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BASIL PERFORMANCE EVALUATION AND WATER QUALITY MONITORING IN A RECIRCULATING AQUAPONICS SYSTEM

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Abstract

Resource scarcity and food security concerns have driven the adoption of innovative farming methods like aquaponics. This sustainable system merges aquaculture and hydroponics, offering a solution to drought and declining soil fertility while efficiently producing both fish and vegetables. The global aquaponics market is projected to more than double by 2028 due to its economic and environmental advantages. This study investigated basil (Ocimum basilicum) growth performance and water quality dynamics in a recirculating aquaponic system stocked with common carp (Cyprinus carpio). The system demonstrated effective nutrient cycling with stable water quality parameters conducive to plant health. Over four weeks, basil exhibited vigorous growth with significant increases in stem length, leaf size, and leaf number. These results highlight aquaponics' potential for efficient resource use and sustainable production of fish and high-value crops. The study provides valuable insights into optimizing aquaponic systems for improved food security and environmental sustainability.

Key words**:** *aquaponics market, basil (Ocimum basilicum), basil performance, water quality*

INTRODUCTION

Feeding a projected global population of 10 billion by 2050 poses a monumental challenge. To meet this demand, food production must increase by 50% [10], but obstacles such as climate change, pollution, and shrinking farmland stand in the way [13]. Despite advancements in agriculture, current production trends are insufficient to meet future needs [5]. A study by Goddek et al. (2019) [13] indicates a notable decline in the global area allocated to agricultural activities over the past five decades. The research indicates that the global agricultural area declined by more than 50% between 1970 and 2013. Addressing the urgent issue of food insecurity, which already affects a billion people, demands innovative solutions in food production systems and practices.

One promising solution is aquaponics, an innovative system that integrates aquaculture (fish farming) and hydroponics (soilless plant cultivation) [27, 33]. Aquaponics stands out as a beacon of sustainability in food production, leveraging circular and biomimetic principles to optimize resource utilization while seamlessly aligning with intensive agricultural practices [24]. This dynamic system presents a promising avenue to address food security challenges posed by climate change, especially in arid regions. Due to practical improvements in design and methodology, which have significantly increased both fish and crop yields and production efficiency, aquaponics is rapidly transitioning from a primarily backyard-based practice to an industrial-scale operation [6].

This approach is rapidly expanding globally. It effectively addresses food security concerns, minimizes water usage, and reduces the environmental impact inherent in traditional agriculture. The statistical data illustrated in Figure 1 delineates the projected market valuation of aquaponics on a global scale from 2017 to 2028. The global aquaponics market reached a valuation of approximately 523.7 million U.S. dollars in 2017, reached 870.60 million dollars in 2022 and is projected to expand to a valuation of about 1,807.29 million U.S. dollars by 2028. This translates to an anticipated compound annual growth rate (CAGR) of approximately 12.9% during the forecast period [12].

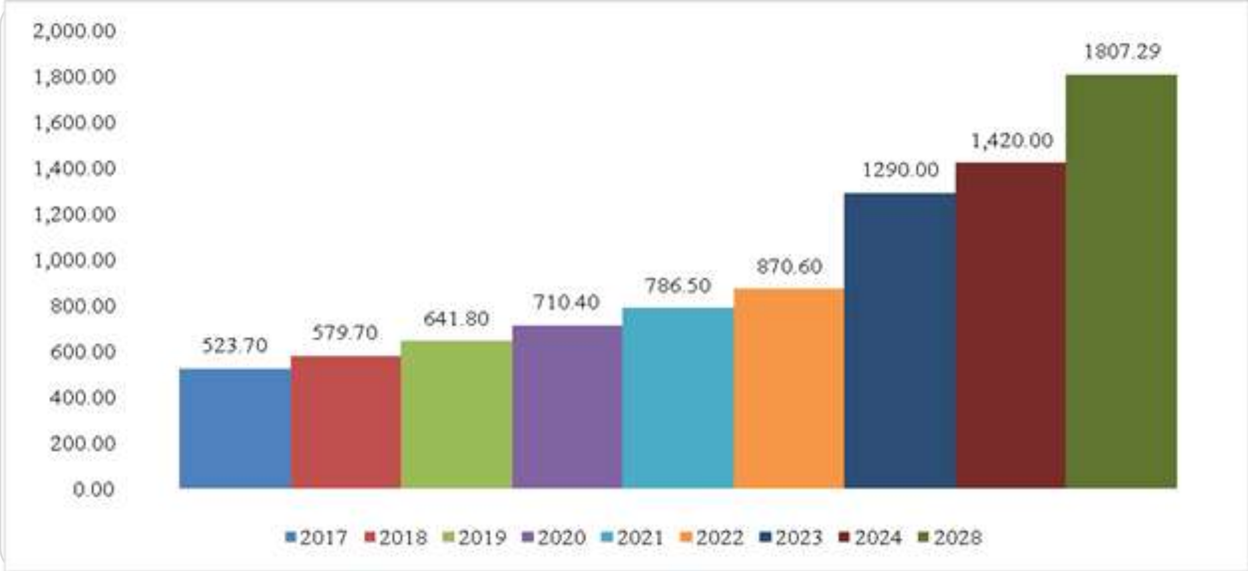

Fig. 1. Global aquaponics market value 2017-2028 (USD Million)
Source: Own representation based on data available on Global Aquaponics Market [12].

North America boasts the world's largest aquaponics market, fueled by the adoption of modern agricultural practices and the growing demand for organic produce. The Asia-Pacific region follows, driven by technological advancements and the need for improved agricultural output in countries like China and India. Europe holds the third-largest market share, benefiting from established infrastructure, user-friendly technologies, and rising incomes. Aquaponics is also gaining traction in Latin America, the Middle East, and Africa due to its low operating costs and the increasing demand for organic food [3].

The European aquaponics market, valued at USD 219.24 million in 2023, is projected to reach USD 565.66 million by 2030, exhibiting a CAGR of 14.5% during the forecast period [9]. The European aquaponics market is thriving, driven by a desire for sustainable, locally produced food. This innovative system combines fish farming and soilless plant cultivation, promoting resource efficiency and environmental responsibility. Market expansion is further fueled by growing awareness of food security, environmental concerns, and consumer preference for fresh, chemical-free produce. With government support, aquaponics is poised for a promising future in European agriculture. The EU Aquaponics Hub initiative (2014-2018) catalyzed aquaponics' growth in Europe by fostering collaboration between research and industry, leading to its recognition as a potential game-changer. Germany leads the European aquaponics sector, accounting for 24.8% of market revenue, due to its advanced agricultural practices, commitment to innovation, and consumer preference for sustainable food. Government support has also significantly contributed to the sector's expansion. France is the fastest-growing region, with a projected CAGR of 14% during the forecast period, driven by consumer demand for eco-friendly and locally sourced produce, coupled with government incentives.

The long-term sustainability of aquaponics is evaluated by examining its environmental, economic, and social impacts.

Economically, these systems require a substantial initial investment, but operating costs are low, and there's a dual income stream from fish and vegetable production.

Environmentally, aquaponics prevents pollution by containing aquaculture waste and allows for better control over water usage and production processes. The absence of chemical fertilizers, pesticides, and herbicides also results in safer food.

Socially, aquaponics enhances quality of life by promoting local food production and culturally relevant crops. It can also create livelihood opportunities, providing food security and income for disadvantaged communities.

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Aquaponic systems have proven versatile, successfully cultivating various plant types, including vegetables, herbs, flowers, and even small trees. These diverse plants have flourished in various aquaponic setups, ranging from research laboratories to residential and commercial operations. Leafy green vegetables such as basil, spinach, and lettuce are particularly well-suited to aquaponic systems due to their ability to efficiently absorb and accumulate nutrients [17, 26].

In the European aquaponics market, leafy greens and herbs collectively represent approximately 67% of the market share. These crops are among the most frequently cultivated and harvested in aquaponic systems across the continent. Leafy greens and herbs flourish in the highly nutritious aquatic environment characteristic of aquaponics.

Their relatively short growth cycles allow for quicker harvesting and higher turnover, further enhancing their marketability. Savidov's Alberta [31] trials showed annual aquaponic yields varied by species, with water spinach and Swiss chard producing 50-60 kg/m², while amaranth, lettuce, and other herbs yielded 20-30 kg/m² (Fig. 2). With robust and consistent consumer demand, these crops represent an attractive option for growers engaged in aquaponics, supplying local markets, restaurants, and supermarkets [9].

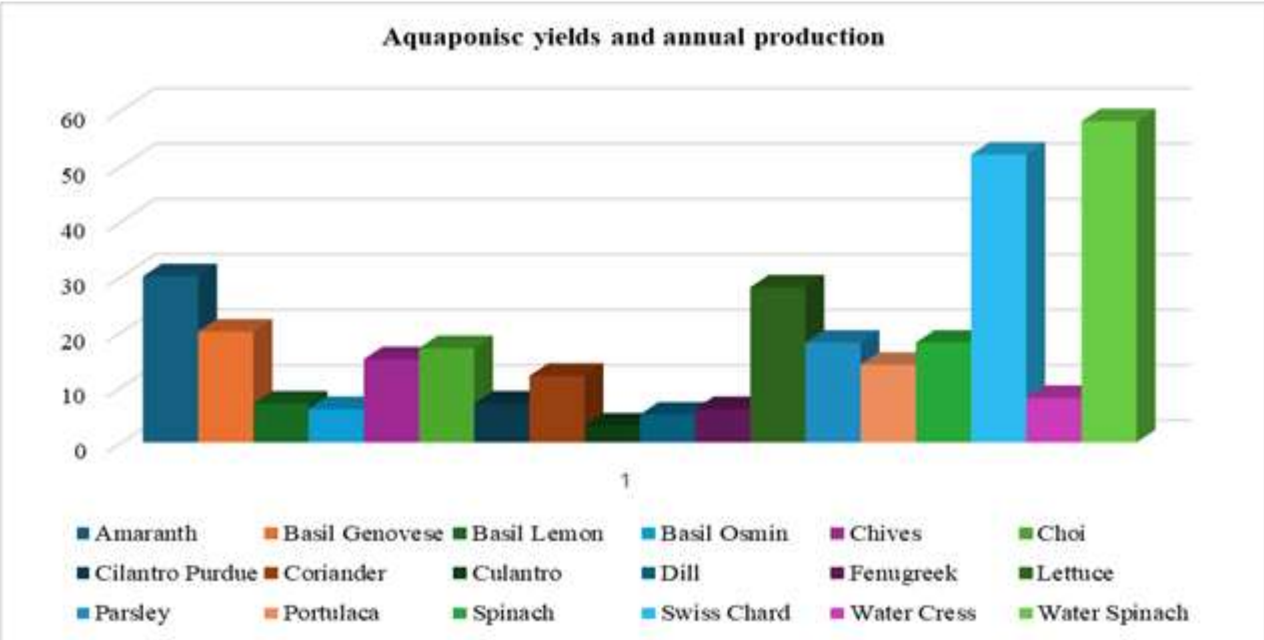

Fig. 2. Aquaponics yields and annual production (kilograms of leafy greens per square meter)
Source: [31].

Furthermore, as many aquaculture investors and farmers seek to improve both environmental and economic sustainability, basil emerges as a prime candidate [18]. Its exceptional ability to absorb nutrients and its high market value make it a particularly attractive option for achieving these combined objectives [8, 28]. The herb basil (*Ocimum basilicum*) dominated plant production in aquaponics, accounting for 81% of all cultivated herbs [19]. Basil is utilized as a medicinal herb and a culinary ingredient, and its dried and fresh forms are staples in many cultures worldwide [1, 2, 23]. The demand for basil among aquaponics and hydroponics producers is high due to the plant's suitability for soilless cultivation [25, 36]. Basil has been used in numerous aquaponics and hydroponics experiments due to these attributes [15, 29]. Under aquaponic production, basil can yield up to 1.8 kg per square meter, significantly higher than its yield in soil cultivation, which is only about 0.6 kg per square meter [4].

Mourantian et al. (2023) [22] found that decoupled aquaponic systems outperformed hydroponics in basil growth and efficiency while using less fertilizer, suggesting aquaponics as a greener option for commercial farming. Modarelli et al. (2023) [21] showed that while basil grown in aquaponics and hydroponics had comparable photosynthesis and fresh biomass, aquaponics yielded higher dry biomass and matter, suggesting its potential for reducing fertilizer use and boosting sustainability.

Bonea (2020) [7] found that basil extracts can stimulate maize seed root and shoot growth, suggesting basil's potential allelopathic influence on plant development.

Given their economic importance, plant species such as basil (*Ocimum basilicum*) warrant further investigation in aquaponics. The present study aimed to monitor the physicochemical parameters of water in a recirculating aquaponic system to facilitate basil (*Ocimum basilicum*) growth. Furthermore, the study evaluated basil performance characteristics, including stem length, leaf length, and the number of true leaves over four weeks.

MATERIALS AND METHODS

Experimental design

In this study, we employed an ecological recirculating aquaculture system for the controlled indoor rearing of fish (Fig. 3). This system mimics the natural nutrient cycles found in aquatic environments. Water flows continuously, starting from the fish tank, passing through filters and plant grow beds, and returning to the fish tank, creating a self-sustaining ecosystem. This symbiotic relationship between fish, plants, and bacteria creates a thriving and balanced environment when properly maintained [11, 16, 32]. The combined cultivation of fish and plants in aquaponics offers economic advantages by generating two crops and boosting production through nutrient recycling and efficient water use. Additional benefits include a smaller environmental footprint, year-round plant production, and the ability to grow organic produce with minimal chemical additives [14].

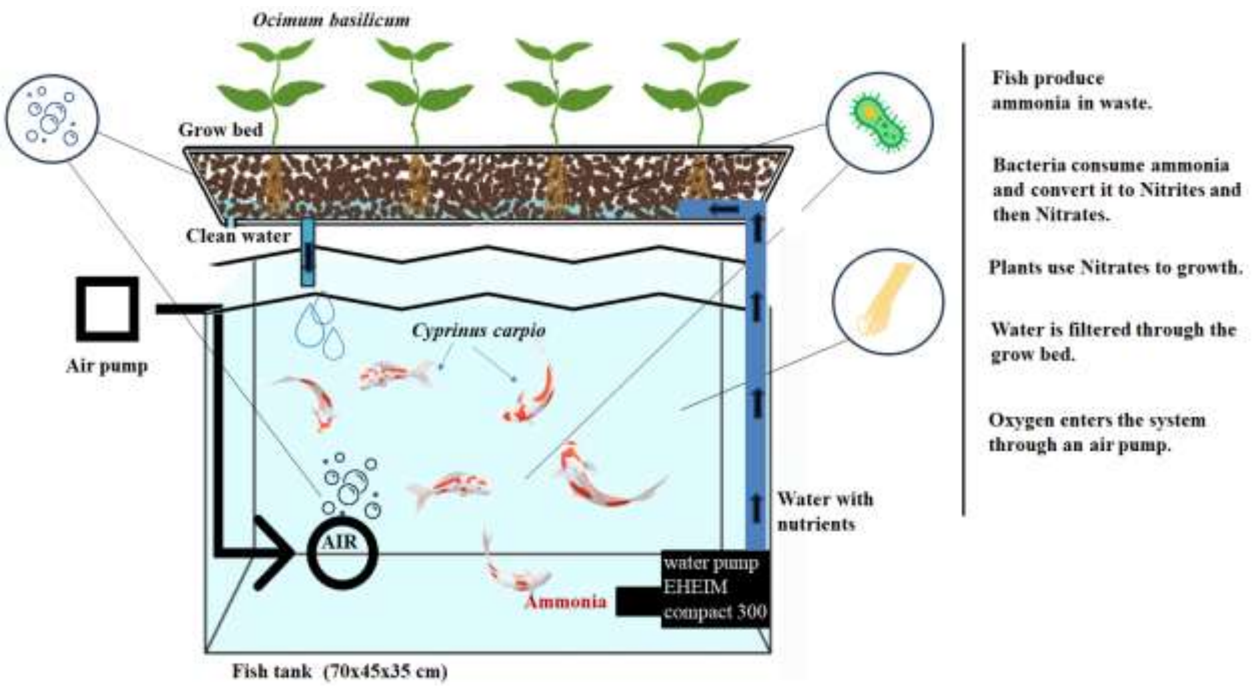

Fig. 3. Aquaponic system with recirculation - schematic representation
Source: Authors' drawing.

The aquaponic system consisted of several key components:

-a reservoir/tank for fish rearing (70x45x35 cm, 100 cm³ volume).

-a biofilter, crucial for providing an environment where bacteria can thrive and carry out the nitrification process.
-biofiltration material (expanded clay) with a specific surface area of 600 m^2/m^3.
-a water recirculation pump (EHEIM compact 300 model) with a capacity of 150-300 l/h to ensure continuous water circulation.
This configuration facilitates effective communication between fish and plants, maintaining a conducive habitat. The four-week experiment integrated an aquaponic system with light-expanded clay substrate, common carp (*Cyprinus carpio*), and basil (*Ocimum basilicum*). Native to Asia, *Cyprinus carpio*, is currently the most cultivated carp species worldwide [34].
The implementation of this system will serve to mitigate the potential for adverse environmental impact, as well as the potential for adverse effects upon carp production (as evidenced by the findings of Mihai et al. (2023) [20].

Water quality parameters

Table 1 outlines the ideal ranges for various water parameters in aquaponics, striking a balance necessary for maintaining optimal water quality and ensuring a thriving ecosystem for both plants and fish.

Table 1. The optimum ranges for aquaponics parameters

Parameter	Optimal range	Reference
pH	6.0–7.0	[38]
Water Temp.	17–34°C	[37]
Dissolved Oxygen	> 5 mg/L	[37]
Electrical conductivity	30–5,000 µS/cm	[35]
Nitrites	0.25–1 mg/L	[38]
Nitrates	5–150 mg/L	[8]

Source: Set up by authors based on the cited references.

Key water parameters were monitored weekly to maintain ideal growth conditions: temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), ammonia content (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-) and phosphate (PO_4^{3-}) levels.

Physical water parameters (DO, temperature, pH, EC) were recorded Monday and Friday at 12:30 pm using a using a HI9811-5 portable meter (Hanna Instruments).
Water samples were collected on Wednesdays and Fridays for analysis of chemical parameters (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}) using an SP-830 Plus spectrophotometer, following ASRO Standard Methods.
Nitrate concentration (NO_3^-) was quantified using the phenol disulphonic acid method. This method involves converting nitrate to nitrite, which is then quantified through the Griess reaction. The Griess reaction involves treating the sample with sulphanilic acid and naphthyl-1-amine in an acidic environment. Ammonia nitrogen (NH_4^+) was quantified spectrophotometrically at 420 nm through the Nessler reagent method. The concentration of phosphate (PO_4^{3-}) was determined through the molybdenum blue method at a wavelength of 720 nm [30].
Instruments were calibrated before determinations to ensure quality and precision.

Basil performance evaluation

Plant performance evaluation assessed basil's developmental stage, overall health, vegetative growth, and adaptation to the aquaponic environment.
Seedling cells (5.6x6.8x5 cm) with a bottom hole for water absorption supported plant seedlings initiated from seeds. Coconut coir, chosen for its water retention and aeration properties, served as the substrate in aquaponic cultivation beds (Photo 1).

Photo 1. *Ocimum basilicum* seedling in the aquaponic system
Source: Original photo obtained through the laboratory experiment.

The following measurements were taken:
-Plant height: base of the stem to the tip of the highest leaf/flower cluster;
-Number of leaves: count of all fully developed leaves;
-Leaf measurement: from the middle of the stem.

RESULTS AND DISCUSSIONS

Water quality parameters

The fluctuations in physicochemical parameters remained within the recommended standards for aquaponics. Table 2 presents the physicochemical characteristics of the water parameters.

The recorded water temperature (23.81 ± 0.61°C) aligns with the recommended range for basil cultivation (20–25°C) proposed by Saha et al. (2016) [29] to enhance market quality and production. The average temperature remained around 23.8°C with slight weekly variations. Temperature significantly influences aquaponics parameters. Temperatures below 17°C hinder nitrification, limiting bacteria production for ammonia/nitrite oxidation. Conversely, high temperatures can restrict calcium absorption by plants.

Initially, conductivity exceeded 250 µS/cm, increased to over 270 µS/cm in the following two weeks, and then declined to 180 µS/cm. The average EC (247.25 µS/cm) indicates moderate dissolved salt levels. Optimal EC for basil in aquaponics ranges from 300 to 600 µS/cm, positively affecting shoot axis height and leaf number [25].

The pH values were slightly acidic, averaging 6.58. Maintaining a pH of approximately 7.0 can achieve equilibrium between nitrification and nutrient availability in aquaponics.

Dissolved oxygen is vital for fish health and nitrifying bacteria. A minimum DO level of 5 ppm is recommended. The average DO (7.31 mg/L) suggests healthy oxygen levels. As expected, dissolved oxygen decreased as temperature increased, as warmer water holds less oxygen.

In well-functioning aquaponic systems, ammonia and nitrite levels typically remain between 0 and 1 mg/L, posing no threat to plants. The average ammonium nitrogen concentration (0.27 ± 0.21 mg/L) fell within this safe range. The mean nitrite concentration was 0.56 mg/L. The monitored parameters stabilized after 28 days, with ammonium and nitrite concentrations dropping, ensuring optimal conditions for the aquaponic system and healthy growth. Nitrates increased from 40 mg/L initially to 140 mg/L in the last week. Nitrates primarily originate from nitrification, where aquaculture waste is broken down into ammonium/ammonia and then converted into nitrates by bacteria. This explains the observed rise in nitrate levels. However, the nitrate concentration remained stable, not exceeding 140 mg/L, likely due to plant absorption and the bacterial community reaching maximum nitrification capacity. Although less toxic than ammonia and nitrites, nitrate levels must be monitored to prevent excessive buildup, which could negatively impact plants and fish.

Table 2. Results obtained to monitoring the water in the aquaponic system

Week No, Day	**T (^{0}C)**	**pH**	**EC µS/cm**	**DO mg O_2/L**	**NH_4^+ mg N/L**	**NO_2^- mg N/L**	**NO_3^- mg N/L**	**PO_4^{3-} mg P/L**
W_1 Monday	23.1	6.81	268	7.93	0.05	0.2	40	0.02
W_1 Friday	23.5	6.53	263	7.68	0.05	0.25	50	0.2
W_2 Monday	24.4	6.65	279	6.82	0.05	0.5	60	0.3
W_2 Friday	24.6	6.37	273	6.42	0.1	0.7	70	0.2
W_3 Monday	24.5	6.23	250	7.02	0.3	0.6	90	0.2
W_3 Friday	24.2	6.74	255	7.23	0.5	1.0	110	0.3
W_4 Monday	23.6	6.56	210	7.52	0.1	0.7	130	0.2
W_4 Friday	23.2	6.72	180	7.88	0.1	0.5	140	0.2
Median value	*23.81*	*6.58*	*247.25*	*7.31*	*0.27*	*0.56*	*55*	*0.20*
Standard deviation	*0.61*	*0.20*	*34.49*	*0.54*	*0.21*	*0.26*	*12.91*	*0.09*

Source: Original data from the experiment.

Phosphates averaged 0.20 ± 0.09 mg/L, indicating rapid absorption by plants, reflecting good plant nutrition.

Basil performance evaluation

Plant performance evaluation involves the collection and analysis of various physical and physiological characteristics of plants to track their growth, health, and overall development.

Table 3 illustrates the biometric measurements of basil (*Ocimum basilicum*) growth and development in an aquaponic system over a four-week period (W_1-W_4).

Throughout the experiment, all plants survived, and no mortality was observed.

Table 3. *Ocimum basilicum* growth parameters

Week No	Stem length (cm)	Number of leaves (pcs)	Leaf length (cm)
W_1	3.5÷4	6÷8	2.5÷3
W_2	14÷15	10÷12	5.1÷5.5
W_3	15.5÷21	16÷18	5.5÷6.2
W_4	29÷35.1	22÷28	5.6÷5.3

Source: Original data from the experiment.

Over four weeks, basil demonstrated notable growth, with consistent increases in stem length, leaf length, and leaf number (Photo 2).

Photo 2. *Ocimum basilicum* thriving in aquaponics: a 4-week journey
Source: Original photo obtained through the laboratory experiment.

Week 1 (W_1): early growth stage with short stems (3.5-4 cm) and small leaves (2.5-3 cm). Limited leaf number (6-8) reflects initial development.

Week 2 (W_2): significant increase in all parameters. Stem length expands to 14-15 cm, leaves grow to 5.1-5.5 cm, and leaf number rises to 10-12, indicating vigorous foliage production.

Week 3 (W_3): continued growth with stem length reaching 15.5-21 cm. Leaves increase to 5.5-6.2 cm, and leaf number grows to 16-18.

Week 4 (W_4): advanced development stage. Stem length peaks at 29-35.1 cm. Leaves reach maximum size (5.6-6.3 cm), and leaf number reaches its highest point (22-28), reflecting a dense and vigorous crown.

Figure 4 depicts healthy and vigorous basil growth. The increase in stem length and number of leaves, coupled with the initial rapid leaf growth, points to successful plant development.

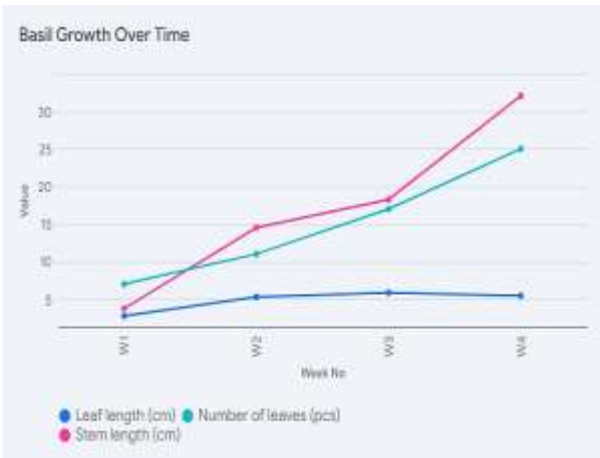

Fig. 4 . The basil plant's growth over four weeks
Source: Original figure.

The plateauing of leaf length in the later weeks suggests that the plant's resources might be shifting towards stem elongation and leaf production rather than further increasing individual leaf size.

Stem length increased consistently, with the most significant growth between W3 and W4, peaking at approximately 30 cm in W4. Leaf length showed a slight increase from W1 to W2 but remained relatively stable afterward, generally under 6 cm. The number of leaves grew steadily, mirroring the stem length pattern, with the most substantial increase between W3 and W4, reaching a maximum of about 25 leaves in W4.

Figure 6 illustrates a clear positive relationship between stem length and the number of leaves. As stem length increases, so does the number of leaves, suggesting a close link between these growth parameters. In contrast, leaf length appears less influenced by growth stages, maintaining relative consistency throughout.

CONCLUSIONS

The escalating global demand for food, coupled with the challenges of climate change, resource depletion, and shrinking arable land, necessitates innovative and sustainable solutions for food production. Aquaponics, an integrated system combining aquaculture and hydroponics, emerges as a promising answer. Its inherent resource efficiency, environmental friendliness, and potential for local food production position it as a viable alternative to traditional agriculture.

Market trends further underscore aquaponics' potential. The global market is projected to experience substantial growth in the coming years, driven by rising consumer awareness and government support. This growth is particularly evident in regions like Europe, where Germany leads the market and France demonstrates rapid expansion. The cultivation of leafy greens and herbs, particularly basil, is a key driver of this growth, given their adaptability to aquaponic systems and strong market demand.

Research highlights the advantages of aquaponics over traditional hydroponics, showcasing its superior nutrient utilization and potential for reducing fertilizer use. Additionally, studies on basil, a prominent crop in aquaponics, suggest its potential to enhance the growth of other plants, underscoring the need for further exploration of its role within aquaponic systems.

Our research findings indicate that an aquaponic system, integrating fish (*Cyprinus carpio*) farming with basil (*Ocimum basilicum*) cultivation, can successfully support the growth of both species. This is achieved by maintaining suitable water quality and promoting increased plant yields.

The collected data demonstrate the optimal functioning of the nitrification process, crucial for converting toxic ammonia into nitrates, essential nutrients for plants. The low levels of ammonia and nitrites, along with the steady rise in nitrate levels, confirm the effectiveness of nitrifying bacteria in maintaining a safe environment for fish.

The evolution of the basil plant over the four-week observation period reveals an accelerated growth pattern, marked by substantial increases in stem length, leaf size, and leaf number. The study underscores the potential for rapid growth and robust development in basil plants. This accelerated growth suggests that basil is a resilient and adaptable plant, capable of thriving in favorable conditions. Understanding these growth patterns can help optimize basil cultivation and maximize production. Moreover, the study highlights the adaptability and resilience of basil, demonstrating its potential for high yields in aquaponic environments.

This study serves as a steppingstone towards a more comprehensive understanding of aquaponics and its role in shaping a sustainable future for food production.

Overall, aquaponics represents a promising avenue for addressing the complex challenges of food security in the 21st century. Its environmental, economic, and social benefits make it an attractive option for a wide range of stakeholders, from small-scale farmers to large commercial operations. As research and technology continue to advance, aquaponics has the potential to play a pivotal role in shaping a more sustainable and food-secure future.

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