Vol. 21(2), pp. 131-138, February, 2025
DOI: 10.5897/AJAR2024.16821
Article Number: 4D89AD472994
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

*Full Length Research Paper*

# Barley (*Hordeum vulgare* L.) productivity and nutritive value in aquaponic versus hydroponic systems

**Angham Bani Owdeh[1,2], Muayad Salman[3]*, Maria Chikha[4] and Mohamed Salah Romdhane[1]**

[1]Aquatic Ecosystems and Resources Laboratory, National Institute of Agricultural Sciences, University of Carthage, 1082 Tunis, Tunisia.
[2]General Directorate of Fisheries and Aquaculture, Ministry of Agriculture, Palestine.
[3]Department of Ruminant, General Directorate of Extension and Rural Development, Ministry of Agriculture, Palestine.
[4]Laboratory of Science and Techniques for Living, Institute of Agricultural and Veterinary Sciences, Mohamed Cherif Messaadia University, BP 41000 Souk Ahras, Algeria.

Received 16 November, 2024; Accepted 9 January, 2025

**This study evaluated the effects of aquaponic and hydroponic systems on the germination and growth of barley (*Hordeum vulgare* L.) in Nablus, West Bank, Palestine. A randomized complete block design with three treatments was employed. Barley seeds were pre-treated through washing, disinfection, and soaking, and germination was conducted in polyethylene trays under three conditions: aquaponic with tilapia, hydroponic with tap water, and hydroponic with a commercial nutrient solution. Growth parameters, including fresh and dry weights of barley sprouts, were measured on days 7 and 14. Water quality parameters, such as total dissolved solids, electrical conductivity, pH, nitrite, nitrate, chlorine, carbonate, total hardness, and temperature, were monitored throughout the study. On day 7, the average fresh weight of barley trays was 7.13 kg, increasing to 10.21 kg by day 14. The aquaponic system exhibited superior performance, achieving a mean fresh weight of 11.80 ± 0.231 kg on day 14, compared to 9.27 ± 0.202 kg and 9.58 ± 0.219 kg in the hydroponic treatments. Additionally, barley grown in the aquaponic system had the highest dry matter net weight (1.963 ± 0.035 kg) and crude protein content (19%) by day 14. These findings highlight the potential of aquaponic systems to enhance barley growth and nutrient content compared to hydroponic systems.**
**of aquaponic systems to enhance barley growth and nutrient content compared to hydroponic systems.**
**barley growth and nutrient content compared to hydroponic systems.**

**Key words:** Aquaponics, hydroponics, barley, growth performance, water quality, crude protein.

## INTRODUCTION

Barley (*Hordeum vulgare* L.) is a staple crop that plays a vital role in ensuring global food security and economic stability. With the growing interest in controlled environment agriculture, techniques such as aquaponics and hydroponics are being explored for barley cultivation. These innovative systems offer the potential to enhance

*Corresponding author. E-mail: moayednas@yahoo.com.

barley productivity and nutritional quality by providing precise control over environmental factors and nutrient delivery (FAO, 2013; Bernstein, 2011).

Aquaponics integrates fish farming with hydroponic plant cultivation, where fish waste is transformed by microbes into nutrients suitable for plant uptake, creating a closed-loop, resource-efficient system (Somerville et al., 2014; Tomlinson, 2015). Similarly, hydroponics allows for soil-free cultivation by using nutrient solutions to optimize plant growth, yield, and quality (Gruda, 2009; Salo, 2019).

Farmers face numerous challenges, including limited land and water resources, labor demands, and inconsistent access to high-quality fodder. This underscores the need for alternative cultivation methods. Aquaponics and hydroponics present promising solutions by using less water and reducing the need for chemical fertilizers, thereby addressing some of these issues (Bernstein, 2011; Terefe and Mengistu, 2022). Moreover, hydroponic barley offers higher nutritional content, which is beneficial for livestock feed and aligns with the goal of improving feed efficiency and animal productivity (Salo, 2019; El-Morsy et al., 2013).

Aquaponics and hydroponics are innovative agricultural systems that offer significant potential for enhancing the productivity and nutritional value of barley. Aquaponics combines aquaculture with hydroponics, creating a symbiotic environment where fish waste provides organic nutrients for plants, while plants help purify the water for fish. This system maximizes resource efficiency, reduces water usage, and eliminates the need for chemical fertilizers, leading to faster growth rates and higher yields (Rakocy et al., 2006; Love et al., 2015).

Hydroponics, on the other hand, provides a controlled environment for precise nutrient management, optimizing plant growth and enhancing nutritional content. Research indicates that hydroponically grown plants can have higher concentrations of essential nutrients, such as vitamins and minerals, compared to their soil-grown counterparts (Resh, 2012; Saha et al., 2016). These systems also support sustainable agriculture by reducing the carbon footprint and promoting local food systems (Goddek et al., 2015). Although initial setup costs can be high, the long-term benefits of reduced input costs, higher yields, and year-round production can offset these investments (Quagrainie et al., 2017). Further research is needed to optimize conditions for barley in these systems, but their potential to meet future food security challenges is promising (Tyson et al., 2011).

Despite these advantages, extensive research is necessary to evaluate the feasibility and effectiveness of these systems for barley cultivation. Recent studies have highlighted the potential of soilless farming systems to boost barley productivity and nutritional value, but there is limited comparative data on aquaponic versus hydroponic barley production (Fussy and Papenbrock, 2022; Naik et al., 2011). This study aimed to bridge this knowledge gap by comparing barley growth performance, yield, and nutritional quality when cultivated in aquaponic versus hydroponic systems. The present findings will contribute to advancing sustainable agricultural practices and enhancing the nutritional quality of barley-based products, thereby promoting global food security and agricultural sustainability.

## MATERIALS AND METHODS

### Ethical approval

The study was conducted in accordance with ethical standards. However, it is important to note that there is no specialized committee in Palestine to provide formal ethical approval for this type of research. All efforts were made to ensure the welfare and ethical treatment of any subjects involved in the study.

### Location and experimental design

The experimental trial was conducted in the Nablus governorate within the West Bank, Palestine, from December 20, 2023, to January 4, 2024, utilizing barley seeds to investigate germination and growth in hydroponic and aquaponic systems. The barley seeds underwent a meticulous preparation process, involving thorough washing, disinfection, and a 24-h soaking period. Post-treatment, the seeds were placed in locally crafted polyethylene trays measuring 90 by 30 cm and kept moist for an additional 48 h to ensure optimal germination under uncontrolled conditions. The germination process was carried out without any adjustments to temperature, light, or humidity. Each tray contained 1 kg of local barley, and the sprouted seeds were subsequently introduced into both hydroponic and aquaponic systems for growth trials.

The study comprised three groups/treatments, each consisting of three barley trays. In the first group, trays were connected to a 150 L fish tank containing 33 tilapias (*Oreochromis niloticus*), each weighing approximately 100 g, and fed a diet produced by a local feed mill, equivalent to 1% of their body weight daily (feed composition detailed in Table 1). The second group's trays were irrigated with tap water, while the third group's trays were irrigated with tap water supplemented with 1,400 mL of nutrient solution (composition details in Table 2). Barley sprouts were weighed on days 7 and 14. On each of these days, triplicate samples were collected, dried at 60°C, ground through a 1 mm sieve, and preserved for chemical analyses.

Throughout the experiment, water quality parameters, including total dissolved solids (TDS), electrical conductivity (EC), pH, nitrite (NO2), nitrate (NO3), chlorine (Cl2), carbonate, total hardness, and temperature, were closely monitored to assess environmental conditions.

### Chemical analyses

Chemical analyses were conducted at the National Agricultural Research Center Lab Ministry of Agriculture, Palestine. Moisture content ($H_2O$) and dry matter (DM) were determined by drying the samples at 60°C for 48 h in a forced-air oven (Protherm PFL 110/10 muffle furnace). Nitrogen (N) content was measured using the Kjeldahl method and crude protein (CP) was calculated by multiplying the nitrogen value by 6.25 (AOAC, 1990). Ash levels were determined by incinerating plant samples at 550°C for 4 h in a

**Table 1.** Nutrient composition of the tilapia feed used in this experiment.

| Nutrient | Percentage |
|---|---|
| Protein | 35 |
| Fat | 6 |
| Wet | 10 |
| Cellulous | 5 |
| Ash | 8 |
| Calcium | 17 |
| Phosphorus | 1.2 |
| Salt | 0.7 |

**Table 2.** Composition of the nutrient solution used in the barley hydroponic treatment (Group 3).

| Nutrient type | Nutrient component | Source | Concentration (mg/L) |
|---|---|---|---|
| **Macronutrient** | | | |
| Nitrogen (N) | Nitrate/Ammonium | Nitrate salts | 180 |
| Phosphorus (P) | Phosphate | Mono-potassium phosphate (MKP) | 60 |
| Potassium (K) | Potassium salt | Potassium sulfate ($K_2SO_4$) | 250 |
| Calcium (Ca) | Calcium salt | Calcium nitrate ($Ca(NO_3)_2$) | 120 |
| Magnesium (Mg) | Magnesium salt | Magnesium sulfate ($MgSO_4$) | 40 |
| Sulfur (S) | Sulfate | Sulfate salts | 25 |
| **Micronutrient** | | | |
| Iron (Fe) | Chelated iron | Iron chelates | 2.5 |
| Manganese (Mn) | Manganese salt | Manganese sulfate ($MnSO_4$) | 0.75 |
| Zinc (Zn) | Zinc salt | Zinc sulfate ($ZnSO_4$) | 0.75 |
| Copper (Cu) | Copper salt | Copper sulfate ($CuSO_4$) | 0.25 |
| Boron (B) | Boron compound | Boric acid ($H_3BO_3$), | 0.75 |
| Molybdenum (Mo) | Molybdenum salt | Sodium molybdate ($Na_2MoO_4$) | 0.075 |

Protherm PFL 110/10 muffle furnace.

To determine crude fiber content, the dried samples were ground so that the material passed through a 1 mm mesh sieve. The analysis involved two main steps. First, samples were boiled in a neutral detergent solution containing sodium lauryl sulfate for one hour, and the resulting residue, representing neutral detergent fiber (NDF), was collected by filtration. Next, the NDF residue was boiled in an acid detergent solution, composed of sulfuric acid and cetyl trimethyl ammonium bromide, for another hour. The remaining acid detergent fiber (ADF) residue was filtered, dried at 105°C, and then ignited in a muffle furnace at 550°C for four hours to determine the ash content.

Crude fiber content was calculated as a percentage of the original sample weight based on the weight of the ADF residue, using the method outlined by Soest et al. (1991). This is a widely accepted approach in animal nutrition and feed analysis for assessing the fiber content of feedstuffs.

#### Statistical analyses

Statistical analyses were conducted using the general linear model (GLM) procedure in the software package SPSS 22 (IBM® NY, USA). The analysis used a completely randomized model with three treatments, three replicates, and two sampling points (7 and 14 days). The model is represented in Equation 1:

$$Yij = \mu + Ti + Dj + eij \quad (1)$$

In Equation 1, Yij represents the observation, μ represents the overall mean, Ti represents the the effect of the treatments (T1, T2, T3), Dj indicates the day the plants were sampled (7 days, 14 days), and eij represents the residual error. To identify statistical differences, a threshold of $P < 0.05$ was used, while trends were identified at $0.05 < P < 0.10$.

## RESULTS

### Water quality

Table 3 presents a comprehensive analysis of water quality parameters across three distinct treatments over specified time intervals: Day 1, Days 2 to 7 and Days 8 to 14. The parameters assessed include Total Hardness (TH), Nitrate ($NO_3$-), Nitrite ($NO_2$-), Chlorine ($Cl_2$), Total

**Table 3.** Water quality parameters on day 1, from day 2 to day 7, and from day 8 to day 14 in the 3 different treatments.

| Parameter | T-D | | | | | | |
|---|---|---|---|---|---|---|---|
| | $D_1$ | $T_1D_{2\text{-}7}$ | $T_2D_{2\text{-}7}$ | $T_3D_{2\text{-}7}$ | $T_1D_{8\text{-}14}$ | $T_2D_{8\text{-}14}$ | $T_3D_{8\text{-}14}$ |
| TH (mg/l) | $225^{ab}\pm5.0$ | $125^{c}\pm3.5$ | $112.5^{c}\pm4.0$ | $225^{ab}\pm5.0$ | $235^{ab}\pm6.0$ | $150^{cb}\pm4.5$ | $257^{b}\pm5.5$ |
| $NO_3$- mg/l) | $50^{a}\pm1.2$ | $39^{a}\pm1.0$ | $43^{a}\pm1.1$ | $203^{b}\pm2.5$ | $32^{a}\pm0.8$ | $30^{a}\pm0.7$ | $130^{c}\pm1.8$ |
| $NO_2$- mg/l) | $1.66^{a}\pm0.1$ | $5.83^{a}\pm0.2$ | $4.83^{a}\pm0.2$ | $22.5^{c}\pm0.5$ | $0.28^{a}\pm0.05$ | $3.14^{a}\pm0.1$ | $14.71^{b}\pm0.3$ |
| $Cl_2$ (mg/l) | $0.15^{a}\pm0.01$ | $0.016^{a}\pm0.002$ | $0.016^{a}\pm0.002$ | $0.016^{a}\pm0.002$ | $0^{a}\pm0.0$ | $0^{a}\pm0.0$ | $0^{a}\pm0.0$ |
| KH (mg/l) | $140^{ab}\pm3.0$ | $200^{b}\pm4.0$ | $120^{ac}\pm2.5$ | $60^{cd}\pm1.5$ | $202^{b}\pm3.5$ | $120^{ad}\pm2.0$ | $0^{c}\pm0.0$ |
| C (mg/l) | $18.66^{ab}\pm0.5$ | $150^{d}\pm3.0$ | $140^{cd}\pm2.5$ | $15.33^{ab}\pm0.4$ | $108.57^{c}\pm2.0$ | $108.57^{c}\pm2.0$ | $0^{a}\pm0.0$ |
| DO (mg/l) | $7.6^{ab}\pm0.2$ | $7.01^{ab}\pm0.1$ | $7.2^{ab}\pm0.1$ | $6.61^{ab}\pm0.2$ | $4.98^{bc}\pm0.3$ | $6.98^{ab}\pm0.1$ | $6.21^{c}\pm0.2$ |
| TDS PPM) | $285.33^{a}\pm10.0$ | $303.5^{a}\pm8.0$ | $314^{a}\pm9.0$ | $1715^{b}\pm15.0$ | $258.42^{a}\pm7.0$ | $250^{a}\pm6.0$ | $1019.28^{c}\pm12.0$ |
| EC(ms/cm) | $462.33^{a}\pm15.0$ | $570.16^{a}\pm12.0$ | $756.33^{a}\pm14.0$ | $3640^{b}\pm20.0$ | $515.57^{a}\pm10.0$ | $500^{a}\pm9.0$ | $2038.14^{c}\pm18.0$ |
| PH | $7.88^{a}\pm0.05$ | $7.63^{ab}\pm0.03$ | $7.59^{ab}\pm0.04$ | $5.79^{c}\pm0.06$ | $7.60^{ab}\pm0.02$ | $7.54^{ab}\pm0.03$ | $5.62^{c}\pm0.05$ |
| Temp | $17.46^{a}\pm0.1$ | $17.16^{ab}\pm0.1$ | $17.43^{a}\pm0.1$ | $17.13^{ab}\pm0.1$ | $17.37^{a}\pm0.1$ | $17.27^{ab}\pm0.1$ | $17.3^{ab}\pm0.1$ |

T-D = Treatment by day; $D_1$=Day 1; $T_1D_{2\text{-}7}$= Barley Aquaponic from day 2 to day 7; $T_2D_{2\text{-}7}$= Barley Hydroponic with tap water from day 2 to day 7; $T_3D_{2\text{-}7;}$ $T_3D_{2\text{-}7}$= Barley Hydroponic with nutrient solution from day 2 to day 7, $T_1D_{8\text{-}14}$= Barley Aquaponic from day 8 to day 14; $T_2D_{8\text{-}14}$= Barley Hydroponic with tap water from day 8 to day 14; $T_3D_{8\text{-}14}$= Barley Hydroponic with nutrient solution from day 8 to day 14. TH= Total Hardness; ($No_{3\text{-}}$) = Nitrate; ($No_{2\text{-}}$) = Nitrite; $Cl_2$= Chlorine; (KH)-= Total Alkality; (C)= Carbonate; DO = dissolved oxygen; TDS= total dissolved solids; EC= Electrical conductivity; PH= acidity; Temp= temperature. Means (N = 18) in the same row with similar letters are not significantly different (P > 0.05).

Alkalinity (KH), Carbonate (C), Dissolved Oxygen (DO), TDS, EC, pH, and Temperature.

The data indicate that TH exhibited a significant variation across the treatments, with values on Day 1 recorded at 225 mg/l, which remained consistent in the Barley Aquaponic treatment from Days 8 to 14. Conversely, the Barley Hydroponic treatment with nutrient solution demonstrated a marked increase to 257 mg/l during Days 8 to 14, suggesting a potential influence of the nutrient solution on hardness levels.

Nitrate concentrations were highest in the Barley Hydroponic treatment with nutrient solution during Days 2 to 7, reaching 203 mg/l, while the other treatments maintained lower levels, particularly in the Barley Aquaponic treatment, which recorded 50 mg/l on Day 1. Notably, Nitrite levels were significantly elevated in the Barley Hydroponic treatment with nutrient solution, peaking at 22.5 mg/l during Days 2 to 7, indicating a potential risk for aquatic life due to increased toxicity.

Chlorine levels remained consistently low across all treatments, with the highest recorded value being 0.15 mg/l on Day 1, suggesting effective management of chlorine concentrations throughout the experimental period. Total Alkalinity (KH) showed a notable decline in the Barley Hydroponic treatment with nutrient solution, dropping to 60 mg/l during Days 2 to 7, which may reflect the impact of nutrient dynamics on alkalinity.

Carbonate levels varied significantly, with the Barley Hydroponic treatment with tap water exhibiting a peak of 150 mg/l during Days 2 to 7, while the Barley Hydroponic treatment with nutrient solution recorded a substantial decrease to 0 mg/l by Days 8 to 14, indicating a potential depletion of carbonate ions.

DO levels were relatively stable across treatments, with the Barley Aquaponic treatment maintaining the highest levels, particularly on Day 1 at 7.6 mg/l. However, a decline was observed in the Barley Aquaponic treatment, which recorded a low of 4.98 mg/l during Days 8 to 14, raising concerns regarding oxygen availability for aquatic organisms.

TDS and EC exhibited significant fluctuations, particularly in the Barley Hydroponic treatment with nutrient solution, which reached alarming levels of 1715 PPM and 3640 ms/cm, respectively, during Days 2 to 7. These elevated values may indicate a high concentration of dissolved substances, potentially detrimental to water quality.

pH levels remained within a relatively narrow range, with the Barley Hydroponic treatment with nutrient solution showing a significant drop to 5.79 during Days 2 to 7, suggesting an acidic shift that could adversely affect aquatic life. Temperature readings were consistent across all treatments, averaging around 17.3°C, indicating stable thermal conditions throughout the study.

## Nutritive values

Table 4 provides a detailed examination of barley net weights and associated chemical analysis values categorized by day and treatment. The parameters assessed include net weight (Nwt), moisture content

**Table 4.** Barley net weights and chemical analysis values by day and treatment.

| Group | Nwt (kg) | $H_2O$ (%) | DM (%) | DMNwt (kg) | Ash (%) | CF (%) | CP (%) | CPNwt (g) |
|---|---|---|---|---|---|---|---|---|
| 7-DT1 | $7.94^{a}$ ±0.173 | $87^{ab}$ ±1.7 | $13^{ab}$ ±1.2 | $0.99^{ab}$ ±0.029 | $9.1^{a}$±0.86 | $17^{a}$ ±2.8 | $16^{b}$±2.8 | $163.31^{ab}$±2.88 |
| 7-DT2 | $6.82^{a}$ ±0.144 | $88^{b}$ ±2.2 | $12^{ab}$±1.5 | $0.773^{a}$ ± 0.025 | $9.3^{a}$ ± 0.94 | $17^{a}$ ± 2.5 | $17^{bc}$ ± 3.7 | $134.83^{b}$ ± 2.5 |
| 7-DT3 | $6.63^{a}$ ±0.115 | $88^{b}$ ± 1.5 | $12^{ab}$±0.8 | $0.756^{a}$ ± 0.02 | $9.3^{a}$ ± 8.5 | $18^{a}$ ± 3 | $13^{a}$ ±2.5 | $101.65^{a}$ ± 2.3 |
| Average | 7.13 | 87.66 | 12.33 | 0.84 | 9.23 | 17.33 | 15.33 | 133.26 |
| | | | | | | | | |
| 14-DT1 | $11.80^{b}$ ±0.231 | $84^{a}$ ± 2.5 | $16^{b}$ ±1.5 | $1.963^{c}$ ± 0.035 | $9^{a}$ ± 0.82 | $22^{a}$ ± 3.5 | $19^{c}$ ± 4.3 | $387.44^{c}$± 3.5 |
| 14-DT2 | $9.27^{c}$ ±0.202 | $86^{ab}$ ± 1.8 | $13^{ab}$± 1.2 | $1.320^{b}$ ± 0.03 | $9.2^{a}$ ± 0.75 | $17^{a}$ ± 2.8 | $17^{b}$ ± 2.9 | $227.18^{b}$ ± 2.8 |
| 14-DT3 | $9.58^{c}$ ±0.219 | $86^{ab}$ ± 2.2 | $0.13^{a}$ ±1.3 | $1.263^{b}$ ± 0.028 | $8.9^{a}$ ±0.78 | $21^{a}$ ± 3.2 | $18^{bc}$ ± 3.1 | $232.15^{b}$ ± 2.90 |
| Average | 10.21 | 85.33 | 14 | 1.51 | 9.03 | 20 | 18 | 282.25 |

$7\text{-}DT_1$=Aquaponic barley grown on day 7; $7\text{-}DT_2$= Hydroponic barley grown in tap water on day 7; $7\text{-}DT_3$= Hydroponic barley grown in tap water with nutrient solution water on day 7; $14\text{-}DT_1$= Aquaponic barley grown on day 14; $14\text{-}DT_2$= Hydroponic barley grown in tap water on day 14; $14\text{-}DT_3$= Hydroponic barley grown in tap water with nutrient solution water on day 14. $N_{wt}$= tray Net weight; $H_2O$= Moisture; DM=Dry Matter; DMNwt = Tray Dry Matter net weight; Ash= Ash Content; CF= Crude Fiber; CP= Crude Protein; $CPN_{wt}$= Total Protein per tray.
Means (N = 18) in the same column with similar letters are not significantly different (P > 0.05).

($H_2O$ %), dry matter (DM %), dry matter net weight (DMNwt), ash content (Ash %), crude fiber (CF %), crude protein (CP %), and total protein per tray (CPNwt). The data reveal that the net weight of barley on Day 7 (7-DT1) in the Aquaponic treatment was recorded at 7.94 kg, which is significantly higher than the net weights observed in both Hydroponic treatments (7-DT2 and 7-DT3), which were 6.82 and 6.63 kg, respectively. This suggests a potential advantage of the Aquaponic system in promoting biomass accumulation during the early growth phase. Moisture content was notably high across all treatments on Day 7, with values ranging from 87 to 88%. However, the moisture content decreased in the Aquaponic treatment on Day 14 (14-DT1) to 83%, indicating a possible reduction in water retention as the plants matured.

The dry matter percentage remained relatively consistent across treatments, with values around 13% on Day 7, while a significant increase to 16% was observed in the Aquaponic treatment on Day 14.

The dry matter net weight (DMNwt) exhibited a marked increase in the Aquaponic treatment on Day 14 (14-DT1), reaching 1.963 kg, which is substantially higher than the values recorded for the Hydroponic treatments on the same day (14-DT2 and 14-DT3), which were 1.320 and 1.263 kg, respectively. This finding underscores the efficacy of the Aquaponic system in enhancing dry matter accumulation over time.

Ash content remained relatively stable across treatments, with values around 9% on Day 7 and slightly varying on Day 14.

Crude fiber percentages were consistent, with the Aquaponic treatment on Day 14 (14-DT1) exhibiting the highest value at 22%, suggesting an increase in fibrous material as the plants matured.

Crude protein content varied among treatments, with the Aquaponic treatment on Day 14 (14-DT1) yielding the highest protein content at 19%. In contrast, the Hydroponic treatments on Day 14 (14-DT2 and 14-DT3) recorded lower protein levels of 17 and 21%, respectively.

The total protein per tray (CPNwt) also reflected these trends, with the Aquaponic treatment on Day 14 (14-DT1) achieving a substantial total protein yield of 387.44 g, significantly surpassing the yields from the Hydroponic treatments.

## DISCUSSION

### Water quality

The analysis of the results from this study underscores the pivotal role of water quality parameters as indicators of the health and efficiency of aquaponic and hydroponic systems. These parameters were maintained within the recommended ranges for optimal crop yield, thereby demonstrating the effectiveness of both cultivation methods.

Notably, the aquaponic system exhibited stability in Total Hardness (TH), which aligns with the findings of Ayipio et al. (2019a), suggesting that aquaponics can sustain balanced nutrient levels through its integrated nutrient recycling process. This stability is crucial for maintaining crop yields, as emphasized by Rakocy et al. (2006), who highlight the importance of nutrient balance in aquaponic systems.

In contrast, the study revealed a decline in nitrate levels over time within the aquaponic system, while the hydroponic system experienced a significant increase.

This discrepancy underscores the potential for nutrient accumulation in hydroponics, which may not be utilized as efficiently as in aquaponics. The meta-analysis conducted by Ayipio et al. (2019b) supports the notion that aquaponics can maintain nutrient balance, potentially leading to yields comparable to hydroponics despite lower initial nutrient concentrations. This assertion is further corroborated by Graber and Junge (2009), who emphasize the efficient nutrient utilization inherent in aquaponic systems. The observed increase in nitrite concentrations within the hydroponic system, particularly following nutrient solution additions, raises concerns regarding plant health and yield, as nutrient imbalances are more pronounced in hydroponic systems. Although, Ayipio et al. (2019a) do not specifically address nitrite levels, the variability observed could be detrimental, as noted by Lennard and Leonard (2006), who discuss the challenges associated with maintaining nutrient balance in hydroponic systems.

The increase in Total Alkalinity (KH) within the aquaponic system is consistent with findings that indicate this culture system can effectively maintain nutrient balance, which is essential for optimal plant growth. Love et al. (2015) emphasize the role of aquaponics in sustaining nutrient levels, further supporting our results. Conversely, the decrease in DO levels in the hydroponic system could pose risks to plant health. The integration of aquaculture into hydroponic systems—termed aquaponics—may better support oxygen levels and enhance plant growth, a point also noted by Rakocy et al. (2006). The significant increase in TDS and EC in the hydroponic system with the addition of nutrient solutions indicates potential nutrient accumulation. While nutrient supplementation can lead to higher yields, excessive accumulation may not be beneficial, as highlighted by Resh (2013), who discusses the risks associated with nutrient imbalances in hydroponics. The pH in the hydroponic system was recorded below 6, indicating potential acidification, whereas aquaponics maintained a more stable pH. A stable pH is critical for nutrient uptake and overall plant health, as reported by Graber and Junge (2009).

Overall, the stability in water quality parameters observed in the aquaponic system suggests that such systems can maintain more consistent nutrient levels and conditions, potentially leading to comparable or even superior crop yields relative to conventional hydroponics, as clearly demonstrated in this study. The variability and nutrient accumulation observed in hydroponics may not always translate into improved yields, underscoring the importance of balanced nutrient management in both systems (Ayipio et al., 2019a). This finding is consistent with other studies, such as those by Eck et al. (2019) and Tetreault et al. (2023), which also emphasize the advantages of aquaponics in maintaining nutrient stability and promoting plant health.

**Nutritive value**

The evaluation of growth metrics and nutritional composition of barley cultivated in aquaponic and hydroponic systems provides valuable insights into their respective efficiencies and impacts on crop quality. The results indicate that barley grown in aquaponic systems consistently achieved higher net weights compared to those grown hydroponically, suggesting that the nutrient-rich environment of aquaponics enhances growth potential. This observation is supported by previous research, which highlighted the benefits of aquaponic systems in promoting optimal growth rates through the integration of aquaculture, thereby supplying essential nutrients to the plants (Partap et al., 2023). Moisture content emerged as another critical parameter analyzed in this study. The data reveal that barley grown in aquaponic systems exhibited a slightly lower, though not statistically significant, moisture percentage than hydroponically grown barley at the 7-day mark. However, as the barley matured over the 14-day treatment period, moisture content decreased across all groups, potentially indicating a shift in resource allocation as the plants developed. This trend aligns with existing literature, which suggested that microgreens often display varying moisture levels based on their growth conditions and maturity, underscoring the dynamic nature of plant development across different cultivation systems (Ghoora et al., 2020a, b).

The analysis of dry matter percentages reveals noteworthy trends. While the 7-day treatments show relatively low dry matter percentages, the 14-day treatments indicate a slight, although not statistically significant, increase, particularly in aquaponically grown barley. This increase suggests that aquaponic systems may enhance the efficiency of nutrient conversion into biomass over time. Previous studies support this notion, indicating that aquaponic systems can lead to higher dry matter accumulation in seedlings due to improved nutrient availability and uptake (Zhang et al., 2021).

Ash content remained relatively stable across the different treatments, indicating that the mineral content of the barley was not significantly influenced by growth conditions in the short term. This stability is consistent with findings from other studies that report uniform ash content in herb shoots, regardless of the cultivation method employed (Jambor et al., 2022).

Crude fiber values exhibited a slight increase across all groups between days 7 and 14, particularly for aquaponically grown barley. This rise in fiber content may enhance the health benefits of barley, as dietary fiber is known to support digestive health. This finding is corroborated by literature that highlighted the potential of soilless greens as a valuable source of dietary fiber (Ayoub, 2003).

Finally, crude protein values increased over the 14-day

treatment period, especially for aquaponically grown barley. This trend of increasing protein levels over time supported previous findings that microgreens, particularly those cultivated in nutrient-rich environments like aquaponics, can provide enhanced protein content (Partap et al., 2023).

The total protein content per tray (CPNwt) also reflects this increase, underscoring the nutritional advantages of aquaponically grown barley. This observation is consistent with studies by Partap et al. (2023) and Pinho et al. (2021), which reported higher protein levels in crops grown in aquaponic systems compared to traditional methods.

## Conclusion

In the present study, the cultivation of barley in both aquaponic and hydroponic systems was evaluated, with a particular focus on the integration of tilapia production as a distinctive advantage of aquaponics. The aquaponic system not only facilitated enhanced growth of barley but also contributed an additional protein source through tilapia farming. The findings indicate that the net weight of barley was significantly greater in the aquaponic system (11.80 kg) compared to the hydroponic systems (9.27 and 9.58 kg), and the crude protein content of the barley was notably higher (19%). The inclusion of tilapia production underscores the additional benefits of aquaponics, presenting a sustainable agricultural approach that enhances both plant and protein production.

## ACKNOWLEDGEMENTS

The authors express their gratitude to Prof. Anthony Kurt Gamperl, Department of Ocean Sciences, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador, Canada, for providing comprehensive technical support.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## REFERENCES

Ayipio E, Kim SH, Kim JK, Roh SW (2019a). Comparison of the growth of lettuce (Lactuca sativa) in hydroponic and aquaponic systems. Journal of Plant Nutrition 42(14):1629-1635.

Ayipio E, Wells DE, McQuilling A, Wilson AE (2019b). Comparisons between aquaponic and conventional hydroponic crop yields: A meta-analysis. Sustainability (11)6511.

Ayoub NA (2003). Unique phenolic carboxylic acids from Sanguisorba minor. Phytochemistry 63(4):433-436.

Bernstein S (2011). Aquaponic gardening: A step-by-step guide to raising vegetables and fish together. Gabriola Island: New Society Publishers.

Eck M, Körner O, Jijakli MH (2019). Nutrient cycling in aquaponics systems. In: Goddek S, Joyce A, Kotzen B, Burnell GM (eds) Aquaponics Food Production Systems. Springer, Cham. https://doi.org/10.1007/978-3-030-15943-6_9.

El-Morsy AT, Abul-Soud M, Eman MSA (2013). Localized hydroponic green forage technology as a climate change adaptation under Egyptian conditions. Research Journal of Agriculture and Biological Sciences 9(6):341-350.

FAO (2013). Statistical year book 2013 World Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome.

Fussy A, Papenbrock J (2022). An overview of soil and soilless cultivation techniques: Chances, challenges and the neglected question of sustainability. Plants 11(9):1153 https://doi.org/10.3390/plants11091153.

Ghoora MD, Babu DR, Srividya N (2020a). Nutrient composition, oxalate content and nutritional ranking of ten culinary microgreens. Journal of Food Composition and Analysis 91: Article 103495.

Ghoora MD, Haldipur AC, Srividya N (2020b). Comparative evaluation of phytochemical content, antioxidant capacities and overall antioxidant potential of select culinary microgreens. Journal of Agriculture and Food Research 2: Article 100046.

Goddek S, Delaide B, Mankasingh U, Ragnarsdottir K, Jijakli M, Thorarinsdottir R (2015). Challenges of sustainable and commercial aquaponics. Sustainability 7(4):4199-4224. https://doi.org/10.3390/su7044199.

Graber A, Junge R (2009). Aquaponic systems: Nutrient recycling from fish wastewater by vegetable production. Desalination 246(1-3):147-156. https://doi.org/10.1016/j.desal.2008.03.048.

Gruda N (2009). Do soilless culture systems have an influence on product quality of vegetables? Journal of Applied Botany and Food Quality 82:141-147.

Jambor T, Knizatova N, Valkova V, Tirpak F, Greifova H, Kovacik A, Lukac N (2022). Microgreens as a functional component of the human diet: A review. Journal of Microbiology, Biotechnology and Food Sciences 12(1): e5870.

Lennard WA, Leonard BV (2006). A comparison of three different hydroponic subsystems (gravel bed, floating raft, and nutrient film technique) in an aquaponic test system. Aquaculture International 14(3):1-12..

Love DC, Fry JP, Li X, Hill ES, Genello L, Semmens K, Thompson RE (2015). Commercial aquaponics production and profitability: Findings from an international survey. Aquaculture 435:67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023.

Naik PK, Dhuri RB, Singh NP (2011). Technology for production and feeding of hydroponics green fodder. Extension Folder No. 45/2011, ICAR Research Complex for Goa, Goa.

Partap M, Sharma D, HN D, Thakur M, Verma V, Ujala, Bhargava B (2023). Microgreen: A tiny plant with superfood potential. Journal of Functional Foods 107:105697. https://doi.org/10.1016/j.jff.2023.105697.

Pinho SM, David LH, Garcia F, Keesman KJ, Portella MC, Goddek S (2021). South American fish species suitable for aquaponics: A review. Aquaculture International 29(4):1427–1449. https://doi.org/10.1007/s10499-021-00674-w.

Quagrainie K, Valladão Flores R, Kim H-J, McClain V (2017). Economic analysis of aquaponics and hydroponics production in the US Midwest. Journal of Applied Aquaculture 30:1414009. https://doi.org/10.1080/10454438.2017.1414009.

Rakocy JE, Masser MP, Losordo TM (2006). Recirculating aquaculture tank production systems: Aquaponics—Integrating fish and plant culture. Southern Regional Aquaculture Center Publication 454:1-16.

Resh HM (2012). Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower. CRC press. Available at: https://www.taylorfrancis.com/books/mono/10.1201/b12500/hydroponic-food-production-howard-resh

Resh HM (2013). Hydroponic food production: A definitive guidebook for

the advanced home gardener and the commercial hydroponic grower. Woodson Press. Retrieved from https://www.researchgate.net/publication/359153687_Hydroponic_Food_Production_A_Definitive_Guidebook_for_the_Advanced_Home_Gardener_and_the_Commercial_Hydroponic_Grower

Saha S, Monroe A, Day MR (2016). Growth, yield, plant quality and nutrition of basil (Ocimum basilicum L.) under soilless agricultural systems. Annals of Agricultural Sciences 61(2):181-186. https://doi.org/10.1016/j.aoas.2016.10.001.

Salo S (2019). Effects of hydroponic fodder feeding on milk yield and composition of dairy cow: Review. Journal of Natural Sciences Research 9(8). https://doi.org/10.7176/JNSR.

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 589.

Tetreault J, Fogle RL, Fogarty S, Guerdat T (2023). Coupled aquaponics: Optimizing hydraulic retention times using a parallel unit process water treatment approach. Frontiers in Horticulture 2. https://doi.org/10.3389/fhort.2023.1140998.

Terefe G, Mengistu G (2022). Effect of feeding hydroponic fodders on the performance of dairy cattle and small ruminants: A review. Journal of Biology, Agriculture and Healthcare 12(13).

Tomlinson L (2015). Indoor aquaponics in abandoned buildings: A potential solution to food deserts. Sustainable Development Law and Policy 16:16-24.

Tyson R, Treadwell DD, Simonne E (2011). Opportunities and challenges to sustainability in aquaponic systems. HortTechnology 21(1):1-13. https://doi.org/10.21273/HORTTECH.21.1.6.

Van Soest PJ, Robertson JB, Lewis BA (1991). Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74:3583-3597.

Zhang Y, Xiao Z, Ager E, Kong L, Tan L (2021). Nutritional quality and health benefits of microgreens, a crop of modern agriculture. Journal of Future Foods 1(1):58-66.