agronomy

MDPI

Article

A Comparative Evaluation of Aquaponic and Soil Systems on Yield and Antioxidant Levels in Basil, an Important Food Plant in Lamiaceae

Maryam A. O. K. Albadwawi, Zienab F. R. Ahmed *, Shyam S. Kurup, Mohammed A. Alyafei and Abdul Jaleel *

Department of Integrative Agriculture, College of Agriculture and Veterinary Medicine, United Arab Emirates University, Al Ain P.O. Box 15551, United Arab Emirates
* Correspondence: zienab.ahmed@uaeu.ac.ae (Z.F.R.A.); abdul.jaleel@uaeu.ac.ae (A.J.)

Abstract: Greenhouse and aquaponic productions of basil (*Ocimum basilicum* L.) are well established, but the comparison between these two methods is not studied in detail. A study was conducted to evaluate the performance of basil in both aquaponic and soil systems under greenhouse conditions. The plants were raised in aquaponic beds with ornamental fish and a set of plants was raised in soil pots under a greenhouse setup. The studied parameters were morphological, biochemical and antioxidant levels. In order to analyze the stress effects of an aquaponic system on plant defense mechanism, two different antioxidant enzymes (catalase and peroxidase) were analyzed. Water quality parameters were monitored during the entire study period. Based on the results, there was a significant increase in growth parameters in the aquaponic system when compared to the conventional greenhouse cultivation of basil plants. The photosynthetic parameters showed a decline in the aquaponic system, but the biochemical parameters showed an enhancement in the aquaponic system of growing basil plants. The antioxidants exhibited a significant increase in the aquaponic system, which suggests a water stress effect on the plants induced by the aquaponic growing system. From the results of this study, it can be concluded that the aquaponic system is the best suitable method for basil production in the UAE condition.

Keywords: *Ocimum*; ornamental fish; aquaponics; antioxidants; sustainable production

check for updates

Citation: Albadwawi, M.A.O.K.; Ahmed, Z.F.R.; Kurup, S.S.; Alyafei, M.A.; Jaleel, A. A Comparative Evaluation of Aquaponic and Soil Systems on Yield and Antioxidant Levels in Basil, an Important Food Plant in Lamiaceae. *Agronomy* **2022**, *12*, 3007. https://doi.org/10.3390/agronomy12123007

Academic Editor: Sara Di Lonardo

Received: 17 October 2022
Accepted: 28 November 2022
Published: 29 November 2022

1. Introduction

Water management is the one of the main challenges worldwide, especially in countries such as the United Arab Emirates, in which it poses a problem which needs immediate attention. The present system of conventional agriculture is no longer feasible in this aspect, as it requires a lot of water, which is very precious in this country.

As an alternative way of modern agriculture, aquaponics is considered as a system that can use the water-containing residues from fish production for producing plants in order to save water and produce clean products in a shorter time [1]. The principle of aquaponics is that it uses the waste from fish and utilizes it in the form of nutrients required for normal plant growth [2]. In this aspect, an aquaponics system can conserve precious water, especially in countries such as the UAE, where the water supply is limited, and there are very few arable lands. Additionally, the environmental impact is lower compared to the conventional farming systems. With aquaponic technology, a sustainable fish and vegetable production can be achieved with the simultaneous conservation of precious natural resources in the country.

The UAE is moving toward sustainable food security in the near future, and for that, a multi-faceted agro-ecological intensification of food production and a decoupling from unsustainable resource use is of utmost importance. Techniques such as aquaponics perform a great role in achieving the food security of modern times [3]. In countries such as the UAE, where the climatic and land characteristics are not adapted for conventional farming, this type of low water consumption agricultural systems is more promising [4]. Additionally, the usage of synthetic fertilizers can partly or completely be eliminated in aquaponic systems, and the use of pesticides is likewise reduced in this type of aquaponic systems, as the system relies on fish waste to provide nutrients to the plants [5].

The working principle of aquaponics is quite simple, as it involves only three kinds of living organisms: fish, beneficial bacteria and plants. The interrelations between them are highly complex and interdependent [6]. Additionally, the issue of toxic components such as ammonia created in the system from fish and food waste is resolved by the action of bacteria by the process of conversion of ammonia into nitrite and then into nitrate, which is non-toxic and at the same time beneficial to plants [7]. In a recirculating aquaponics system (RAS), the water is circulated through the fish tanks and grow beds, and the waste of water can be highly reduced [8]. It can produce fish and plants in high quantity and quality simultaneously.

When selecting the fish to be used in an aquaponic system, the main point to be noted is the resistance of the fish species to various environmental and water conditions [9]. The availability and usefulness of the species is also to be considered. The major fish species used in any aquaponics system is Nile Tilapia (*Oreochromis niloticus*), which can be used to run the plant-based system very successfully [10]. The studies related to the usage of ornamental fish in aquaponics systems is relatively scanty [11]. In this study, we selected koi fish (*Cyprinus rubrofuscus* var. "koi"), which is an important ornamental species loved by the hobbyists and aquaculturists throughout the world. Koi fish belong to the family Cyprinidae and are relatively resistant to different situations in fish tanks [12]. The resistance of this fish to various levels of water parameters and its ability to grow and reproduce in significant numbers is the main reason for our selection for it in aquaponics. This fish is comparatively less disease-susceptible and also fast growing, making it an easy species when cultivated together with plants [13].

Ocimum basilicum, popularly known as basil, is a very popular culinary herb that is mainly used in food production [14]. Growing basil is also very common among farmers. Basil has repellent or pathogen-killing properties such as nematicidal, antimicrobial, fungistatic and insecticidal effects [15]. Considering these benefits and effects, basil has multiple interesting uses in the food industries, perfume industry, traditional medicine industry as well as pharmaceutical industry. *O. basilicum* is a very common plant that is grown in aquaponics or more specifically in coupled aquaponic conditions [14]. Basil leaves develop an unmistakable and distinctive scent via peculiar oil glands, and basil is therefore considered as a very useful herb [15]. Apart from being a very common and important ingredient in the kitchen, basil has several essential properties, and is therefore used in fresh and dry form in almost all countries and cultures. Basil is suitable for soil as well as soilless cultivation [16].

Basil production through aquaponics is well established [17]. Basil has high growth potential and is therefore especially suitable for aquaponics. Inevitably, the demand for basil is considerably high among both hydroponics and aquaponics producers. Studies indicate that owing to its characteristics, basil is the most used herb for different hydroponics and aquaponics experiments [18]. Basil produces 1.8 kg per meter square under aquaponic production, and only 0.6 kg per meter square in soil cultivation [19]. Thus, aquaponic production is considered to be more efficient and environmentally friendly than soil cultivation [20]. Basil is among one of the top priorities for farmers all over the world due to the high value that it carries as a cash crop [21–23].

Even though previous studies show that basil growth and production is higher in the case of aquaponic systems compared to soil cultivation, researchers did not focus adequately on comparing the level of antioxidants in the basil grown in both cases. This research considers and seeks to fulfil this research gap by conducting a comparative evaluation of yield as well as levels of antioxidants in basil grown in aquaponics and soil systems.

The soil system of growing basil or *O. basilicum* is one of the most profound and rich ways of producing basil [24]. Basil does its best work when growing with the help of rich soil that has an accurate pH level for its growth. A perfect drainage system, a soil that has the required pH level and a place where sunlight reaches for about six to eight hours every day, will give any farmer basil of high quality. Basil, in its most basic nature, is a tropical herb that will grow and thrive easily in moist and nutrition-filled soil [24–26].

With the use of the aquaponic crop-production system, basil can be grown in a way that is environmentally friendly; no soil, less water and high-quality crop yield [27]. The crops produced with the help of the aquaponic system are not affected by any shift in the environment and sudden shifts in the climate [28]. The aquaponic system takes the help of fish, water tanks, plants and bacteria to grow products that are of high quality [29]. The quality is maintained through proper checkups and maintenance of the system.

Previous studies showed that basil has a lot of characteristics and properties that make it one of the most common herbs used extensively in the kitchen as well as in several other business sectors [15,18,20]. Nevertheless, while previous researchers found that basil production and yield is higher in the case of aquaponic systems than in soil systems, no information is available on the level of antioxidants present in basil grown in both systems. The purpose of this research was to investigate the efficiency of aquaponic systems in comparison to soil systems, particularly in the context of yield and level of antioxidants in basil. In other words, this research seeks to identify and understand how basil grown in soil systems differs from basil grown in aquaponic systems.

2. Materials and Methods

2.1. Experiment Location

The experiment was carried out in in a polycarbonate greenhouse in Falaj Hazza campus unit of aquaponics of the College of Agriculture and Veterinary Medicine, the UAEU, in Al Ain city, 160 km East of Abu Dhabi, the capital city of the United Arab Emirates, co-ordinate latitude and longitude of 24.2191° N and 55.7146° E, with ambient lighting, average daily temperature 19.2–26.4 °C and relative humidity 40–60%.

2.2. Seed Collection and Germination

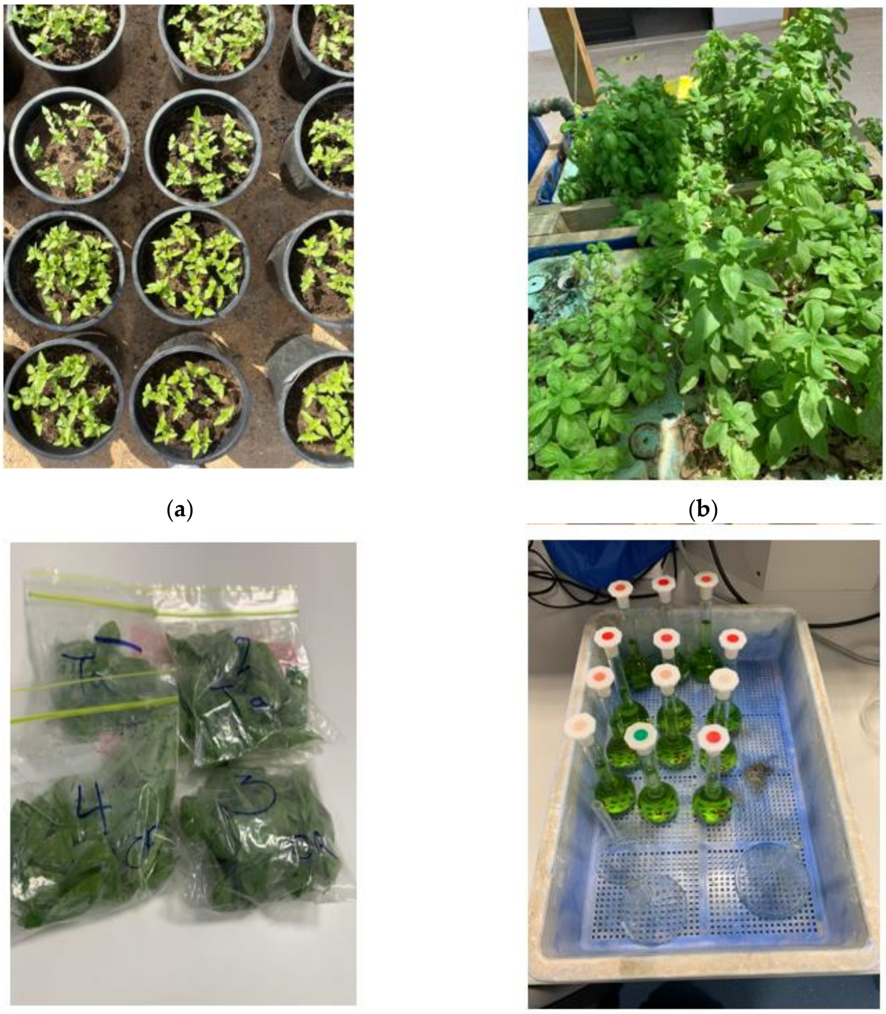
The certified seeds of *Ocimum basilicum* were obtained from agriculture material supply companies in Al Ain. Seeds of *O. basilicum* were sown in the nursery in foam plates under slight media layer and kept in the greenhouse conditions. Water spray was performed two times per day. Plants were germinated after 4–6 days. The plants were sown along with the commencement of fish culture. Normal cultivation practices were followed for soil-based plants in the greenhouse using agriculture sandy soil.

2.3. Experimental Setup

The seedlings were grown in moisturized Rockwool cubes (2.0 cm × 2.0 cm × 2.0 cm), placed in plastic containers and sprayed with water every day. The well-grown seedlings were transplanted in a Rockwool slabs (100 cm × 20 cm × 2.5 cm) and connected to the hydroponics system, with water circulated from the fish tanks after filtration (Figures S1 and 1).

2.4. Fish Selection and Growth Conditions

A total of 50 fingerlings per m^3 of *Cyprinus rubrofuscus* var. "koi" were added in each fish tank (500 L) with an average weight of 5 g. The fish were fed as per 2.5% bodyweight with 36% protein commercial fish diet from Arabian Agricultural Services Company (ARASCO), Saudi Arabia. They were fed three times a day.



(**a**) (**b**)

(**c**) (**d**)

Figure 1. Different stages during the experimental study. (**a**) Early stages of growth in green house, (**b**) growth in aquaponic bed, (**c**) sample collection, (**d**) laboratory analysis.

2.5. Plant Growth Conditions and Parameters Analyzed

Basil was harvested on 40 and 70 days after sowing (DAS). Group of plants were randomly harvested on each harvesting time. Basil characteristics of each harvest was evaluated by measuring the length from leaf to root, shoot length, root length, total weight, shoot weight, leaf weight and average leaf number per plant. The plant height (from the soil level to the tip of the shoot) was measured and the values are expressed in cm. The plant root length of longest root was measured (from the point of first cotyledonary node to the tip) and expressed in cm. The total number of fully developed leaves were counted and expressed as number of leaves per plant.

The total leaf area of fully developed leaves was measured using a leaf area meter (LICOR Photo Electric Area Meter, Model LI-3100, Lincoln, NE, USA) and expressed in cm^2 per plant. Fresh weight was determined by using an electronic balance and the values were expressed in grams. The plants were dried for 48 h at 60 °C in a hot air oven after taking fresh weight. After drying, the weight was measured and the values were expressed in grams.

2.6. Estimation of Photosynthetic Pigments

Chlorophyll and carotenoid of the leaf were extracted and assessed by the method of Arnon [30]. Five hundred milligrams of fresh leaf were ground with 10 mL of 80% acetone at 4 °C and centrifuged at 2500 rpm for 10 min at 4 °C. The extract was transferred to a graduated tube and made up to 10 mL with 80% acetone and assayed immediately. The absorbance was read at 645, 663 and 480 nm with a spectrophotometer (U-2001-Hitachi) against 80% acetone as blank. Chlorophyll content was calculated using the formula of Arnon [30] and expressed in milligram/gram of fresh weight (FW).

Anthocyanin [31] and xanthophyll [32] from the basil were extracted and estimated and the results were expressed in milligrams/gram FW.

2.7. Biochemical Analysis

Protein was estimated according to the method of Bradford [33]. Five hundred milligrams of fresh plant material were ground with 10 mL of 20% trichloro acetic acid (TCA), homogenized and centrifuged for 15 min at 800× *g*. A total of 5 mL of 0.1 N NaOH was added to the pellet after the supernatant was discarded, to solubilize the protein, and the solution was centrifuged at 800× *g* for 15 min. The supernatant was composed of 10 mL with 0.1 N NaOH, and then used for the estimation of the protein content. The protein solution containing 10–100 μg protein in a volume of 0.1 mL was pipetted into 12 × 100 mm test tubes. Five milliliters of Bradford's reagent were added to the test tube and the contents were mixed by vortexing. The absorbance at 595 nm was measured after 2 min with 3 mL cuvette against a reagent blank, prepared by adding 0.1 mL of 0.1 N NaOH and 5 mL of Bradford's reagent. A standard curve was prepared using BSA V fraction, which was used to determine the protein content.

Total phenols were estimated according to the method by Malick and Singh [34]. Five hundred milligrams of fresh plant tissue were ground in a pestle and mortar with 10 mL of 80% ethanol. The homogenate was centrifuged at 10,000 rpm for 20 min. The supernatant was evaporated, and then the residue was dissolved with 5 mL of distilled water and used as extract. A volume of 0.5 mL of Folin–Ciocalteau reagent was added to 2 mL of the extract. After 3 min, 2 mL of 20% Na_2CO_3 solution was added and mixed thoroughly. The mixture was kept in boiling water for exactly one min and after cooling; the absorbance was read at 650 nm. The total phenols were determined using a standard curve prepared with different concentrations of gallic acid.

2.8. Non-Enzymatic Antioxidant Contents

Ascorbic acid content was assayed as described by Omaye et al. [35]. One gram of fresh material was ground in a pestle and mortar with 5 mL of 10 per cent TCA, and the extract was centrifuged at 3500 rpm for 20 min. The pellet was re-extracted twice with 10 per cent TCA and 10 mL of supernatant was used for estimation. To 0.5 mL of extract, 1 mL of DTC reagent (2,4-Dinitrophenyl hydrazine-Thiourea-$CuSO_4$ reagent) was added and mixed thoroughly. The tubes were incubated at 37 °C for 3 h, and to this 0.75 mL of ice-cold 65 per cent H_2SO_4 was added. The tubes were then allowed to stand at 30 °C for 30 min. The resulting color was read at 520 nm in spectrophotometer (U-2001-Hitachi). The ascorbic acid content was determined using a standard curve prepared with ascorbic acid and the results are expressed in mg g^{-1} fresh weight.

α-Tocopherol content was estimated as described by Backer et al. [36]. Five hundred milligrams of fresh tissue was homogenized with 10 mL of a mixture of petroleum ether and ethanol (2:1.6 v/v) and the extract was centrifuged at 10,000 rpm for 20 min. The supernatant was used for estimation of α-tocopherol. To one mL of extract, 0.2 mL of 2 per cent 2,2-dipyridyl in ethanol was added and mixed thoroughly and kept in the dark for 5 min. The resulting red color was diluted with 4 mL of distilled water and mixed well. The resulting color in the aqueous layer was measured at 520 nm. The α-tocopherol content was calculated using a standard graph made with known amount of α-tocopherol and expressed in mg g^{-1} fresh weight.

2.9. Antioxidant Enzymes

Peroxidase and catalase crude enzyme extract were prepared according to a method by Hwang et al. [37]. One gram of plant tissue was homogenized with 10 mL of ice-cold buffer 50 mM sodium phosphate containing 1 mM PMSF. The homogenate was strained through two layers of cheesecloth and then centrifuged at 12,500× g for 20 min at 4 °C. The supernatant content was 10 mL with 50 mM of sodium phosphate buffer, used as the source of enzymes. The enzyme protein was determined using a method by Bradford [33] for expressing the specific activity of all the enzymes.

Catalase activity was assayed as a method described by Chandlee and Scandalios [38]. Frozen material (0.5 g) was homogenized in 5 mL of ice-cold 50 mM sodium phosphate buffer (pH 7.5) containing 1 mM PMSF (phenyl methyl sulfonyl fluoride). The homogenate was centrifuged at 4 °C for 20 min at 12,500× g. The supernatant was used for enzyme assay. The assay mixture contained 0.4 mL of 15 mM H_2O_2, 2.6 mL of 50 mM potassium phosphate buffer (pH 7.0) and 0.04 mL of enzyme extract. The decomposition of H_2O_2 was followed by the decline in absorbance at 240 nm. The enzyme activity was expressed in units of 1 mM of H_2O_2 reduction per minute per mg protein.

Peroxidase was assayed according to a method by Kumar and Khan [39]. The assay mixture of peroxidase contained 2 mL of 0.1 M phosphate buffer (pH 6.8), 1 mL of 0.01 M pyrogallol, 1 mL of 0.005 M H_2O_2 and 0.5 mL of enzyme extract. The solution was incubated for 5 min at 25 °C, after which the reaction was terminated by adding 1 mL of 2.5 N H_2SO_4. The amount of purpurogallin formed was determined by measuring the absorbance at 420 nm against a blank (the extract after the addition of 2.5 N H_2SO_4 at zero time). The activity was expressed in unit mg^{-1} protein. One unit is defined as the change in the absorbance by 0.1 $min-1$ mg^{-1} protein.

2.10. Microelements and Macroelements

The analysis was conducted using ICP-OES-Agilent Technologies [40]. Samples were prepared accurately by weighing 0.5 g in the microwave digestion vessels. The digestion process began by adding 10 mL of concentrated nitric acid (HNO_3) and 2 mL of hydrochloric acid (HCL) to the sample. The vessels were capped and placed in the microwave digestion system. The analysis was conducted using ICP-OES-Agilent Technologies, 710. The percentages of different elements in this sample were determined by the corresponding standard calibration curves obtained by using standard AR grade solutions of the elements, for example K, Mg, Ca, Na, Fe, Mn, Zn, P and S.

2.11. Statistical Analysis

The experiment followed a complete randomized design. The data were analyzed by SAS (SAS Institute Inc., 2000, Cary, NC, USA). Comparisons between the aquaponic (soilless) and soil systems at the harvest times of 40 and 70 days were conducted using the *t*-test at $p \leq 0.05$. The values are mean ± SD for seven replicates from each cultivation system.

3. Results

3.1. Morphological Parameters

The plants in aquaponic and soil system exhibited an increase in height with age, as they started growing since the first DAS, and almost reached their maximum height at 70 DAS. However, when compared to the aquaponic system at 40 DAS (69.42 cm), the greenhouse-grown plants exhibited (65.55 cm) a decreased height. A similar trend was noticed in the case of 70 DAS, when aquaponic-grown plants measured 98.05 cm, while the greenhouse-grown plants measured only 84.21 cm in height (Table 1).

The root length increased with age in both systems. The root length decreased in the soil system when compared to aquaponic-grown plants (Table 1). The average root length of basil plants was 27.98 cm in the aquaponic system, but it was further reduced in soil-system-grown plants to 23.21 cm at 40 DAS. Additionally, at 70 DAS, the root length of the basil plants in the aquaponic and greenhouse systems were 59.21 cm and 54.36 cm, respectively.

Table 1. Different growth parameters of *Ocimum basilicum* in aquaponic and soil (greenhouse) systems at 40 and 70 DAS.

Growth Parameters	DAS	Soilless (aquaponic) System	Soil (Greenhouse) System
Total plant height (cm)	40	69.42 ± 6.22^{a}	65.55 ± 6.11^{b}
	70	98.05 ± 4.35^{a}	84.21 ± 9.55^{b}
Root length (cm)	40	27.98 ± 4.15^{a}	23.21 ± 2.11^{b}
	70	59.21 ± 3.98^{a}	54.36 ± 5.23^{b}
Leaves (No.)	40	107.00 ± 20.19^{a}	99.88 ± 10.03^{b}
	70	174 ± 12.55^{a}	148 ± 15.19^{b}
Leaf area $(cm)^2$	40	3.78 ± 0.22^{a}	3.08 ± 0.70^{a}
	70	3.74 ± 0.31^{a}	3.66 ± 0.38^{a}
Total fresh weight (g)	40	47.80 ± 5.31^{a}	45.89 ± 3.33^{b}
	70	84.31 ± 5.89^{a}	79.25 ± 6.31^{b}
Total dry weight (g)	40	4.96 ± 0.51^{a}	3.77 ± 0.19^{b}
	70	7.11 ± 0.22^{a}	6.33 ± 0.35^{b}
Root dry weight (g)	40	0.77 ± 0.03^{a}	0.44 ± 0.01^{b}
	70	1.2 ± 00.02^{a}	0.99 ± 0.022^{b}

Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a,b) differ significantly at $p \leq 0.05$ using *t*-test. DAS—Days after sowing.

The number of leaves increased with age in aquaponic- and greenhouse-grown plants. However, the number of leaves was reduced in the greenhouse system when compared to the aquaponic system at both 40 and 70 DAS. In the aquaponic system, the number of leaves at 40 DAS was 107.00, while in the soil system it was reduced to 99.88. Similarly, at 70 DAS, the aquaponic exhibited 174 leaves when compared with 148 in the soil system.

The total leaf area showed a similar trend under the greenhouse system when compared to aquaponic basil plants, representing 3.78 cm and 3.74 cm in the aquaponic system at 40 and 70 DAS, respectively. In greenhouse plants, it represented 3.08 and 3.66, respectively, at 40 and 70 DAS. The fresh weight was lower in greenhouse-grown plants when compared to aquaponic plants. This is due to the higher shoot and root growth of aquaponic plants, which contributed to the increased fresh and dry weights of the basil plants in the system.

3.2. Photosynthetic Pigments

The chlorophyll 'a' content of the basil leaves was extracted and estimated from the randomly selected leaves at 40 and 70 DAS (Figure 2). Contrary to the growth parameters, the chlorophyll pigment contents in basil showed an increasing trend under the greenhouse cultivation system. In the case of chlorophyll 'a', it represented 0.48 mg/g FW and 0.55 mg/g FW at 40 DAS in the aquaponic and green house systems, respectively. At 70 DAS, the content had increased and represented 0.37 mg/g FW and 0.49 mg/g FW, respectively, in the aquaponic and greenhouse systems. At 40 DAS, the chlorophyll 'b' content represented 0.68 mg/g FW and 0.82 mg/g FW in aquaponic and greenhouse plants, respectively, and it is evident that chlorophyll 'b' was enhanced in the greenhouse system (Figure 2). The total chlorophyll content of the basil leaves increased in greenhouse-cultivated plants (Figure 2). The greenhouse-grown plants harvested at 40 DAS showed higher contents (0.137 mg/g FW) when compared to the aquaponic plants (0.116 mg/g FW). A similar trend was observed in the case of plants harvested at 70 DAS, where the soil-cultivated plants' chlorophyll content (1.15 mg/g FW) was higher than that of the soilless-cultivated plants (0.88 mg/g FW).

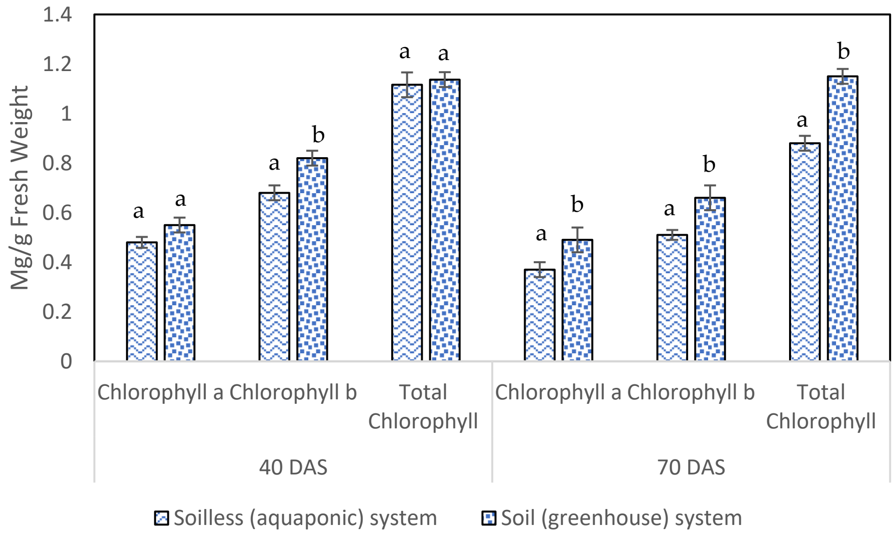
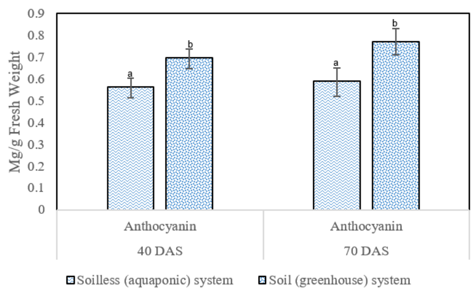
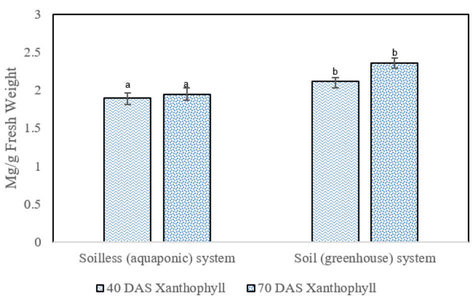


Figure 2. Chlorophyll contents of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems at 40 and 70 DAS. Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a, b) differ significantly at $p \leq 0.05$ using *t*-test.

The anthocyanin content of basil plants increased with age in both production systems. Additionally, in comparison with the aquaponic system, the greenhouse system exhibited more anthocyanin content in the leaves. At 40 DAS, the basil plants exhibited an anthocyanin concentration of 0.562 mg/g FW in aquaponics- and 0.698 mg/g FW in greenhouse-cultivated plants. Similarly, the basil leaves from the aquaponic system at 70 DAS exhibited a 0.59 mg/g FW anthocyanin concentration and the greenhouse-system plants exhibited a 0.77 mg/g FW anthocyanin concentration. Overall, the highest anthocyanin contents were recorded in basil leaves grown in the greenhouse system at 70 DAS (Figure 3a).



(**a**)



(**b**)

Figure 3. Anthocyanin (**a**) and xanthophyll (**b**) concentrations of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems at 40 and 70 DAS. Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a, b) differ significantly at $p \leq 0.05$ using *t*-test.

The xanthophyll concentration (Figure 3b) at 40 DAS in basil plants was the lowest among the studied samples. As the age increased, the xanthophyll pigment concentration showed an increase in concentration. The highest concentration was recorded in basil plants grown in the greenhouse system at 70 DAS (2.36 mg/g FW) when compared to plants grown in the aquaponic system (1.95 mg/g FW).

3.3. Biochemical Parameters

The plants grown under the aquaponic system exhibited higher protein contents (36.25 μg mL^{-1}) when compared to the plants grown under the conventional greenhouse system (29.03 μg mL^{-1}) at 40 DAS. The protein content was high at 70 DAS as well in aquaponic-grown plants. However, the different samplings at 40 and 70 DAS did not influence the quantity of protein in both the aquaponic and greenhouse plants. The phenol concentration showed a remarkable increase in plants with age. The increase was clear at 40 and 70 DAS in both the systems. The phenol concentration at 40 DAS was 8.84 μg mL^{-1} and 7.01 μg mL^{-1} in aquaponic and soil systems, respectively. This increased to 10.11 and 9.98 μg mL^{-1}, respectively, at 70 DAS (Table 2).

Table 2. Biochemical parameters of *Ocimum basilicum* in soilless (aquaponic) and soil (greenhouse) systems at 40 and 70 DAS.

Biochemical Parameters	DAS	Soilless (aquaponic) System	Soil (Greenhouse) System
Protein (μg mL^{-1})	40	36.25 ± 12.7 ^{a}	29.03 ± 8.62 ^{b}
	70	36.90 ± 12.8 ^{a}	30.00 ± 8.7 ^{b}
Total phenol (mg GAEq g^{-1} DW)	40	8.84 ± 2.8 ^{a}	7.01 ± 2.0 ^{b}
	70	10.11 ± 3.6 ^{a}	9.98 ± 2.9 ^{b}

Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a, b) differ significantly at $p \leq 0.05$ using *t*-test.

3.4. Antioxidants

The ascorbic acid content of the basil plants increased with age in the soil- and aquaponic-growing systems. The aquaponic system significantly increased the ascorbic acid content of the plants as compared to the greenhouse plants; it represented 3.57 mg/g FW at 70 DAS when compared to 3.2 mg/g FW in the greenhouse system (Figure 4a). Like ascorbic acid, in basil plants, the α-tocopherol content increased with age in the soil- and aquaponic-growing systems. The aquaponic system significantly increased the ascorbic acid content of the plants as compared to the greenhouse plants, representing 6.66 mg/g FW at 70 DAS when compared to 5.02 mg/g FW in the greenhouse system (Figure 4b).

3.5. Antioxidant Enzyme Activities

The antioxidant enzyme activities, such as catalase and peroxidase, increased with time in soilless- and aquaponic-grown plants. Their activities were higher in aquaponic-grown plants when compared to soilless-grown plants. At 40 DAS, the content was 7.19 units/mg protein in aquaponic-grown plants and 4.227 in soil-grown plants. The difference in activities of the catalase enzyme at 40 and 70 DAS was significant between aquaponic and greenhouse plants (Figure 5a).

The peroxidase enzyme activity was higher in aquaponic plants when compared to greenhouse-grown plants. Their activity was 1.571 in aquaponic plants at 40 DAS and 1.161 in greenhouse-grown plants. Similarly, the activity was higher at 70 DAS as well in aquaponic plants when compared to greenhouse-grown basil plants (Figure 5b).

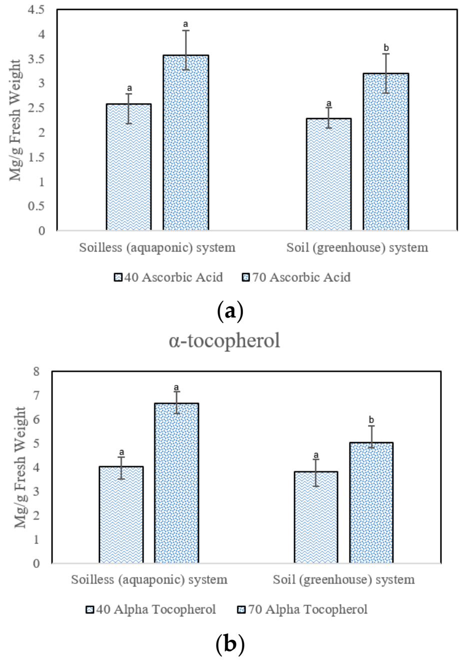


Figure 4. Ascorbic acid (**a**) and α-tocopherol (**b**) concentrations of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems at 40 and 70 DAS. Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a, b) differ significantly at $p \leq 0.05$ using *t*-test.

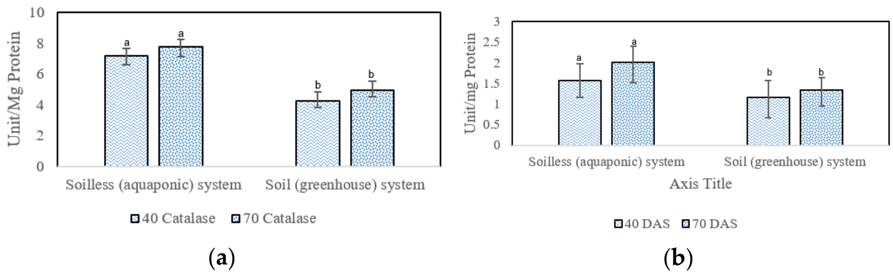


Figure 5. Catalase (**a**) and peroxidase (**b**) activities of *Ocimum basilicum* in soilless (aquaponic) and soil (greenhouse) systems at 40 and 70 DAS. Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a,b) differ significantly at $p \leq 0.05$ using *t*-test.

3.6. Macronutrients and Micronutrients

The analysis of elements was only conducted at the end of the experimental period (70 DAS). Some of the levels of macro- and micronutrients were higher in the soilless system when compared to the conventional greenhouse system (Table 3).

Table 3. Macronutrients (%) and micronutrients (mg kg^{-1}) in basil leaves under soilless (aquaponic) and soil systems at 70 DAS.

Nutrients	**Growth Systems**	
Macronutrients (%)	Aquaponics	Soil
Nitrogen (N)	6.32 ± 0.09 ^{a}	4.89 ± 0.11 ^{b}
Phosphorus (P)	1.70 ± 0.05 ^{a}	0.99 ± 0.0 ^{b}
Potassium (K)	0.69 ± 0.02 ^{a}	0.71 ± 0.02 ^{a}
Magnesium (Mg)	0.59 ± 0.01 ^{a}	0.38 ± 0.0 ^{b}
Calcium (Ca)	2.81 ± 0.11 ^{a}	2.87 ± 0.13 ^{a}
Sulphur (S)	0.29 ± 0.01 ^{a}	0.29 ± 0.01 ^{a}

Table 3. *Cont.*

Nutrients	Growth Systems	
Micronutrients (mg kg^{-1})		
Boron (B)	41.9 ± 1.70 [a]	34.9 ± 1.10 [b]
Copper (Cu)	13.4 ± 0.86 [a]	13.8 ± 0.64 [a]
Iron (Fe)	95.2 ± 4.10 [a]	97.2 ± 2.70 [b]
Manganese (Mn)	99.8 ± 10.50 [a]	87.7 ± 2.40 [b]
Sodium (Na)	88.6 ± 13.50 [a]	74.0 ± 6.10 [b]
Zinc (Zn)	51.1 ± 5.30 [a]	61.1 ± 1.80 [b]

Values are given as mean ± SD of seven samples in each group. Values that do not share a common superscript (a,b) differ significantly at $p \leq 0.05$ using *t*-test.

3.7. Water Parameters

The levels of water temperature, dissolved oxygen, pH, total dissolved solids (TDSs), electrical conductivity (EC), ammonia, nitrate and nitrite showed variations during different intervals in the aquaponic system. It is known that when ammonia increased, the nitrate and nitrite levels increased. The pH level also exhibited various levels during the period of the experiment.

The highest level of dissolved oxygen was recorded to be 5.22 mg/l on day 10 and the lowest was of 5.01 mg/l on day 1. The level of hydrogen pH was recorded to be the highest on day 10 at 6.99 and the lowest on day 30 at 6.42. The level of TDS was recorded throughout the analysis of 40 days from the recorded 310 ppm on the 1st day to 410 ppm on the 40th day. The average water parameters of EC resulted from the fluctuation throughout the observation of 40 days. It was recorded to be the highest on day 40 and the lowest on day 20. The percentage of ammonia was recorded to be the highest on day 40 at 0.60 mg/l and the lowest on days 1–10 at 0.10 mg/l. On day 20, the level of ammonia was recorded to be 0.12 mg/l, and on day 30 it was reduced to 0.11 mg/l. As per the results, the highest level of nitrate was recorded to be of 18.79 mg/l, and the lowest was level of nitrate was recorded to be 5.81 mg/l. The level of nitrite was recorded to be the highest on day one and the lowest on day 20 (Table 4).

Table 4. The average water parameters under aquaponic system during 10 day intervals.

Analysis Intervals	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	TDS (ppm)	EC (mS/cm)	Ammonia (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)
Day 1	24.01 ± 0.03	5.01 ± 0.03	6.85 ± 0.03	310 ± 1.100	0.62 ± 0.04	0.10 ± 0.03	5.81 ± 0.03	0.30 ± 0.02
Day 10	25.09 ± 0.03	5.22 ± 0.04	6.99 ± 0.03	380.11 ± 1.24	0.76 ± 0.04	0.10 ± 0.03	6.09 ± 0.04	0.10 ± 0.04
Day 20	24.02 ± 0.03	5.10 ± 0.04	6.87 ± 0.02	350.21 ± 0.81	0.70 ± 0.04	0.12 ± 0.03	11.99 ± 0.07	0.08 ± 0.04
Day 30	25.02 ± 0.02	5.03 ± 0.03	6.42 ± 0.04	390.10 ± 1.32	0.78 ± 0.02	0.11 ± 0.02	17.22 ± 0.06	0.10 ± 0.03
Day 40	25.24 ± 0.03	5.10 ± 0.03	6.99 ± 0.04	410.41 ± 1.05	0.82 ± 0.03	0.60 ± 0.02	18.79 ± 0.09	0.11 ± 0.03
Day 50	24.84 ± 0.02	5.20 ± 0.03	7.01 ± 0.05	420.47 ± 1.06	0.84 ± 0.04	0.61 ± 0.02	17.79 ± 0.09	0.12 ± 0.03
Day 60	26.01 ± 0.04	5.11 ± 0.03	6.91 ± 0.04	420.61 ± 1.15	0.84 ± 0.03	0.71 ± 0.03	14.11 ± 0.06	0.12 ± 0.03
Day 70	24.21 ± 0.03	5.10 ± 0.03	6.98 ± 0.05	410.11 ± 1.05	0.82 ± 0.02	0.62 ± 0.02	18.25 ± 0.08	0.14 ± 0.04

4. Discussion

Ocimum basilicum L., commonly known as basil, is a herbal plant used for medicinal purposes in the treatment of headaches, coughs as well as also kidney malfunctions. There are many major chemical components in the plant which are the basis for these medicinal properties. Basil is a source of antioxidant vitamins E, A and C [41]. These sources of antioxidants help to elevate the health system of humans.

4.1. Plant Growth Parameters

Primarily, the total height of the basil plant exhibited an increase with the consequences of age. This is based on the analysis of the first DAS of the aquaponics and soil systems.

The plant was able to reach its maximum height in seventy days. The result of plants grown on the soil system of the greenhouse showed a distinct difference from the aquaponic plant growth. The root length of the plants of both systems showed a similar result regarding height. In comparison with conventional basil cultivation, plant height in the present study was higher, which is contrary to the findings of a previous study by Pasch et al. [17], where they reported a reduction in growth of basil in different culture conditions with catfish (*Clarias gariepinus*) in decoupled aquaponics. Our results agree with the earlier studies of Mangmang et al. [42,43], where the inoculation effect of *Azospirillum brasilense* on basil significantly increased the growth and production under the aquaponics production system.

Roosta [44] showed a decrease in vegetative growth when studying the comparison of the vegetative growth, eco-physiological characteristics and mineral nutrient content of basil plants irrigated with different hydroponic:aquaponic solutions. In aquaponics, the plants exhibited high growth performance and basil leaf area, fresh herbage yield and root weight were increased by up to 27, 11 and 11%, respectively. An increase in biomass and height were reported in basil plants grown in decoupled aquaponics by Rodgers et al. [45].

4.2. Photosynthetic Pigment Contents

The chlorophyll contents of plants show defining results at both 40 and 70 DAS. Chlorophyll 'a' was subjected to show higher pigments in the greenhouse-grown basil than the aquaponic-grown basil. Chlorophyll 'b' also showed similar results to chlorophyll 'a', namely that the increase was seen more in the greenhouse plants than in the aquaponic plants. Similar to that of chlorophyll, the plants showed high levels of anthocyanin in greenhouse growth and lower levels in the aquaponic system. The contents of xanthophyll, the highest concentration, were recorded in plants grown in the greenhouse as well as in the aquaponic system.

There was visible chlorosis, as reported by Roosta [44], in basil plants under irrigation with different ratios of hydroponic:aquaponic solutions. That means the content was lesser in the aquaponic system of growth, which is concomitant with our studies. Leaf chlorosis can be considered as an indicator of less physiological functions under aquaponics [46,47].

There was no difference in chlorophyll content or leaf nutrients between the aquaponics and hydroponics of basil plants when grown in comparison to conventional systems [48]. Saha et al. [48] also reported that the pigment concentrations were unaltered in the aquaponic production of basil, whereas, contrary to our results, Ferrarezi and Bailey [49] reported an increase in chlorophyll contents in basil plants grown in aquaponics. Similarly, in one of the recent studies by Rodgers et al. [45], high chlorophyll index ratios in basil plants when grown in decoupled aquaponic setups were reported.

4.3. Biochemical Analysis

According to the results, the biochemical composition of the basil plants exhibited a higher content of proteins in the aquaponic system than in the conventional soil system. Additionally, the total phenol level was high in the aquaponic system and low in the soil system. As basil is considered a herbal medicinal plant, it is of importance that the high level of phenol provides antioxidant properties [50]. An increase in protein and other biochemical concentrations were reported earlier in aquaponic-grown basil by Yang and Kim [24,51].

4.4. Non-Enzymatic Antioxidant Contents

The antioxidants present in basil provide medical benefits. As per the analysis of the results, ascorbic acid contents in basil showed an increase in the aquaponics system in both the analyses at different DAS. The contents of ascorbic acid in greenhouse plants were lower. This can be based on the fact that the aquaponic system delivers more essential nutrients and helps build plant food in a better way than the greenhouse system [6]. Ascorbic acid is known as vitamin C, which is an essential antioxidant that works to protect firm cellular components from damage. These elements of basil tend to scavenge free radicals [52].

As per the results, α-tocopherol also increased in the aquaponic system as compared to the low α-tocopherol components in the soil system. The content of alpha-tocopherol is proven to provide antioxidant activity that helps in protecting the membrane components, similar to that in ascorbic acid [53]. We can assume that the plants under aquaponic growth are probably subjected to a type of water stress (flooding), which in turn increased the antioxidant content in the plants to fight against it [54].

4.5. Antioxidant Enzymes

Antioxidant activity in basil plants is based on several activities, such as catalase and peroxide. The results show that these activities tend to increase with the age factor of the plants in both systems. The activities are higher in aquaponic plants than that in soil systems. In the case of peroxidase, the activities are also higher in aquaponic systems.

These antioxidant enzyme activities help in eliminating superoxides and the hydrogen peroxide [55]. Additionally, the survival of many plants depends on their antioxidant activities. Overall, the plants under the aquaponic system experience a type of flood stress at the root level, which can be the reason behind the increased activities of antioxidant enzymes. Antioxidant enzyme activities are used to scavenge the potential free radicals which are produced due to the stress in the plants [56]. The increase in peroxidase in plants at 70 DAS can be correlated to the onset of flowering as reported earlier [57].

4.6. Microelements and Macroelements

The results are based on the macro- and micronutrients in basil plants in the analysis at 70 DAS in both aquaponic and soil systems. The major macronutrients present in basil plants are nitrogen, phosphorus, potassium, calcium and magnesium. The analysis showed that in an aquaponic system, the contents of nitrogen were higher than that of the soil system. The components of phosphorus also showed similar results as that of nitrogen. While the content of potassium and calcium exhibited a lower content in the aquaponic system and higher contents in the soil system, conversely, the macronutrients of sulphur exhibited the presence of equal levels in both the aquaponic and soil system at 70 DAS and after. As per the results, the levels of micronutrients were also shown. Boron, magnum and sodium exhibited higher content levels in the aquaponic system than in the soil system, while the level of copper, iron and zinc showed lower content levels in the aquaponic system and higher content levels in the soil system at 70 DAS.

Soil-system plants have lower levels of nutrient content. Aquaponics plants, with water beds of recirculating water, contain more nutrients, and this helps the basil plant to grow faster. The waste generated by fish in the aquaponics system tends to deliver essential nutrients for plant growth, such as nitrogen, calcium, magnesium and potassium [58]. As per the recent data, the information on aquaponic nutrient manipulation is scanty. Potassium and iron can be added to the system as main nutrient elements to be added as a supplement to the aquaponic solution as potassium hydroxide and iron chelates as a foliar spray [59].

4.7. Water Quality Parameters

The results of the water quality parameters are based on the analysis of different internal observations on the aquaponic system of basil plants. In the analysis, the temperature kept fluctuating throughout days 1–40 from 24 °C to 25 °C. The dissolved oxygen level was considered to be the highest on day 10 of the analysis

As per the literature, the accurate pH ranges are 6–9 for tilapia fish, 5.5–6 for plants and 7–8 for nitrifying bacteria, so we can conclude that pH 7 is considered an ideal compromise for aquaponics [60]. In this study, the EC in aquaponics resulted mainly from the daily nutrient release from the fish feed. The water temperature recommendation for basil is 20–25 °C in any system of cultivation [49].

5. Conclusions

The main aim of this experiment was to standardize the aquaponic production of basil plants with the help of ornamental fish, such as Koi fish, and to compare the growth and quality of basil plants with conventional production methods such as greenhouse cultivation in the UAE's climatic condition. Based on the obtained results, the growth parameters showed an increase under aquaponic production, while the photosynthetic pigments were higher under greenhouse cultivation. The biochemical parameters exhibited a significant enhancement in aquaponic-grown plants when compared to the standard greenhouse system. The non-enzymatic and enzymatic antioxidants exhibited a significant increase under the aquaponic system in basil plants. The conventional greenhouse system exhibited lower antioxidant levels. Micro- and macro-nutrient levels also exhibited varied responses under aquaponic cultivation. From the results of this study, it can be concluded that the basil crop can be grown in both aquaponic and greenhouse soil systems, but the quantity and quality of the crop can be increased when a soilless system is adopted. In a soilless aquaponic system, the height, fresh and dry weight of basil increased significantly when compared to conventional soil systems. This increase may be due to the additional fertilizers from the fish waste produced in the system.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy12123007/s1, Figure S1. Experimental set up showing tanks, growth trays and filters.

Author Contributions: Conceptualization, A.J. and Z.F.R.A.; methodology, A.J. and M.A.A.; validation, A.J., Z.F.R.A., S.S.K. and M.A.A.; formal analysis, M.A.O.K.A.; investigation, M.A.O.K.A.; data curation, M.A.O.K.A.; writing—original draft preparation, M.A.O.K.A., A.J. and Z.F.R.A.; writing—review and editing, M.A.O.K.A., A.J., S.S.K. and Z.F.R.A.; supervision, A.J. and M.A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the support from UAEU in the form of research support to Master Students from MS Horticulture Program. The assistance from staff of Falaj Hazza Experimental Station for aquaponic and greenhouse setups and collection of samples and E3, F1 labs, CAVM, UAEU are greatly acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Blidariu, F.; Grozea, A. Increasing the economic efficiency and sustainability of indoor fish farming by means of aquaponics-review. *Anim. Sci. Biotechnol.* **2011**, *44*, 1–8.
2. Yildiz, H.Y.; Robaina, L.; Pirhonen, J.; Mente, E.; Domínguez, D.; Parisi, G. Fish Welfare in Aquaponic Systems: Its Relation to Water Quality with an Emphasis on Feed and Faeces—A Review. *Water* **2017**, *9*, 13. [CrossRef]
3. Khan, M.M.; Akram, M.T.; Janke, R.; Qadri, R.W.K.; Al-Sadi, A.M.; Farooque, A.A. Urban Horticulture for Food Secure Cities through and beyond COVID-19. *Sustainability* **2020**, *12*, 9592. [CrossRef]
4. Al Shamsi, K.B.; Compagnoni, A.; Timpanaro, G.; Cosentino, S.L.; Guarnaccia, P. A Sustainable Organic Production Model for "Food Sovereignty" in the United Arab Emirates and Sicily-Italy. *Sustainability* **2018**, *10*, 620. [CrossRef]
5. Joyce, A.; Timmons, M.; Goddek, S.; Pentz, T. Bacterial Relationships in Aquaponics: New Research Directions. In *Aquaponics Food Production Systems*; Springer: Cham, Switzerland, 2019; pp. 145–161.
6. Goddek, S.; Delaide, B.; Mankasingh, U.; Ragnarsdottir, K.V.; Jijakli, H.; Thorarinsdottir, R. Challenges of Sustainable and Commercial Aquaponics. *Sustainability* **2015**, *7*, 4199–4224. [CrossRef]
7. Zou, Y.; Hu, Z.; Zhang, J.; Xie, H.; Liang, S.; Wang, J.; Yan, R. Attempts to improve nitrogen utilization efficiency of aquaponics through nitrifies addition and filler gradation. *Environ. Sci. Pollut. Res.* **2016**, *23*, 6671–6679. [CrossRef]
8. Yep, B.; Zheng, Y. Aquaponic trends and challenges–A review. *J. Clean. Prod.* **2019**, *228*, 1586–1599. [CrossRef]
9. Pinho, S.M.; David, L.H.; Garcia, F.; Keesman, K.J.; Portella, M.C.; Goddek, S. South American fish species suitable for aquaponics: A review. *Aquac. Int.* **2021**, *29*, 1427–1449. [CrossRef]
10. Liang, J.-Y.; Chien, Y.-H. Effects of feeding frequency and photoperiod on water quality and crop production in a tilapia–water spinach raft aquaponics system. *Int. Biodeterior. Biodegrad.* **2013**, *85*, 693–700. [CrossRef]

11. Maucieri, C.; Forchino, A.A.; Nicoletto, C.; Junge, R.; Pastres, R.; Sambo, P.; Borin, M. Life cycle assessment of a micro aquaponic system for educational purposes built using recovered material. *J. Clean. Prod.* **2018**, *172*, 3119–3127. [CrossRef]
12. Hu, F.; Li, Y.; Wang, Q.; Zhu, B.; Wu, S.; Wang, Y.; Zeng, W.; Yin, J.; Liu, C.; Bergmann, S.M.; et al. Immersion immunization of koi (*Cyprinus carpio*) against cyprinid herpesvirus 3 (CyHV-3) with carbon nanotube-loaded DNA vaccine. *Aquaculture* **2021**, *539*, 736644. [CrossRef]
13. Adamek, M.; Oschilewski, A.; Wohlsein, P.; Jung-Schroers, V.; Teitge, F.; Dawson, A.; Gela, D.; Piackova, V.; Kocour, M.; Adamek, J.; et al. Experimental infections of different carp strains with the carp edema virus (CEV) give insights into the infection biology of the virus and indicate possible solutions to problems caused by koi sleepy disease (KSD) in carp aquaculture. *Vet. Res.* **2017**, *48*, 12. [CrossRef]
14. Mokat, D.N.; Kharat, T.D. Essential Oil Composition in Leaves of *Ocimum* Species Found in Western Maharashtra, India. *J. Essent. Oil Bear. Plants* **2022**, *25*, 1–8. [CrossRef]
15. Knaus, U.; Pribbernow, M.; Xu, L.; Appelbaum, S.; Palm, H.W. Basil (*Ocimum basilicum*) cultivation in decoupled aquaponics with three hydro-components (grow pipes, raft, gravel) and African catfish (*Clarias gariepinus*) production in Northern Germany. *Sustainability* **2020**, *12*, 8745. [CrossRef]
16. Rehman, R.; Hanif, M.A.; Mushtaq, Z.; Mochona, B.; Qi, X. Biosynthetic factories of essential oils: The aromatic plants. *Nat. Prod. Chem. Res.* **2016**, *4*, 227. [CrossRef]
17. Moncada, A.; Miceli, A.; Vetrano, F. Use of plant growth-promoting rhizobacteria (PGPR) and organic fertilization for soilless cultivation of basil. *Sci. Hortic.* **2021**, *275*, 109733. [CrossRef]
18. Pasch, J.; Ratajczak, B.; Appelbaum, S.; Palm, H.W.; Knaus, U. Growth of basil (*Ocimum basilicum*) in DRF, raft, and grow pipes with effluents of African catfish (*Clarias gariepinus*) in decoupled aquaponics. *AgriEngineering* **2021**, *3*, 92–109. [CrossRef]
19. Babmann, B.; Harbach, H.; Weißbach, S.; Palm, H.W. Effect of plant density in coupled aquaponics on the welfare status of African catfish, *Clarias gariepinus*. *J. World Aquac. Soc.* **2020**, *51*, 183–199. [CrossRef]
20. Hundley, G.C.; Navarro, F.K.S.P.; Filho, O.P.R.; Navarro, R.D. Integration of Nile tilapia (*Oreochromis niloticus* L.) production *Origanum majorana* L. and *Ocimum basilicum* L. using aquaponics technology. *Acta Sci. Technol.* **2018**, *40*, 35460. [CrossRef]
21. Obirikorang, K.A.; Sekey, W.; Gyampoh, B.A.; Ashiagbor, G.; Asante, W. Aquaponics for Improved Food Security in Africa: A Review. *Front. Sustain. Food Syst.* **2021**, *5*, 705549. [CrossRef]
22. Pandey, J.; Verma, R.K.; Singh, S. Suitability of aromatic plants for phytoremediation of heavy metal contaminated areas: A review. *Int. J. Phytoremed.* **2019**, *21*, 405–418. [CrossRef] [PubMed]
23. Bahl, J.R.; Singh, A.K.; Lal, R.K.; Gupta, A.K. High-yielding improved varieties of medicinal and aromatic crops for enhanced income. In *New Age Herbals*; Springer: Singapore, 2018; pp. 247–265.
24. Yang, T.; Kim, H.-J. Comparisons of nitrogen and phosphorus mass balance for tomato-, basil-, and lettuce-based aquaponic and hydroponic systems. *J. Clean. Prod.* **2020**, *274*, 122619. [CrossRef]
25. Tolay, I. The impact of different Zinc (Zn) levels on growth and nutrient uptake of Basil (*Ocimum basilicum* L.) grown under salinity stress. *PLoS ONE* **2021**, *16*, e0246493. [CrossRef] [PubMed]
26. Simon, J.E.; Morales, M.R.; Phippen, W.B.; Vieira, R.F.; Hao, Z. Basil: A source of aroma compounds and a popular culinary and ornamental herb. *Perspect. New Crops New Uses* **1999**, *16*, 499–505.
27. Quagrainie, K.K.; Flores, R.M.V.; Kim, H.-J.; McClain, V. Economic analysis of aquaponics and hydroponics production in the U.S. Midwest. *J. Appl. Aquac.* **2018**, *30*, 1–14. [CrossRef]
28. Danner, R.I.; Mankasingh, U.; Anamthawat-Jonsson, K.; Thorarinsdottir, R.I. Designing Aquaponic Production Systems towards Integration into Greenhouse Farming. *Water* **2019**, *11*, 2123. [CrossRef]
29. Ahmed, N.; Thompson, S.; Glaser, M. Global Aquaculture Productivity, Environmental Sustainability, and Climate Change Adaptability. *Environ. Manag.* **2019**, *63*, 159–172. [CrossRef]
30. Arnon, D.I. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* **1949**, *24*, 1. [CrossRef]
31. Beggs, C.J.; Wellmann, E. Analysis of light-controlled anthocyanin formation in coleoptiles of *Zea mays* L.: The role of UV-B, blue, red and far-red light. *Photochem. Photobiol.* **1985**, *41*, 481–486. [CrossRef]
32. Neogy, M.; Datta, J.K.; Mukherji, S.; Roy, A.K. Effect of aluminium on pigment content, Hill activity and seed yield in mungbean. *Indian J. Plant Physiol.* **2001**, *6*, 381–385.
33. Bradford, M.M. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.* **1976**, *72*, 248–254. [CrossRef] [PubMed]
34. Malik, C.P.; Singh, M.B. *Plant Enzymology and Histo-Enzymology*; Kalyani Publications: New Delhi, India, 1980.
35. Omaye, S.T.; Turnbull, J.D.; Sauberlich, H.E. Selected methods for the determination of ascorbic acid in animal cells, tissues, and fluids. In *Methods in Enzymology*; Academic Press: Amsterdam, The Netherlands, 1979; Volume 62, pp. 3–11.
36. Baker, H.; Frank, O.; Deangelis, B.; Feingold, S. Plasma tocopherol in man at various times after ingesting free or acetylated tocopherol. *Nutr. Rep. Int.* **1980**, *21*, 531–536.
37. Hwang, S.-Y.; Lin, H.-W.; Chern, R.-H.; Lo, H.F.; Li, L. Reduced susceptibility to waterlogging together with high-light stress is related to increases in superoxide dismutase and catalase activities in sweet potato. *Plant Growth Regul.* **1999**, *27*, 167–172. [CrossRef]
38. Chandlee, J.M.; Scandalios, J.G. Analysis of variants affecting the catalase developmental program in maize scutellum. *Theor. Appl. Genet.* **1984**, *69*, 71–77. [CrossRef] [PubMed]

39. Kumar, K.B.; Khan, P.A. Peroxidase and polyphenol oxidase in excised ragi (Eleusine corocana cv PR 202) leaves during senescence. *Indian J. Exp. Biol.* **1982**, *20*, 412–416.
40. USEPA United States Environmental Protection Agency. *Revision 5.4 Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma–Mass Spectrometry*; Method 200.8; USEPA United States Environmental Protection Agency: Washington, DC, USA, 1994.
41. Juliani, H.R.; Simon, J.E. Antioxidant activity of basil. In *Trends in New Crops and New Uses*; ASHS Press: Alexandria, VA, USA, 2002; Volume 575.
42. AlShrouf, A. Hydroponics, aeroponic and aquaponic as compared with conventional farming. *Am. Acad. Sci. Res. J. Eng. Technol. Sci.* **2017**, *27*, 247–255.
43. MangMang, J.S.; Deaker, R.; Rogers, G. Inoculation effect of Azospirillum brasilense on basil grown under aquaponics production system. *Org. Agric.* **2016**, *6*, 65–74. [CrossRef]
44. Roosta, H.R. Comparison of the vegetative growth, eco-physiological characteristics and mineral nutrient content of basil plants in different irrigation ratios of hydroponic: Aquaponic solutions. *J. Plant Nutr.* **2014**, *37*, 1782–1803. [CrossRef]
45. Rodgers, D.; Won, E.; Timmons, M.B.; Mattson, N. Complementary Nutrients in Decoupled Aquaponics Enhance Basil Performance. *Horticulturae* **2022**, *8*, 111. [CrossRef]
46. Yang, T.; Kim, H.-J. Nutrient management regime affects water quality, crop growth, and nitrogen use efficiency of aquaponic systems. *Sci. Hortic.* **2019**, *256*, 108619. [CrossRef]
47. Mullis, D.; Reyes, J. The overall effects of soilless agricultural system on basil (*Ocimum basilicum* L.). *Ccamlr Sci.* **2019**, *26*, 300–307.
48. Saha, S.; Monroe, A.; Day, M.R. Growth, yield, plant quality and nutrition of basil (*Ocimum basilicum* L.) under soilless agricultural systems. *Ann. Agric. Sci.* **2016**, *61*, 181–186. [CrossRef]
49. Ferrarezi, R.S.; Bailey, D.S. Basil Performance Evaluation in Aquaponics. *HortTechnology* **2019**, *29*, 85–93. [CrossRef]
50. Shahrajabian, M.H.; Sun, W.; Cheng, Q. Chemical components and pharmacological benefits of Basil (*Ocimum basilicum*): A review. *Int. J. Food Prop.* **2020**, *23*, 1961–1970. [CrossRef]
51. Yang, T.; Kim, H.-J. Characterizing Nutrient Composition and Concentration in Tomato-, Basil-, and Lettuce-Based Aquaponic and Hydroponic Systems. *Water* **2020**, *12*, 1259. [CrossRef]
52. Ghandar, A.; Ahmed, A.; Zulfiqar, S.; Hua, Z.; Hanai, M.; Theodoropoulos, G. A decision support system for urban agriculture using digital twin: A case study with aquaponics. *IEEE Access* **2021**, *9*, 35691–35708. [CrossRef]
53. Liebler, D.C.; Kling, D.S.; Reed, D.J. Antioxidant protection of phospholipid bilayers by alpha-tocopherol. Control of alpha-tocopherol status and lipid peroxidation by ascorbic acid and glutathione. *J. Biol. Chem.* **1986**, *261*, 12114–12119. [CrossRef]
54. Yiu, J.-C.; Juang, L.-D.; Fang, D.Y.-T.; Liu, C.-W.; Wu, S.-J. Exogenous putrescine reduces flooding-induced oxidative damage by increasing the antioxidant properties of Welsh onion. *Sci. Hortic.* **2009**, *120*, 306–314. [CrossRef]
55. Wang, F.; Yang, Q.; Zhao, Q.; Li, X. Cold shock treatment with oxalic acid could alleviate chilling injury in green bell pepper by enhancing antioxidant enzyme activity and regulating proline metabolism. *Sci. Hortic.* **2022**, *295*, 110783. [CrossRef]
56. Ahmad, S.; Wang, G.-Y.; Muhammad, I.; Chi, Y.-X.; Zeeshan, M.; Nasar, J.; Zhou, X.-B. Interactive Effects of Melatonin and Nitrogen Improve Drought Tolerance of Maize Seedlings by Regulating Growth and Physiochemical Attributes. *Antioxidants* **2022**, *11*, 359. [CrossRef]
57. Al Shamsi, S.R.H.A.; Rabert, G.A.; Kurup, S.S.; Alyafei, M.A.M.; Jaleel, A. Biochemical Changes and Antioxidant Variations in Date Palm (*Phoenix dactylifera* L.) Varieties during Flower Induction and Development. *Plants* **2021**, *10*, 2550. [CrossRef] [PubMed]
58. Rakocy, J.; Shultz, R.C.; Bailey, D.S.; Thoman, E.S. Aquaponic production of tilapia and basil: Comparing a batch and staggered cropping system. In *South Pacific Soilless Culture Conference-SPSCC 648*; International Society for Horticultural Science: Leuven, Belgium, 2003; pp. 63–69.
59. Roosta, H.R.; Hamidpour, M. Effects of foliar application of some macro-and micro-nutrients on tomato plants in aquaponic and hydroponic systems. *Sci. Hortic.* **2011**, *129*, 396–402. [CrossRef]
60. Heise, J.; Müller, H.; Probst, A.J.; Meckenstock, R.U. Ammonium Removal in Aquaponics Indicates Participation of Comammox Nitrospira. *Curr. Microbiol.* **2021**, *78*, 894–903. [CrossRef] [PubMed]