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Comparative Evaluation of Water Quality Properties: A Case Study of Coupled Commercial Aquaponics System

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Abstract: The current study intends to evaluate the influence of seasonal changes on the water quality parameters of a coupled commercial aquaponics system. The determined water quality parameters for the comparative study were total ammonium-nitrogen (TAN), nitrate-nitrogen (NO_3-N) and phosphate (PO_4^{3-}), water temperature (WT), water pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS). The WT and DO analysis were carried out using a portable dissolved oxygen meter (Model: PDO-520, Taiwan). A portable electrode pH meter (Model: PH-220, Taiwan) was utilized for the pH measurement. The TDS and EC readings were obtained using a multi-parameter water quality meter (PHT-27, China). The TAN, NO_3-N, and PO_4^{3-} determinations were done using their individual Merck Spectro-quant® test kits. The research results indicated a significant ($p<0.05$) difference in the NO_3-N, PO_4^{3-}, WT, pH, EC, and TDS values among the comparative four seasons (winter, spring, summer, and autumn). However, the TAN and DO levels revealed no significant ($p>0.05$) difference. The observed significant increase of NO_3-N, PO_4^{3-}, EC, and TDS in the summer and autumn periods could be associated to the increased fish feeding rate (which increases waste production) as well as relative increase in microbial waste conversion/mineralization. The investigated water quality makers were within the recommended amounts in the aquaponics system. Thus, in this study, seasonal differences have induced variation in the NO_3-N, PO_4^{3-}, WT, pH, EC, and TDS amounts. However, these differences do not affect the TAN and DO levels.

Keywords: Autumn, nitrate-nitrogen, pH, parameters, seasonal changes

1. Introduction

Water is an essential natural resource for human development, and therefore, it is crucial to conserve and understand the processes occurring in the aquatic ecosystem. In the aquaponics system, uneaten fish feed, feces, water source, flow rate, growing media type, and supplementation influences the water quality profile (Crossley et al., 2002; Enduta et al., 2009; Noratiqah et al., 2016). Hence, water quality monitoring and evaluation are critical to providing favorable conditions for fish, microorganisms, and plants that survive in this system (Lennard and Rakocy, 2010; Somerville et al., 2014; Noratiqah et al., 2016; Sallenave, 2016). Each water quality parameter has a specific tolerance limit to fish, microorganisms, and plants (Somerville et al., 2014). Thus, it is vital to maintain a balance such that each of the above living entities can thrive and grow healthy. The testing frequency depends on the maturity of the system and parameters to be monitored (Somerville et al., 2014). Generally, water quality markers, especially the ammonium-nitrogen, water temperature (WT), pH, and dissolved oxygen testing/monitoring for a start-up system should be carried out daily to allow adjustments if required. For instance, reduced feeding rate, enhanced aeration, and water dilution can decrease high ammonia concentration levels. Once a balanced nutrient cycling is achieved, testing once-off a week can be considered adequate (Sallenave, 2016).

The water quality parameters in the aquatic ecosystem can vary with the type or nature of the season. Seasonal differences in temperature, humidity, and light intensity/duration may have positive or negative impacts on water quality properties. Different seasons manifest specific temperature characteristics. Along with the temperature, all other physical and chemical water quality makers can fluctuate within the aquatic ecosystem. For example, WT is directly related to dissolved oxygen (DO) level. Thus, lower WT enhances a higher DO level and vice versa (Lennard and Rakocy, 2010). Hence, DO level monitoring is crucial to ensure proper bacterial nitrification and assimilation of nutrients by plants.

There were no reports on the impact of seasonal variations in the water quality properties in the aquaponics system. Notwithstanding, a study was cited on the influence of seasonal changes on electrical conductivity in the hydroponics system (Caruso et al., 2011; Amalfitano et al., 2017). In addition, the effect of seasonal differences on the water quality makers in the wetlands (Surya and Raju, 2023), pond water (Dey et al., 2021), coastal water (Balakrishnan et al., 2017), and urban water (Sharma and Singh, 2016) were reported. Therefore, the present research work was carried out for consecutive four seasons (winter, spring, summer, and autumn) to determine the effect of seasonal changes in the water quality profile of the fish tanks and deep-water culture tanks a coupled commercial aquaponics system.

2. Materials and Methods

2.1. Study site, system setup, and operation

The study aquaponics system was sited in Grahams town (Makhanda town), Eastern Cape, South Africa. The system was set up as a coupled commercial system enclosed in a greenhouse and only exposed to ambient sunlight. It consists of 4 × 1.500 L fish tanks; 2 sump tanks (1 × 1.500 L and 1 × 500 L), with an associated submersible pump (SOBO®, WP-7000, 105 W, 5000 L H^{-1}); 20 × 400 L flood-and-drain gravel stones media beds; and 24 × 900 L deep-water culture tanks. The system components were connected with PVC pipes to form a closed loop. The fish water tanks and sumps were placed in a separate housing unit within the aquaponics system greenhouse.

The water from four fish tanks flowed to the first single sump tank (1 × 1.500 L) by gravity, then pumped to gravel stones media beds. As the water volume in flood and drain media beds reaches its highest level, it drains into deep-water tanks by gravity through PVC pipe outlets. The water from each deep-water culture tanks was fed directly into the second single sump (1 × 500 L), that finally delivered to fish-rearing tanks, thus completing a cycle. The flood-and-drain was maintained by bell siphons installed in each gravel stones media bed. The water in the fish-rearing tanks and deep-water culture tanks are oxygenated (aerated) using air pumps (SOBO®, BO-9000A, 70 W). Rainwater stored in a reservoir was the water source for the system operation. The total water volume in the system was approximately 33.000 L. Figure 1 illustrates the schematic setup of the study coupled commercial aquaponics system.

2.2. Experimental fish and plants

Red Mozambique tilapia (*Oreochromis mossambicus*) was the specie cultured in the fish tanks of the study system. Each fish tank of a 1.500 L capacity contained approximately a 30-adult fish, each with an average weight of a 1.0 kg. Rhodes

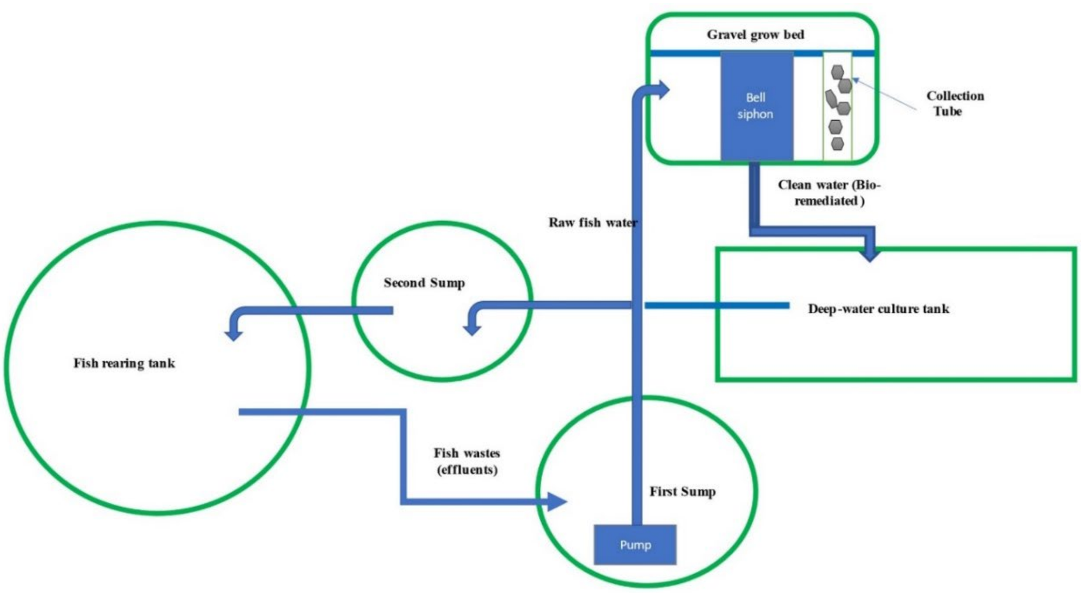

Figure 1. Schematic representation of the study coupled commercial aquaponics system

University Animal Research Ethics Committee (RU-AREC) provided the approval to use fish in this research. The experimental plants monitored were Bird's eye red chili (*Capsicum frutescens* L.), red cherry tomato (large) (*Solanum lycopersicum*), silver-beet green spinach (*Spinacia oleracea*), and green Locarno lettuce (*Lactuca sativa* L.).

2.3. Experimental components and water sample collection

The experimental components were four fish tanks; fish tank-1, fish tank-2, fish tank-3, and fish tank-4) denoted by FWT-1, FWT-2, FWT-3, and FWT-4, respectively. The water from four fish tanks was channeled to a first sump denoted as 'FWT.' Other research components of the system were four deep-water culture tanks; deep-water culture tank-1, deep-water culture tank-2, deep-water culture tank-3, and deep-water culture tank-4 represented as 'DWC-1, DWC-2, DWC-3, and DWC-4', respectively. A water sample from four fish tanks was collected from 'FWT'. The deep-water culture water samples were obtained from DWC-1, DWC-2, DWC-3, and DWC-4. Each water sample was collected into clean 50 mL screw cap falcon tubes, placed on ice box, and transported immediately to the laboratory for the analysis of the total ammonium-nitrogen (TAN), nitrate-nitrogen (NO_3-N), phosphate (PO_4^{3-}), total dissolved solids (TDS), and electrical conductivity (EC). While, the determination of the pH, WT, and DO was done directly from each experimental component within the aquaponics farm. Each water quality parameter was evaluated twice weekly throughout the comparative four seasons (winter, spring, summer, and autumn).

2.4. Chemical reagents and apparatus

Chemical reagents include ammonium chloride ($NH_4Cl_{(s)}$) (Sigma Aldrich, A4514-4-500G, St. Louis, Germany), zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O_{(s)}$) (Saarchem Merck Chemicals, Pty, South Africa), sodium dihydrogen phosphate ($NaH_2PO_{4(s)}$) (Saarchem Merck Chemicals, Wadeville, Gauteng, South Africa), Merck Spectro-quant® ammonium test kit, product number; 1.14752.0001 (Merck, Darmstadt, Germany), Merck Spectro-quant® nitrate test kit, product number; 1.14773.0001 (Merck, Darmstadt, Germany), Merck Spectro-quant® phosphate test kit, product number; 1.14848.0001 (Merck. Darmstadt, Germany). Consumables consist of Milli-Q water (EMD-Millipore machine Model 13681, Switzerland), micropipettes, and Eppendorf tubes. Equipment comprises of Epoch UV-vis microplate reader spectrophotometer (EPOCH2C, Bio-Tek Instruments, Inc., USA) and analytical weighing balance (RADWAG, 220 g × 0.1 mg, Model, AS/220/C/2, Poland).

2.5. Methods of analysis

The WT and DO determinations were conducted using a portable dissolved oxygen meter (Model: PDO-520, Taiwan). The pH measurements were carried out with a portable electrode pH meter (Model: PH-220, Taiwan). The TDS and EC readings were measured with a multi-parameter water quality meter (PHT-27, China). The TAN, NO_3-N, and PO_4^{3-} evaluations were done using their respective TAN, NO_3-N, and PO_4^{3-} Merck Spectro-quant® test kits following the manufacturer instructions with modifications in the volume/weight of test samples and reagents to allow the use of a 96-well plates to replace cuvettes. The DO, pH, TDS, and EC analytical procedures are analogous to American Public Health Association (APHA) standard methods (Eaton et al., 2005). The TAN method is similar to the modified phenol hypo-chloride protocol (Solarzano, 1969; Strickland and Parsons, 1972). The NO_3-N procedure is identical to that of Lawson-Wood and Robertson (2006). While, the PO_4^{3-} technique is alike to the reported approach by Pai et al. (1990). Plants measurements were no made in the course of this research study.

2.6. Data analysis

Data obtained were analyzed using the Microsoft Excel 365® tool package (Microsoft Corporation, New York, USA). To generate linear scatter plot standard curves, average absorbance values for each of the total ammonium-nitrogen, nitrate-nitrogen, and phosphate were plotted against their concentration levels. The regression equation of each plot was utilized to calculate the concentration values of each test sample (unknown) as equivalent milligrams per liter (mg L^{-1}).

2.7. Statistical analysis

The statistical analysis was carried out with Microsoft excel 365® (Microsoft Corporation, New York, USA) using repeated measures analysis of variance (RM ANOVA). The level of significance was 5%. If the RM ANOVA indicated a significant difference among the comparative four seasons, a *post-hoc* test using an unpaired student's *t*-test was conducted to determine the season(s) in which the significant difference exist.

3. Results and Discussion

Table 1 (summary table) depicted the results for the TAN, NO_3-N, PO_4^{3-}, WT, pH, DO, EC, and TDS of the whole seasonal experimental components.

Tables 2 to 9 represents the TAN, NO_3-N, PO_4^{3-}, WT, pH, DO, EC, and TDS values of each seasonal experimental component. The linear standard curve for the TAN, NO_3-N, and PO_4^{3-} were provided in Figures 2, 3, and 4. In addition, Figures 5, 6, and 7 revealed the maximum and minimum levels for each evaluated water quality maker throughout the experimental periods.

Table 1. Water quality properties of the entire experimental components [four fish tanks and four deep-water culture tanks)] for each season

Water quality maker	Winter (June 2020 to August 2020)	Spring (September 2020 to November 2020)	Summer (December 2020 to March 2021)	Autumn (March 2021 to May 2021)
TAN (mg L^{-1})	0.19 ± 0.01^a	0.19 ± 0.01^a	0.21 ± 0.02^a	0.21 ± 0.02^a
NO_3-N (mg L^{-1})	4.05 ± 0.24^a	$5.28 \pm 0.\ 51^b$	7.11 ± 0.14^c	7.09 ± 0.17^c
PO_4^{3-} (mg L^{-1})	2.28 ± 0.07^a	2.31 ± 0.08^a	4.32 ± 0.13^b	3.22 ± 0.11^c
WT (°C)	12.50 ± 0.08^a	18.26 ± 0.16^b	22.27 ± 0.18^c	19.11 ± 0.12^d
pH	7.13 ± 0.07^a	7.06 ± 0.11^a	6.73 ± 0.03^b	6.71 ± 0.03^b
DO (mg L^{-1})	6.84 ± 0.08^a	6.79 ± 0.07^a	6.79 ± 0.07^a	6.80 ± 0.11^a
EC (mS cm^{-1})	0.56 ± 0.01^a	0.59 ± 0.01^b	0.65 ± 0.01^c	$0.62^c \pm 0.07^d$
TDS (mS cm^{-1})	387.47 ± 5.78^a	413.17 ± 1.75^b	$449.\ 45 \pm 5.24^c$	402.97 ± 2.79^d

TAN: Total ammonium-nitrogen, NO_3-N: Nitrate-nitrogen, PO_4^{3-}: Phosphate, WT: Water temperature, DO: Dissolved oxygen, EC: Electrical conductivity, TDS: Total dissolved solids. Each maker was analyzed twice weekly (Mondays and Thursdays) throughout the research period. Results are presented as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

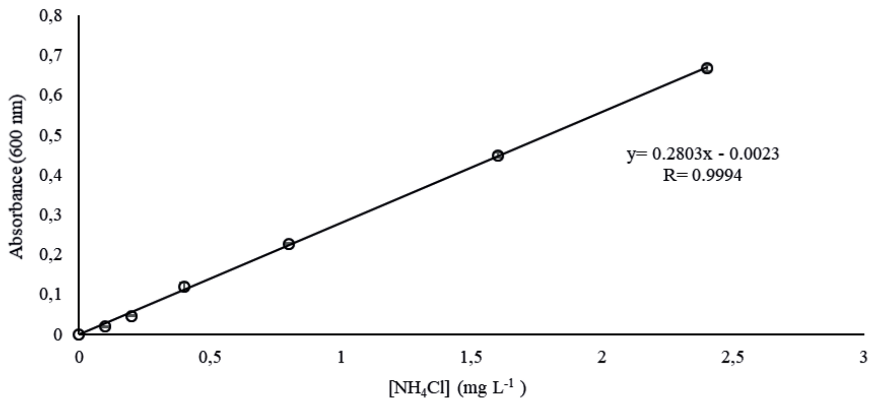

Figure 2. A standard curve of ammonium-nitrogen

The standard curve was generated over a 0.1 to 2.5 mg L^{-1} concentration range. Ammonium chloride was utilized as a reference standard prepared in Milli-Q water. The analysis was done photometrically in triplicate.

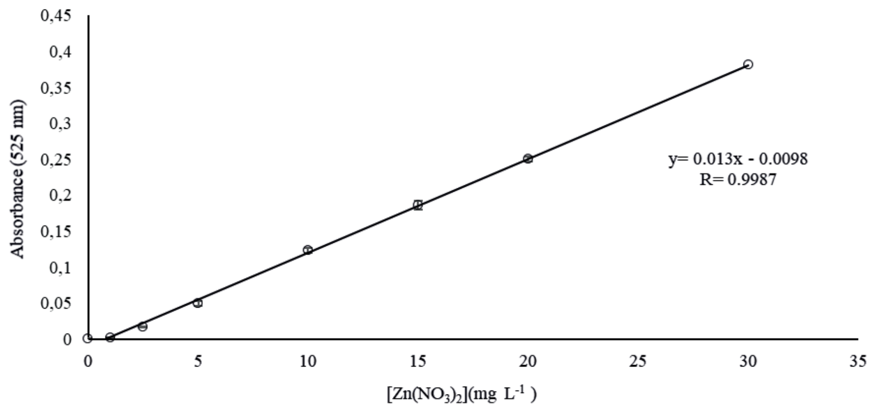

Figure 3. A standard curve of nitrate-nitrogen

The generated standard curve was over a concentration range of 1 to 30 mg L^{-1}. The zinc nitrate was the reference standard prepared in Milli-Q water. The carried-out analysis was photometrically in triplicate.

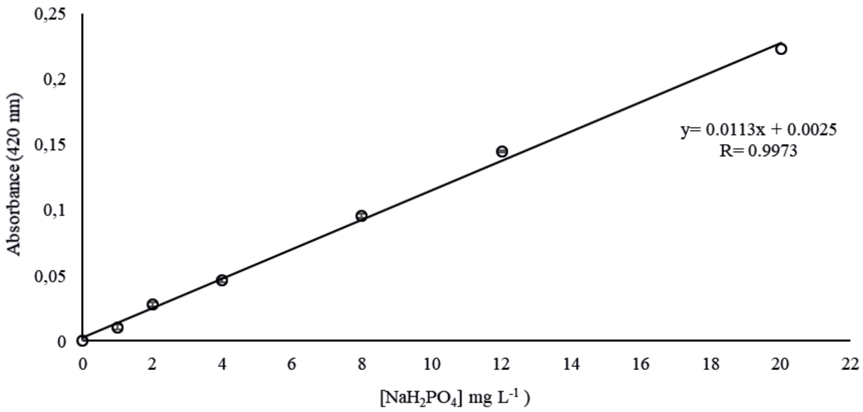

Figure 4. A standard curve of total phosphate

The standard curve was generated over a concentration range of 1 to 20 mg L^{-1}. Sodium dihydrogen orthophosphate was the standard prepared in Milli-Q water. The analysis was conducted using a photometrically in triplicate.

3.1. Total ammonium-nitrogen

There was no significant ($p<0.05$) difference in the mean TAN concentration values among the comparative four seasons (Table 1). The obtained mean TAN concentration levels were relatively uniform (±0.20 mg L^{-1}) (Table 1). No finding was detected on the influence of seasonal changes on TAN concentration amounts in the aquaponics system. Nevertheless, a TAN concentration value of less than 1.0 mg L^{-1} is recommended in this system (Somerville et al., 2014; Sallenave, 2016). Rakocy et al. (2004a) suggested a 0.2 to 1.8 mg L^{-1} values. Timmons et al. (2002) and Al Tawaha et al. (2021) reported a value of less than 3.0 mg L^{-1}.

The detected maximum and minimum mean TAN concentration levels for the complete comparative study were 0.23±0.08 and 0.18±0.09 mg L^{-1} in the summer and winter, respectively (Table 2). Throughout the comparative seasonal research, the recorded upper and lower TAN concentration values were 1.03 mg L^{-1} and 0.1 mg L^{-1}, respectively (Figure 5). In this research work, the mean TAN concentration levels obtained among the comparative four seasons were below the harmful limits to the fish. The mean TAN concentration values were not significantly affected by seasonal changes.

Table 2. Total ammonium-nitrogen concentration levels for each experimental component of the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
TAN (mg L^{-1})	FWT	0.19 ± 0.10[a]	0.19 ± 0.04[a]	0.23 ± 0.08[a]	0.21 ± 0.14[a]
	DWC-1	0.19 ± 0.11[a]	0.19 ± 0.03[a]	0.20 ± 0.08[a]	0.21 ± 0.08[a]
	DWC-2	0.20 ± 0.10[a]	0.20 ± 0.01[a]	0.21 ± 0.07[a]	0.21 ± 0.07[a]
	DWC-3	0.18 ± 0.09[a]	0.19 ± 0.02[a]	0.20 ± 0.06[a]	0.22 ± 0.08[a]
	DWC-4	0.20 ± 0.10[a]	0.19 ± 0.03[a]	0.21 ± 0.05[a]	0.21 ± 0.06[a]

FWT= 4-fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, TAN= Total ammonia-nitrogen, n= Number of times for TAN analysis per season per experimental component. The TAN was determined twice weekly (Mondays and Thursdays) for the whole comparative 4-seasons. Results are presented as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

3.2. Nitrate-nitrogen

A sinificant ($p<0.05$) difference in the mean NO_3-N concentration levels between winter compared with summer and autumn. Similarly, the spring period was statistically different from summer and autumn. Notwithstanding, the summer was not significantly ($p>0.05$) difference the autumn season (Table 1). The effect of seasonal shifts on the NO_3-N concentration levels in the aquaponics was lacking in the available literatures. The detected mean NO_3-N concentration levels (± 5.0 mg L^{-1}) in this research were lower in comparison to the report of Rakocy et al. (2004b), that suggested a 30.9 to 51.8 mg L^{-1}. According to Sallenave (2016), the recommended NO_3-N concentration values are 5 to 150 mg L^{-1}. However, Shete et al. (2013) reported a 0.23±0.04 to 0.20±0.02 mg L^{-1} levels during an experimental trial to grow spinach in aquaponics. A higher NO_3-N level promotes green leafy plants growth, while a

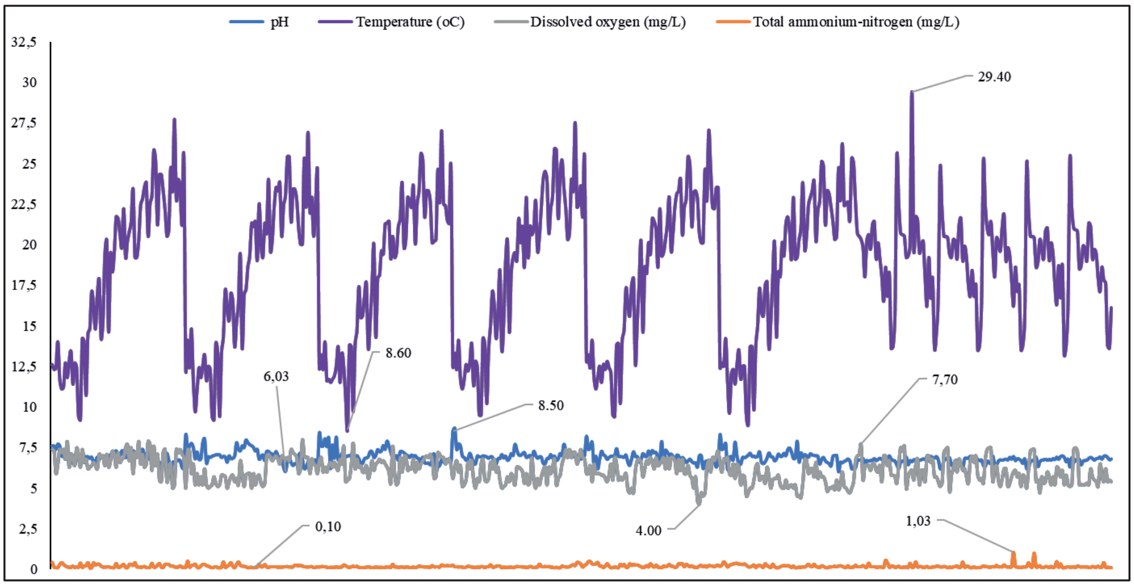

Figure 5. Charts for WT, pH, DO, and TAN levels for the entire experimental components throughout the comparative four seasons research

The recorded lowest and the highest WT, pH, DO, and TAN levels from the entire study data were 8.6 and 29.40 ºC, 6.03 and 8.50, 4.00 and 7.70 mg L^{-1}, 0.10 and 1.03 mg L^{-1}, respectively.

lower value promotes fruit development (Sallenave, 2016). The observed NO_3-N amounts in this study were low in the winter and spring. The reason could be because of lower rate bacterial nitrification efficiency in the two seasons due to their characteristic low temperature. Notwithstanding, relatively higher values were detected in the summer and autumn. The basis could be linked with efficient bacterial nitrification in the warmer periods. Thus, the mean NO_3-N concentration levels obtained in this research can be considered optimal for growing leafy spinach and or even tomatoes fruits in compliance with the findings of Shete et al. (2013) and Sallenave (2016). For the entire study periods, the plant materials (chili, tomato, spinach, and lettuce) growth was observed proper. The reason could be as a result of continuous nutrients flow and generation in the system. A much better ripening of chili and tomato fruits was observed in the summer and autumn.

The observed maximum and minimum mean NO_3-N concentration values for the entire comparative four seasons were 7.31±1.23 and 3.79±2.99 mg L^{-1} in the summer and winter, respectively (Table 3). For the complete seasonal research periods, the detected highest and lowest NO_3-N levels were 15.25 and 1.01 mg L^{-1}, respectively (Figure 6). In this study, seasonal differences have induced some variations in the NO_3-N concentration levels.

3.3. Phosphate

The winter and spring indicated no significant ($p>0.05$) difference in PO_4^{3-} concentration level. Besides, the summer was significant ($p<0.05$) difference in comparison to autumn season (Table 1). The summer period presented the highest mean PO_4^{3-} value (Table 1). The influence of seasonal variations on the PO_4^{3-} levels in the aquaponics system was not cited. The obtained mean PO_4^{3-}

Table 3. Total nitrate-nitrogen concentration values of each experimental component for the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
NO_3-N (mg L^{-1})	FWT	4.12 ± 2.78[a]	5.95 ± 2.70[b]	7.02 ± 1.34[c]	6.91 ± 3.05[c]
	DWC-1	3.79 ± 2.99[a]	4.83 ± 1.32[b]	7.17 ± 1.72[c]	7.18 ± 3.01[c]
	DWC-2	3.80 ± 3.16[a]	4.71 ± 1.44[b]	7.31 ± 1.23[c]	7.30 ± 3.12[c]
	DWC-3	4.19 ± 3.00[a]	5.51 ± 2.23[b]	7.08 ± 1.10[c]	6.93 ± 2.91[c]
	DWC-4	4.33 ± 2.90[a]	5.41 ± 2.01[b]	6.95 ± 0.96[c]	7.17 ± 3.29[c]

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, NO_3-N= Nitrate-nitrogen, n= Number of times for NO_3-N determination per season per experimental component. The NO_3-N was evaluated twice weekly (Mondays and Thursdays) over the comparative seasonal research. Results are indicated as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

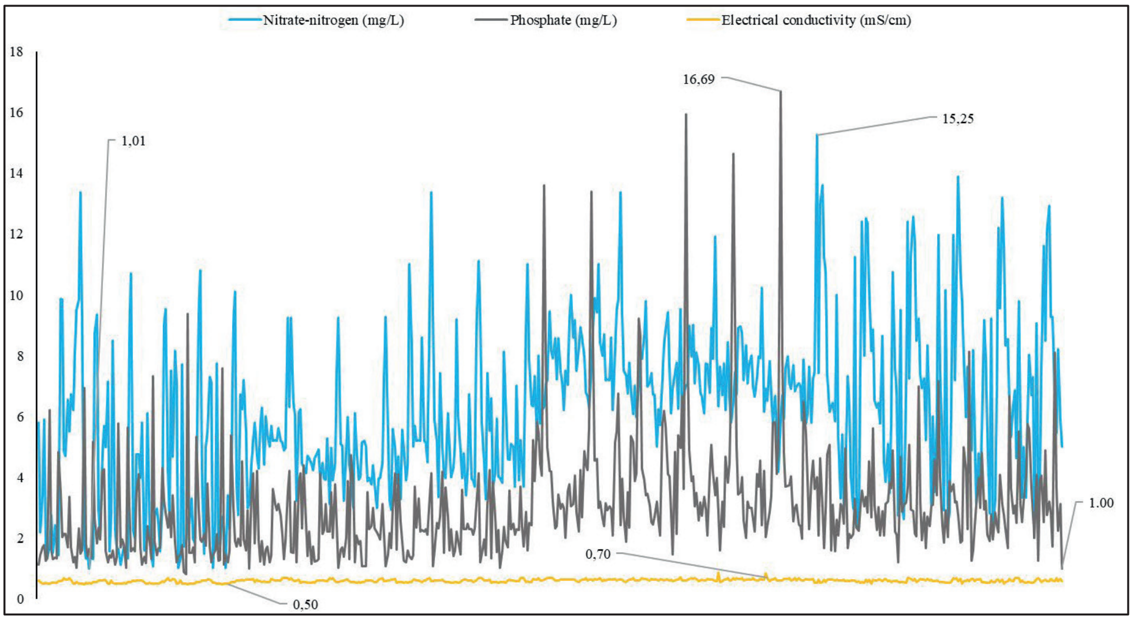

Figure 6. Charts for the NO_3-N, PO_4^{3-}, and EC levels of the entire experimental components throughout the comparative four seasons

The observed minimum and maximum levels of NO_3-N, PO_4^{3-}, and EC were 1.01 and 15.25 mg L^{-1}, 1.00 and 16.69 mg L^{-1}, 0.50 and 0.70 mS cm^{-1}, respectively.

concentration values (±3.0 mg L^{-1}) in this study could be considered relatively sufficient for growing plants in aquaponics, especially the leafy plants. According to McPharlin et al. (1996) and Ludwick (2002), the PO_4^{3-} thresholds for growing lettuce in the aquaponics system range from 3.5 to 8.0 mg L^{-1}. Blidariu et al. (2013) suggested a range between 3 to 3.6 mg L^{-1} as sufficient for cultivating leafy plants in this system. Hence, in this study, the mean PO_4^{3-} concentration values could be considered optimal. The growth of the plant materials (spinach, lettuce, red chili, and red tomato) was indicated proper.

The detected upper and lower mean PO_4^{3-} values were 4.48±3.37 and 2.17±1.52 mg L^{-1} in the summer and winter, respectively (Table 4). Figure 6 presented the maximum (16.69 mg L^{-1}) and minimum (1.00 mg L^{-1}) PO_4^{3-} levels for the whole comparative seasonal research. Seasonal changes have caused some differences in the PO_4^{3-} mean concentration levels.

Table 4. Phosphate concentration levels of each experimental component for the comparative four seasons study

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
PO_4^{3-} (mg L^{-1})	FWT	2.32 ± 1.53^a	2.30 ± 0.96^a	4.34 ± 2.75^b	3.12 ± 1.42^c
	DWC-1	2.33 ± 1.67^a	2.40 ± 1.06^a	4.28 ± 2.38^b	3.16 ± 0.99^c
	DWC-2	2.17 ± 1.52^a	2.19 ± 0.97^a	4.48 ± 3.37^b	3.29 ± 1.42^c
	DWC-3	2.23 ± 2.07^a	2.38 ± 0.81^a	4.12 ± 2.66^b	3.38 ± 1.35^c
	DWC-4	2.33 ± 1.70^a	2.30 ± 0.83^a	4.38 ± 2.93^b	3.15 ± 1.43^c

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, PO_4^{3-}= Phosphate, n= Number of times for PO_4^{3-} analysis per season per experimental component. The PO_4^{3-} was determined twice weekly (Mondays and Thursdays) throughout the comparative 4-seasons. Results presentations were as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

3.4. Water temperature

The mean WT levels indicated a significant ($p<0.05$) difference among the comparative four seasons (Table 1). There were no reports on the effect of seasonal shifts on the mean WT value in the aquaponics system. In the winter, the mean WT level was low, it is below the optimal level for fish, bacteria, and plants. The number of fish deaths recorded in the season (winter) was two, and at that period, the mean WT value was detected as ±8.60 °C. In the spring and autumn, the observed men WT (±18 °C) were relatively fair to the fish, bacteria, and plants to metabolize and grow. The recorded mean WT (±23 °C) in the summer period was optimal to the fish (Lennard and Rakocy, 2010; Bregnballe, 2015), nitrification bacteria (Tyson et al., 2011), and plants (Sallenave, 2016). WT below optimal levels can affect fish feeding rate, fish ability to metabolize, and nutrient availability to plants (Helene and Ivar, 2020). This in turn (WT below optimal levels), influences the health and growth of plants (Pregitzer and King, 2005). Similarly, ability and or efficiency of bacteria to convert/metabolize nutrients can be compromised when the WT is below the optimal limit (Scofield et al., 2015). Thus, the low mean WT, especially in the winter could have affected the fish's ability to metabolize and bacterial conversion rate efficiency, which might be the reason for the observed low NO_3-N and PO_4^{3-} concentration levels.

The detected maximum and minimum mean WT levels were 23.01±1.95 °C and 11.95±1.53 °C in the summer and winter, respectively (Table 5). The highest and lowest WT levels from the complete seasonal study were 29.40 °C and 8.60 °C, respectively (Figure 5). In this experimental study, seasonal changes have affected the mean WT levels in the aquaponics system.

Table 5. Water temperature values of each experimental component for the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
WT (°C)	FWT	12.11 ± 1.40^a	18.08 ± 2.72^b	23.01 ± 1.95^c	19.27 ± 2.65^d
	DWC-1	11.97 ± 1.63^a	18.10 ± 2.95^b	22.63 ± 1.90^c	19.19 ± 3.34^d
	DWC-2	12.11 ± 1.42^a	18.30 ± 2.76^b	22.55 ± 1.86^c	19.03 ± 2.55^d
	DWC-3	12.12 ± 1.34^a	18.38 ± 2.74^b	22.72 ± 1.50^c	18.99 ± 2.57^d
	DWC-4	11.95 ± 1.53^a	18.42 ± 2.78^b	22.67 ± 1.70^c	19.09 ± 2.57^d

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, T= Water temperature, n= Number of times for the determination of water temperature per season per experimental component. The WT was determined twice weekly (Mondays and Thursdays) for the complete study periods. Results are presented as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

3.5. pH

A significant ($p<0.05$) difference in the mean pH values was detected between the winter compared with summer and autumn. Likewise, the spring is significantly ($p<0.05$) difference from summer and autumn seasons (Table 1). However, the winter does not differ statistically with spring, likewise the summer in comparison to autumn. No similar findings were detected on the impacts of seasonal differences on the mean pH levels in the aquaponics. Fish can tolerate a wide range of pH values although, not conducive to them. However, fish prefer a pH range between 6.50 to 8.50 (Tyson et al., 2011). The efficiency of the nitrification process and nutrient solubility decrease when the pH value is below 4.0 or above 8.0 (Tyson et al., 2008). Somerville et al. (2014) reported that the nitrification and availability of nutrients to plants are optimal if the pH level is between 6.5 to 7.0. Gjesteland (2013) suggested a pH level between 5.00 to 6.00 for optimal nutrient assimilation by plants. Roosta (2014) recommended a pH value of 7.00 for optimal plants growth in the aquaponics system. Generally, pH values ranging from 6.0 to 7.0 in aquaponics is optimal (Rakocy et al., 2006, 2011; Sallenave, 2016). Throughout the seasonal research period, the mean water pH values were detected within the acceptable limits for efficient fish metabolism, nitrification efficiency, and nutrient assimilation/accessibility to plants.

The recorded lowest and highest mean water pH values were 7.24±0.48 and 6.67±0.23 in the winter and autumn, respectively (Table 6). For the whole seasonal experimental research, the maximum and minimum water pH values were 8.50 and 6.03, respectively (Figure 5). The current study has indicated some variations in the mean pH levels among the comparative four seasons.

Table 6. Water pH levels of each experimental component for the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
pH	FWT	7.17 ± 0.59^a	6.98 ± 0.25^a	6.74 ± 0.36^b	6.72 ± 0.18^b
	DWC-1	7.24 ± 0.48^a	7.23 ± 0.38^a	6.69 ± 0.34^b	6.67 ± 0.23^b
	DWC-2	7.11 ± 0.58^a	7.09 ± 0.33^a	6.74 ± 0.29^b	6.69 ± 0.18^b
	DWC-3	7.08 ± 0.46^a	7.00 ± 0.30^a	6.71 ± 0.23^b	6.72 ± 0.21^b
	DWC-4	7.07 ± 0.51^a	6.99 ± 0.30^a	6.75 ± 0.28^b	6.76 ± 0.16^b

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, n= Number of times for pH evaluation per season per experimental component. The pH was analyzed twice weekly (Mondays and Thursdays) for the entire 4-seasons. Results are given as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

3.6. Dissolved oxygen

The mean DO levels revealed no significant ($p>0.05$) difference among the comparative seasons (Table 1). Reports on the effect of seasonal variation on the mean DO levels in the aquaponics system is lacking. Lennard and Rakocy (2010) and Noratiqah et al. (2016) reported that DO level increase as the water temperature decreases. Thus, a relatively higher mean DO levels observed in the winter might be due to the characteristic low temperature in this season. DO is a critical parameter that affects biochemical and metabolic changes in the aquatic ecosystem (Sinha et al., 2000). The required minimum and maximum DO levels in the aquaponics system are 4.00 and 10.00 mg L^{-1}, respectively (Lennard and Rakocy, 2010). Eding et al. (2006) suggested DO levels between 4.00 to 6.00 mg L^{-1} for tilapia fish. For optimal nitrification, a DO level between 5.0 to 8.0 mg L^{-1} is preferred (Somerville et al., 2014; Sallenave, 2016). Nitrification does not occur when the DO level is below 2.0 mg L^{-1} (Masser et al., 1999). Plants grow optimally in an aquaponics, if DO values ranges between 4.5 to 5.0 mg L^{-1} (Noratiqah et al., 2016). In this experiment, the mean DO values recorded were optimal for fish health, bacterial nitrification, and plant nutrient assimilation. The rational might be because each experimental component of the system was aerated with air blowers.

The maximum and minimum mean DO levels were 6.98±0.74 and 6.71±0.67 mg L^{-1} (Table 7). The above maximum and minimum DO levels were both obtained in the autumn. For the entire seasonal research, the lower and upper DO levels were 4.00 and 7.70 mg L^{-1}, respectively (Figure 5). From findings of this study, the men DO levels were not influenced by seasonal changes.

Table 7. The dissolved oxygen concentration values of each experimental component for the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
DO (mg L^{-1})	FWT	6.88 ± 0.45^a	6.80 ± 0.39^a	6.85 ± 0.33^a	6.98 ± 0.74^a
	DWC-1	6.89 ± 0.42^a	6.88 ± 0.48^a	6.83 ± 0.31^a	6.82 ± 0.77^a
	DWC-2	6.89 ± 0.57^a	6.87 ± 0.49^a	6.80 ± 0.46^a	6.81 ± 0.76^a
	DWC-3	6.84 ± 0.58^a	6.82 ± 0.58^a	6.79 ± 0.41^a	6.81 ± 0.74^a
	DWC-4	6.71 ± 0.67^a	6.80 ± 0.52^a	6.82 ± 0.45^a	6.73 ± 0.76^a

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, DO= Dissolved oxygen, n= Number of times for DO determination per season per experimental component. The DO was evaluated twice weekly (Mondays and Thursdays) for the whole seasonal research. Results are indicated as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

3.7. Electrical conductivity

The mean water EC significantly ($p<0.05$) differ among the comparative four seasons (Table 1). Reports on the impacts of seasonal changes on the water EC level in aquaponics system was not detected. High levels of dissolved solids and ions such as nitrate, phosphate, and sodium can enhance water electrical conductivity (Brinkop and Piedrahita, 1996). Fish are susceptible to EC. Thus, it is critical to maintain optimal water EC value for fish health and survival. The recommended EC values in the aquaponics system range from 0.3 to 0.6 mS cm^{-1} (Rakocy et al., 2006). Al Tawaha et al. (2021) suggested water EC level between 0.33 to 0.57 mS cm^{-1}. in this research, the mean water EC levels (±0.60 mS cm^{-1}) were detected within the optimal limits for fish and nutrient accessibility to plants.

The maximum and minimum mean water EC values ranged between 0.66±0.03 and 0.55±0.04 mS cm^{-1} in the summer and winter, respectively (Table 8). Figure 6 depicted the lowest (0.5 mS cm^{-1}) and highest (0.7 mS cm^{-1}) water EC values throughout the seasonal experiment. Seasonal dynamics have showed effect on the water EC levels in the aquaponics system.

3.8. Total dissolved solids

A significant ($p<0.05$) difference was observed in the mean TDS levels among the comparative seasons (Table 1). No record was detected on the impacts of seasonal dynamics in the TDS levels in the aquaponics system. In the aquaponics system, TDS levels between 200 to 400 mg L^{-1} are adequate because nutrient generation is continuous (Rakocy et al., 2006). Al Tawaha et al. (2021) reported TDS levels between 201±0.04 to 214±0.05 mg L^{-1} during tilapia and lettuce growth assessment in the aquaponics system. Phytotoxicity occurs if the TDS value is above 2000 mg L^{-1} (Sanchez, 2014). However, very low dissolved solids can limit the growth of plants (Sanchez, 2014). This experimental work indicated relatively higher TDS

Table 8. The electrical conductivity levels of each experimental component for the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
EC (mS cm^{-1})	FWT	0.57 ± 0.06^{a}	0.60 ± 0.04^{b}	0.65 ± 0.04^{c}	0.62 ± 0.03^{d}
	DWC-1	0.56 ± 0.05^{a}	0.59 ± 0.04^{b}	0.65 ± 0.03^{c}	0.63 ± 0.05^{d}
	DWC-2	0.55 ± 0.04^{a}	0.59 ± 0.04^{b}	0.66 ± 0.03^{c}	0.62 ± 0.05^{d}
	DWC-3	0.56 ± 0.05^{a}	0.60 ± 0.04^{b}	0.64 ± 0.05^{c}	0.62 ± 0.04^{d}
	DWC-4	0.56 ± 0.05^{a}	0.60 ± 0.06^{b}	0.64 ± 0.05^{c}	0.63 ± 0.05^{d}

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, EC= Electrical conductivity, n= Number of times for EC analysis per season per experimental component. The EC was determined twice a week (Mondays and Thursdays) over the comparative 4-seasons. Results are presented as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

levels in the summer season. The reason could be as a result of high metabolic rate in fish and increased microbial organic matter decomposition in the season (summer). Hence increased nutrient availability to plants.

The mean highest (455.00±34.09 mg L^{-1}) and lowest (383.89±33.46 mg L^{-1}) TDS levels were recorded in the winter and summer, respectively (Table 9). The detected maximum and minimum TDS values for the complete comparative seasonal research were 590 and 340 mg L^{-1}, respectively, depicted in Figure 7. In this research, seasonal variations have indicated differences in the TDS levels in aquaponics.

Table 9. The total dissolved solids values of each experimental component for the comparative four seasons

Water quality maker	Experimental components	Seasons			
		Winter (n= 17)	Spring (n= 24)	Summer (n= 24)	Autumn (n= 24)
TDS (mg L^{-1})	FWT	396.11 ± 40.11^{a}	414.23 ± 22.30^{b}	448.08 ± 34.18^{c}	402.61 ± 21.76^{d}
	DWC-1	383.89 ± 33.46^{a}	412.31 ± 28.89^{b}	439.23 ± 23.99^{c}	401.30 ± 14.56^{d}
	DWC-2	385.00 ± 27.49^{a}	411.15 ± 23.72^{b}	452.31 ± 29.30^{c}	402.17 ± 14.76^{d}
	DWC-3	384.89 ± 29.13^{a}	414.23 ± 28.73^{b}	452.69 ± 47.54^{c}	407.83 ± 14.45^{d}
	DWC-4	384.89 ± 33.28^{a}	415.00 ± 28.46^{b}	455.00 ± 34.09^{c}	400.96 ± 11.64^{d}

FWT= Fish tanks, DWC-1= Deep-water culture 1, DWC-2= Deep-water culture 2, DWC-3= Deep-water culture 3, DWC-4= Deep-water culture 4, TDS= Total dissolved solids, n= Number of times for TDS analysis per season per experimental component. The TDS was determined twice weekly (Mondays and Thursdays) throughout the 4-seasons. Results are presented as mean ± SD. Values with different superscript letters between seasons are significantly ($p<0.05$) different.

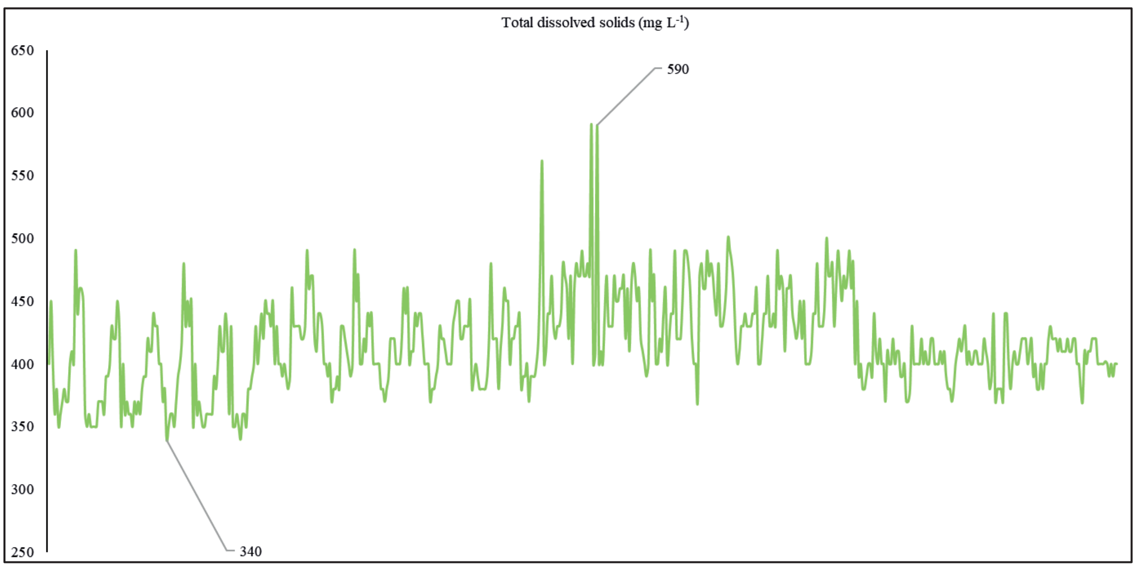

Figure 7. Charts for the TDS level of the entire experimental components throughout the comparative four seasons

The observed minimum and maximum levels were 340 and 590 mg L^{-1}.

4. Conclusions

The research has provided an insight into the scientific understanding of seasonal changes impact on water quality properties in the aquaponics system. This study could additionally be used to predict future seasonal variations and their effects on food production.

The limitation or shortcoming of this research is that the experimental plants materials (chili, tomato, spinach, and lettuce) growth were not measured but, only monitored and or observed. Hence, seasonal growth, yield, and even income evaluations are suggested to be carried out in the future study.

Ethical Statement

The author declares that ethical approval is not required for this research.

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Declaration of Conflicts of Interest

No conflict of interest has been declared by the author.

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