design and performance of a modified double-rotary table aquaponics system derived from a conventional hydroponic configuration. The study employed a Design and Development Research method with an engineering approach involving design, fabrication, testing, and evaluation stages. The system was designed with integrated mechanical and biological filtration, an anti-corrosion resin coating, and a rotating cultivation platform to improve nutrient distribution. Evaluation was conducted through analysis of hydrostatic pressure, compressive stress, and shear stress to assess the system's structural safety. Results show that the tank capacity reaches 507.76 L with a hydrostatic pressure of 3.92×10^{-6} MPa. The compressive stress (2.62 MPa) and shear stress (0.66 MPa) are below the material's allowable limits, indicating that the structure is safe for operation. The system also demonstrated stable water circulation and filtration efficiency. The rotation mechanism has the potential to improve the distribution of light, oxygen, and nutrients more evenly. This study indicates that the proposed aquaponics system is suitable for implementation in urban environments and has the potential to be developed as a sustainable food production system.

INTRODUCTION

Rapid urbanization has led to a decline in the availability of productive land, particularly in densely populated urban areas. This situation has driven the need for innovative, efficient, space-saving, and environmentally sustainable food production systems. Aquaponics, as an integrated system combining aquaculture and hydroponics in a recirculating environment, has emerged as a promising solution due to its efficiency in water and nutrient use and its potential to support food production in urban areas (Goddek et al., 2019).

Previous studies have shown that aquaponic systems can improve water use efficiency and crop productivity in controlled environments. Additionally, various system configurations and cultivation techniques have been developed to optimize

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plant growth and fish production (Fang et al., 2017; Suhl et al., 2018). However, most research still focuses on biological and environmental aspects, with relatively limited attention paid to mechanical design and structural analysis of the system. Consequently, critical aspects such as structural stability, material strength, and the role of mechanical innovations in enhancing system performance remain largely unexplored (Chary et al., 2025).

Nevertheless, in practical implementation, aquaponic systems still face various technical challenges. In many small- to medium-scale systems, limitations are often observed in water circulation efficiency, uneven nutrient distribution, and the accumulation of solid waste due to suboptimal filtration performance (Goddek et al., 2019; Saufie et al., 2020). Additionally, conventional static aquaculture systems can lead to uneven distribution of light and oxygen, which can ultimately affect the overall stability and performance of the system. These conditions highlight the need to develop alternative system designs that integrate mechanical innovations with effective filtration systems and structural reliability to improve overall system performance (Maucieri et al., 2018; Zou et al., 2016).

Modifications to mechanical design offer the potential to significantly improve the performance of aquaponic systems. The implementation of a rotary cultivation platform can support more even distribution of light, oxygen, and nutrients, which is crucial for plant growth. Additionally, the integration of mechanical and biological filtration systems plays a key role in maintaining water quality and creating a stable environment for fish and plants. Structural considerations, such as corrosion resistance and load-bearing capacity, are also important factors in ensuring the long-term sustainability of the system (Petropoulos et al., 2016; Widodo & Iswanto, 2022).

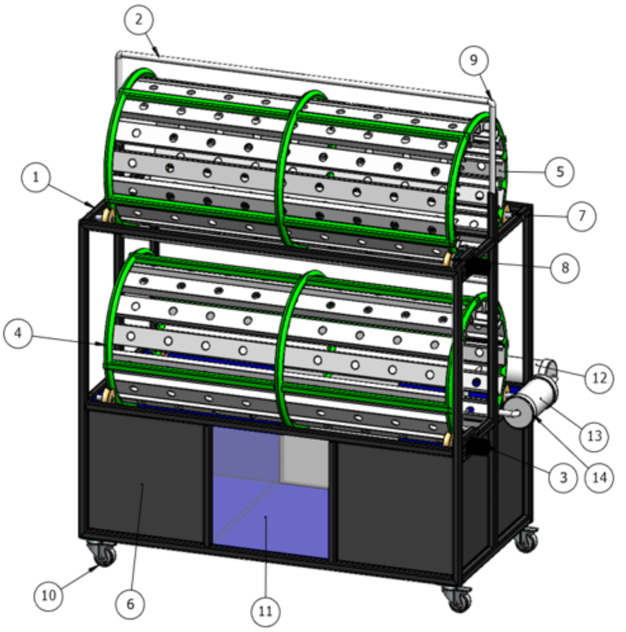
Therefore, this study aims to design and evaluate a double-rotary-table-based aquaponic system modified from a conventional hydroponic system. This system was developed through the integration of filtration units, corrosion protection, and structural improvements. Technical analyses, including hydrostatic pressure and structural stress, were conducted to assess the system's safety and feasibility.

The main contribution of this study lies in the integration of mechanical design and engineering analysis within the aquaponic system, thereby providing a more comprehensive understanding of the system's structural performance and operational feasibility. The developed system is expected to serve as a compact and adaptable solution for urban agriculture applications, particularly in areas with limited land.

METHODS

This study employs the Design and Development Research method based on an engineering approach to develop and analyze the performance of a double-rotary-table-based aquaponics system (Jiao et al., 2021; Song et al., 2024; Wynn & Clarkson, 2018). The research stages include design, fabrication, testing, and evaluation of the prototype (Das & Yang, 2022). The initial system, a double rotary table hydroponic system, was modified into an integrated aquaponic system by adding a fish tank, a filtration system, and a closed-loop water circulation configuration. The developed system has a tank capacity of 507.76 L and is designed to support the simultaneous cultivation of fish and plants. The modifications include the integration of mechanical and biological filtration to maintain water quality, the application of resin coating and protective paint on the tanks and frame to reduce the risk of corrosion, and the addition of transparent glass panels as an observation medium (Estim et al., 2019). Additionally, the piping system is designed to ensure continuous water circulation within a closed loop. The overall schematic of the aquaponics system is shown in Figure 1.

Surface Roughness Levels and Values						Nominal Size (mm)	General Dimensional Tolerances								
Roughness Grade	µm	Roughness Grade	µm	Roughness Grade	µm		>0.5–3	>3–6	>6–30	>30–120	>120–315	>315–1000	>1000–2000	Nominal Size (mm)	>0.5–3
N12	50	N8	3.2	N4	0.2	Fine	±0.05	±0.05	±0.1	±0.15	±0.2	±0.3	±0.5	Fine	±0.05
N11	25	N7	1.6	N3	0.1	Medium	±0.1	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	Medium	±0.1
N10	12.5	N6	0.8	N2	0.05	Coarse	±0.025	±0.2	±0.5	±0.8	±1.2	±2	±3	Coarse	±0.025
N9	6.3	N5	0.4	N1	0.025	Nominal Size (mm)	>0.5–3	>3–6	>6–30	>30–120	>120–315	>315–1000	>1000–2000	Nominal Size (mm)	>0.5–3



No	Part Name	Material	Size
1	Frame	Hollow	30 × 30
2	Nutrient Channel	PVC	Ø12.7
3	Motor	-	28 watt
4	Rotary Table Frame	Hollow	0.6 × Ø15
5	Plant Media Housing	Light Steel	C75
6	Fish Tank	ST37	-
7	Shaft	ST37	Ø25 × 75
8	Drive Wheel	-	Ø100
9	L Bow	PVC	Ø12.7
10	Wheel	-	Ø100
11	Transparent Glass	Glass	470 × 470
12	Mechanical Filter	PVC	Ø4 Inch × 260
13	Biological Filter	PVC	Ø4 Inch × 260
14	End Cap	PVC	Ø4 Inch
Scale: 1:12		Projection:	
Aquaponic Double Rotary Table			

Fig 1. Design of a double rotary table-based aquaponics system

A technical analysis was conducted to ensure the structural feasibility and safety of the system. The parameters analyzed included hydrostatic pressure, compressive stress, and shear stress acting on the tanks and frame. The calculations were based on the principles of fluid mechanics and material strength, taking into account the properties of the materials used, namely ST37 steel and glass. The analysis results showed that the hydrostatic pressure was 3.92×10^{-6} MPa, the compressive stress was 2.62 MPa, and the shear stress was 0.66 MPa, all of which were below the material's allowable stress limits; therefore, the structure was deemed safe for operation (Sidibé et al., 2023).

The designed system was then fabricated using the specified materials. The main structure uses ST37 steel, while the piping system uses PVC pipes. The fish tank is equipped with transparent glass panels and coated with resin to protect against corrosion (Assaffah & Primaditya, 2020; Kankia et al., 2024). The double rotary table mechanism is driven by an electric motor to enable continuous rotation of the growing medium, resulting in more even distribution of light and nutrients (Kankia et al., 2024; Maucieri et al., 2018; Mohapatra et al., 2020).

System testing was conducted to comprehensively evaluate operational performance. The parameters observed include water circulation stability, filtration system effectiveness, and structural stability during system operation. Additionally, the system's ability to distribute light, oxygen, and nutrients through the implemented rotation mechanism was also observed. Performance evaluation was conducted by analyzing test results to assess the effectiveness of system modifications in enhancing overall stability and operational function. Based on these stages, this research method provides a basis for comprehensively evaluating the performance of the developed aquaponic system, both from structural and operational aspects (Palmitessa et al., 2024; Rihayat, 2016).

RESULT AND DISCUSSION

The design of a double-rotary-table-based aquaponic system was successfully implemented in a compact, integrated mechanical configuration, as shown in Figure 2. The system combines fish and plant cultivation units in a single closed-loop circulation cycle with a tank capacity of 507.76 L, designed to maintain a balance between water volume, fish requirements, and nutrient supply for the plants. The main structure uses ST37 steel, which provides adequate mechanical strength and maintains system stability during operation. The two-cylinder rotating configuration allows for more efficient use of vertical space compared to conventional static systems.

Fig 2. Prototype of a double-rotary-table-based aquaponics system following fabrication

The results of the technical analysis show that the hydrostatic pressure acting on the tank is at a very low level, namely 3.92×10^{-6} MPa, so its contribution to the structural load is relatively insignificant. The compressive stress and shear stress are 2.62 MPa and 0.66 MPa, respectively, which are still well below the material's allowable stress limit. These conditions indicate that the design has an adequate safety margin and is capable of accommodating operational loads without the risk of structural failure under normal conditions. Thus, the system is not only functionally viable but also meets mechanical safety requirements (Danner et al., 2019; Qadeer, 2020).

In terms of performance, the system demonstrates stable water circulation in a closed-loop cycle, supported by effective mechanical and biological filtration that suppresses the accumulation of solid waste (Bargaz et al., 2018; Petropoulos et al., 2016; Siaga et al., 2018). The integration of these two filtration types plays a role in maintaining water clarity and supporting the biological processes occurring within the system. The maintained flow stability indicates that the system configuration is capable of sustaining consistent operational conditions throughout the testing.

The double rotary table mechanism contributes to improved homogeneity in the distribution of light, oxygen, and nutrients within the growing medium. Continuous rotation allows each plant unit to receive more even exposure compared to static systems, thereby reducing the potential for imbalances in resource distribution. This finding aligns with previous studies showing that conventional aquaponic systems tend to experience variations in nutrient distribution, suggesting that mechanical approaches such as rotation could serve as an alternative to improve distribution uniformity within the system (Kotzen et al., 2019; Saufie et al., 2020; Suhl et al., 2018). Conceptually, these conditions can support plant growth stability and improve nutrient utilization efficiency, although quantitative measurements of production yields have not yet been conducted in this study (Martin & Molin, 2019).

More uniform distribution within this system is influenced not only by structural configuration but also by the dynamics of rotational movement, which enables more intense interaction between water, nutrients, and plant roots. This continuous movement contributes to increased homogeneity of the microenvironmental conditions around the plants, which ultimately supports the stability of the system as a whole. This indicates that a mechanically-based design approach not only plays a role in structural aspects but also has implications for improving the system's functional efficiency (Solanki et al., 2017; Zou et al., 2016).

Overall, the developed system shows potential as a compact and adaptive aquaponic solution for urban environments with limited space. The system's primary advantage lies in the combination of structural stability and improved resource distribution through a rotation mechanism. Nevertheless, this study still has limitations regarding quantitative measurements of productivity and energy efficiency. Therefore, further research is needed to evaluate the system's performance more comprehensively and to objectively compare it with other aquaponic configurations.

CONCLUSION

This study successfully developed a double-rotary-table-based aquaponic system with an integrated mechanical configuration in a closed-loop circulation scheme. The developed system demonstrated structural feasibility, as evidenced by hydrostatic pressure, compressive stress, and shear stress values that fell within the material's allowable limits, making it safe for operation under normal conditions. From an operational perspective, the system is capable of maintaining stable water circulation with the support of mechanical and biological filtration. The application of the rotation mechanism contributes to improved distribution of light, oxygen, and nutrients in the growing medium, thereby reducing the limitations commonly encountered in static aquaponic systems.

Overall, the proposed system demonstrates the feasibility of integrating a rotation mechanism into aquaponic design to improve resource distribution and spatial utilization efficiency, particularly in urban environments. However, this study is still limited to qualitative performance evaluation and basic technical analysis. Therefore, further research is needed to quantitatively assess plant and fish productivity, as well as to evaluate energy efficiency and long-term system performance.

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DECLARATIONS

Author contribution

Ibnu Rusdi: Writing-Preparation of original manuscript, Visualization, Investigation, analysis, **Eka Sunitra:** Conceptualization, **Hendra:** Methodology, **Arvanza Sundata:** Improve Content, Data accuracy, **Hanief Anwar Hayat:** Improve Language.

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