4-2022

YIELD, NUTRIENT CONTENTS AND ANTIOXIDANT LEVELS IN BASIL (Ocimum basilicum L.) GROWN IN AQUAPONIC AND SOIL SYSTEMS

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MASTER THESIS NO. 2022:12

College of Agriculture and Veterinary Medicine

Department of Integrative Agriculture

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Maryam Ahmed Albedwawi

This thesis is submitted in partial fulfilment of the requirements for the degree of
Master of Sciences in Horticulture

Under the Supervision of Dr. Abdul Jaleel Cheruth

April 2022

Declaration of Original Work

I, Maryam Ahmed Albedwawi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Yield, Nutrient Contents and Antioxidant Levels in Basil* (*Ocimum basilicum* L.) *Grown in Aquaponic and Soil Systems*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Dr. Abdul Jaleel, in the College of Agriculture and Veterinary Medicine at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

A study was conducted to evaluate the performance of *Ocimum basilicum* L. in both aquaponic and soil systems in the UAE climatic condition. The experiments were conducted under greenhouse conditions. Plants were raised in aquaponic beds with ornamental fishes in different concentrations. At the same time, a set of plants were raised in pots under greenhouse set up. The studied parameters were morphological (total weight and leaf number, shoot and root length, number of branches), biochemical (chlorophyll a, chlorophyll b, total chlorophyll, anthocyanin, xanthophyll, protein and phenol contents) and antioxidant levels (Ascorbic acid and tocopherol). For analyzing the stress effects of aquaponic system on plant defense mechanism, two different antioxidant enzymes (catalase and peroxidase) were analyzed. Also, nutritional contents were determined at the end of the study period. Water quality parameters were monitored during the entire study period. Based on the results, the total weight and leaf numbers showed a significant increase under aquaponic setup when compared to normal greenhouse grown plants. There was significant increase in growth parameters in aquaponic system when compared to conventional greenhouse cultivation of basil plants. The photosynthetic parameters showed a decline in aquaponics but the biochemical parameters showed an enhancement in the aquaponic system of growing basil plants. The antioxidants showed a significant increase in aquaponic system which suggests the water stress effect on plants induced by the aquaponic growing system. The nutrient level showed significant enhancement in aquaponic system. From the results of this study, it can be concluded that, the aquaponic system is best suitable method of *Ocimum* production in UAE condition.

Keywords: *Ocimum*, ornamental fish, aquaponics, nutrients, antioxidants, sustainable production.

Title and Abstract (in Arabic)

المحصول ومحتويات المغذيات ومستويات مضادات الأكسدة في نبات الريحان (*Ocimum basilicum* L.)الذي نما بنظام الاستزراع السمكي (الأكوابونيك) أو في التربة

الملخص

أجريت هذه الدراسة لتقييم نمو نبات الريحان في كل من نظام الزراعة الأكوابونيك وفى التربة في الظروف المناخية لدولة الإمارات العربية المتحدة، وأجريت التجارب تحت ظروف البيوت المحمية. تمت تربية النباتات في أحواض أكوابونيك مع أسماك الزينة بتركيزات مختلفة في نفس الوقت، تمت تربية مجموعة من النباتات في أواني تحت الدفيئة. كانت الخصائص المورفولوجية المدروسة للشكل (الوزن الكلي وعدد الأوراق، طول النبتة والجذر، عدد الأفرع)، الخصائص الكيميائية (الكلوروفيل أ، الكلوروفيل ب،الكلوروفيل الكلي، الأنثوسيانين، الزانثوفيل، محتويات البروتين والفينول) ومستويات مضادات الأكسدة (حمض الأسكوربيك وتوكوفيرول).

لدراسة تأثيرات الإجهاد لنظام الاستزراع النباتي على آلية دفاع النبات، تم تحليل اثنين من إنزيمات مضادات الأكسدة المختلفة (الكاتلاز والبيروكسيديز). كما تم تحديد محتوى النبات من العناصر المغذية في نهاية فترة الدراسة، وتم رصد معايير جودة المياه خلال فترة الدراسة بأكملها.

بناءً على النتائج، أظهر الوزن الإجمالي وأعداد الأوراق زيادة معنوية في نظام الزراعة الأكوابونيك مقارنة بالنباتات الكنترول المزروعة في الصوبات. كانت هناك زيادة معنوية في متغيرات النمو في نظام الاستزراع النباتي والسمكي عند مقارنتها بزراعة نباتات الريحان في الصوبات التقليدية. أظهرت معادلات التمثيل الضوئي انخفاضًا في نظام الاستزراع النباتي والسمكي، إلا أن المعايير الكيميائية أظهرت تحسنًا في نظام الزراعة الأكوابونيك لنبات الريحان، وأظهرت مضادات الأكسدة زيادة ملحوظة في نظام الزراعة المائية مما يشير إلى تأثير الإجهاد المائي على النباتات الناجم عن نظام الأكوابونيك. أظهرمستوى المغذيات تحسنًا ملحوظًا في نظام الاستزراع النباتي والسمكي، ومن نتائج هذه الدراسة يمكن الاستنتاج أن نظام الاستزراع النباتي الأكوابونيك هو أفضل طريقة مناسبة للإنتاج المحيطي في دولة الإمارات العربية المتحدة.

مفاهيم البحث الرئيسية: أسماك المحيط، أسماك الزينة، الاستزراع النباتي، مغذيات، مضادات الأكسدة، إنتاج مستدام.

Acknowledgements

I wish to express my hearty, deep sense of gratitude and sincere thanks to Dr. Abdul Jaleel, Associate Professor, Department of Integrative Agriculture, College of Agriculture and Veterinary Medicine.

I thank him for his periodical guidance in the planning and execution of the work. I wish to express my deep sense of gratitude to Dr. Mohammed A. Salem Alyafei, Associate Professor and Chair in the Department of Integrative Agriculture and Vice Dean, and Dr. Shyam Kurup, Associate Professor in the Department of Integrative Agriculture, UAEU for their valuable guidance as Co-Supervisors.

I would like to thank my committee for their guidance, support, and assistance throughout my studies and preparation of this thesis. Special thanks go to Dr. K. Karthishwaran, Visiting Instructor, Department of Integrative Agriculture, College of Agriculture and Veterinary Medicine for being a great help throughout this entire process. I would like to thank the Department Chair and all members of the Department of Integrative Agriculture, College of Agriculture and Veterinary Medicine, United Arab Emirates University for assisting me all through my studies and research. I avail this opportunity to express my sincere thanks to the Engineers and Technicians in Horticultural Lab and Falaj Hazza Experimental Station, especially Engr. Mamdouh Khawanna and Engr. Magdi Abdel Latif for their help and support during my research work. My special thanks are extended to the Library Research Desk for providing me with the relevant reference material.Special thanks go to my mother and family members and my loyal friends who helped me along the way. I am sure they suspected it was endless and without their constant encouragement and support, I would not have been able to undertake and complete this work.

Dedication

To my beloved parents and family

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AA	Ascorbic Acid
CAT	Catalase
DAS	Days After Sowing
POX	Peroxidase
RAS	Recirculating Aquaponics System

Chapter 1: Introduction

1.1 Background Information

Water management is one of the main challenges in United Arab Emirates which emerged as 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 really so precious in this country.

As an alternative way of modern agriculture, aquaponics is considered as a system that can use the water from fish tank for producing plants in order to save water and produce clean products in a shorter time (Blidariu & Grozea, 2011). The principle of aquaponics is that, it uses the waste from fish and utilizes for their growth in the form of nutrients required for their normal growth (Yavuzcan et al., 2017). In this aspect, aquaponics system can conserve the precious water, especially in countries like UAE, where the water supply is limited, and has very few arable lands. Also, the environmental impact is less compared to the conventional farming systems. With aquaponic technology sustainable fish and vegetable production can be achieved with simultaneous conservation of precious natural resources in the country.

1.2 Recirculating Aquaponics System (RAS)

In this type of aquaponics, the water is being circulated through the fish tanks and growth beds, and the wastage of water can be highly reduced (Yep & Zheng, 2019). It can produce fish and plants in high quantity and quality simultaneously.

UAE is moving towards sustainable food security in near future, for that, a multi-faceted agro-ecological intensification of food production and the decoupling from unsustainable resource use is of utmost importance. Techniques like aquaponics has great role to perform in achieving the food security of modern times (Khan et al., 2020).

In countries like UAE, where the climatic and land characteristics are not supportive for conventional farming, this type of less water used agricultural systems are more promising (Butti Al Shamsi et al., 2018). Also, the usage of fertilizers and chemicals can be eliminated in this type of aquaponic systems, as the system relies on fish waste to provide nutrients to help the plants grown in turn, the water will be recycled back to the fish creating a symbiotic relationship (Joyce et al., 2019).

The working principle of aquaponics is quite simple which involve only three kinds of living organisms: fish, beneficial bacteria, and plants. The interrelations between them are highly complex and interdependent (Goddek et al., 2015). Also, the toxic components like ammonia created in the system from fish and food waste are getting solved by the action of bacteria by process of conversion of ammonia to nitrite and then to nitrate which is non-toxic and the same time beneficial to plants (Zou et al., 2016).

1.3 Ornamental Fishes in Aquaponics

When selecting the fish used in an aquaponic system, the main points to be noted is the resistance of the fish species to various environmental and water conditions (Pinho et al., 2021). The availability and usefulness of the species is also to be considered. The major fish species used in any aquaponics system is Tilapia (Oreochromis niloticus) which can be used to run the plant-based system very successfully (Liang & Chien, 2013). Tilapia has been cultured for more than 3,000 years and is one of the foremost fish species (De Silva, 2004).

The researches related to usage of ornamental fishes in aquaponics system is relatively scanty (Maucieri et al., 2018). In this study, we selected koi fish, which is an important ornamental species loved by the hobbyists and aqua culturists throughout the world. Koi fish, belongs to the family Cyprinidae is relatively resistant to different situations in fish tanks (Hu et al., 2021). The resistance of this fish to various levels of water parameters and its ability to grow and produce a huge quantity is the main reason for our selection in aquaponics. The fish is comparatively less disease susceptible and also fast growing, making it an easy species when cultivated together with the plants (Adamek et al., 2017).

1.4 Basil in Aquaponics

Ocimum basilicum, popularly known as basil, is a very popular culinary herb that is used majorly in food production. Growing basil is also very common among farmers. Knaus et al. (2020) states that basil extracts have several medicinal properties. Moreover, basil may also have nematicidal, antimicrobial, fungistatic and insecticidal effects. 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 (Knaus et al., 2020). Basil leaves develop an unmistakable and distinctive scent via peculiar oil glands, and is therefore considered as the most versatile herb (Rehman et al., 2016). 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. Moncada et al. (2021) reported that basil is suitable for soil as well as soilless cultivation.

According to Pasch et al. (2021), basil corresponds to 81% of plant production in aquaponics. Basil has high growth potential, and is therefore especially suitable for aquaponics (Babmann et al., 2020). 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. Hundley et al. (2018) particularly found that basil produces 1.8 kg per meter square under aquaponic production, and only 0.6 kg per meter square in soil cultivation. In this context, Obirikorang et al. (2021) defines aquaponics as a food producing technology that includes a combination of hydroponics and aquaculture in a recirculating and integrated system. Thus, aquaponic production is considered to be more efficient and environment-friendly than soil cultivation.

Even though previous studies showed that basil growth and production is higher in case of aquaponic systems compared to soil cultivation, researchers did not focus adequately on comparing the level of antioxidants in 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.

1.5 Research Problem

With growing population and rising demand for food, shortage in water and land resources has become a problem. Majority of freshwater resources available today are used for agricultural activities, which contributes to the growing scarcity of drinking water for people in several countries in the world (Jury & Vaux Jr, 2007). Popp et al. (2013) states that agricultural companies are using various disruptive methods today to increase yield and meet growing food demands. Such disruptive agricultural techniques are directly harming the environment as well as depleting natural resources at an unprecedented rate. Some of them lead to widespread deforestation and soil erosion. Clearly, harmful agricultural practices are intensifying and contributing to existing environmental concerns and challenges (Tilman, 1999). Owing to such rising concerns, researchers claim that it is imperative to adopt sustainable technology and other sustainable agricultural practices like reusing water in intensive or semi-intensive production systems (Nguyen et al., 2019).

Knaus et al. (2020) also found that the escalating growth in population as well as increasing demand for freshwater has created an immense pressure on agricultural sectors responsible for the production of food. Considering this rising issue, it is important to identify and adopt sustainable food production mechanisms that require minimal nutrients and water. Thus, relying on ethical agricultural practices is crucial to deal with today's environmental problems as well as meet future food demands. Here, Love et al. (2015) identifies the aquaponic technique as a very sustainable food production method that integrates fish farming and vegetable production. Scholars also mention that water required for plant growth in aquaponic systems is much lesser compared to that required for irrigation in traditional agricultural methods. Moreover, Knaus et al. (2020) specifies that aquaponics also requires less land resources and no chemical fertilizers, and therefore does not lead to deforestation and harmful emissions to the atmosphere. Inevitably, aquaponics is a much viable, feasible and environment-friendly agricultural technique that could resolve current issues and concerns associated with traditional agriculture. The current research focuses on the problem described in this section and evaluates both aquaponic systems and soil systems by comparing their efficiency in terms of the yield and level of antioxidants of basil grown in both systems.

1.6 Research Questions

The following research questions are answered, in relation to specific growth conditions in UAE:

1. How is basil grown in aquaponic/soil systems?
2. What is the growth potential of basil in aquaponic/soil systems?
3. What is the quality of basil grown in aquaponic/soil systems?
4. What is the nutrient or antioxidant composition of basil grown in aquaponic/soil systems?
5. Which method is more profitable for growing basil?

1.7 Aims of the Study

Previous studies prove that basil has a host 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. Nevertheless, while previous researchers found that basil production and yield is higher in 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 differ from that grown in aquaponic systems. The primary purpose of this research is to gather accurate and reliable information in this field and assess whether growing basil in aquaponic systems is a better and more fruitful alternative to growing basil in soil systems or not.

1.8 Review of Literature

As per Pandey et al. (2019), basil is among one of the top priorities for farmers all over the world because of the high value that it carries as a cash crop. Basil or scientifically called, *Ocimum basilicum*, is a fast-growing cash crop that is of high value to farmers worldwide, of all types (Bahl et al., 2018). *O. basilicum* can be grown the normal way, that is, with the help of soil systems and harvesting, or it may even be grown with the help of Aquaponic, a modern-day hybrid technology that combines two different fields that are aquaculture and hydroponics. Basil production has high potential in both Aquaponic and soil cultivation (Yang & Kim, 2020a).

1.8.1 Growing Basil in Aquaponic/Soil System

As opined by Parameshwarareddy (2018), aquaponics is the modern-day science study that helps the future by introducing a resourceful and sustainable way of harvesting food production that is environment friendly. Aquaponics is a system of food production that is completely detached from any kind of soil and only takes the help of aquaculture and hydroponic system (Fruscella et al., 2021). Aquaponic only takes the help of fish, bacteria, and several kinds of plants to compose an ecosystem that will be both sustainable and easy to grow basil. Basil cultivars have high priority for the aquaponic system as it allows for a fast-paced system of food production, with the help of modern technology and science (Abbey et al., 2022).

According to Tolay (2021), the soil system of is one of the most profound and rich ways of producing basil. Basil flourishes with the help of rich soil that has an accurate pH level for its growth. A perfect drainage system, 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, with a drainage system that works well (Simon et al., 1999).

1.8.2 Growth Potential in Aquaponic/Soil System

As recommended by Knaus et al. (2020), the system of growing basil in different systems, that is, hydroponic system and aquaculture, give high yield unlike any other method of growing the same. The aquaponic system of growing basil has a ton of potential for growth due to its sustainability and in terms of environmental friendliness. The application of research conducted has proven that basil can grow more in aquaponic than in hydroponic and other ways of cultivation (Quagrainie et al., 2018).

As suggested by Al-Maskari et al. (2012), basil grows well in rich soil and enough sunlight to sustain the growth process and a drainage system that would be excellent for the water movement. A moist soil with enough sunlight that is present for six to eight hours a day, would give the production potential and excellent growth to basil plants. Even though the traditional culture methods of growing basil crops are being challenged, modern technology like aquaponics provide great potential to this crop for increased production (Walters & Currey, 2018).

1.8.3 Quality in Aquaponic/Soil System

The production of basil with the help of the aquaponic system of crop production can be done in a manner that is sustainable to the environment, does not take much land or water, and produces high-quality crops (Danner et al., 2019). 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 (Ahmed et al., 2019). The aquaponic system takes the help of fish, water tanks, plants and bacteria to grow products that are of high quality (Fischer et al., 2021). The quality is maintained through proper checkups and maintenance of the system.

As opined by Al-Maskari et al. (2012), the growth of basil with the help of a soil system produces a rich crop that is excellent in aroma, taste, and flavor. The production of basil in the soil will be helped by a rich and moist soil that would allow for the crop to grow at its full potential, the availability of sunlight and water would be the main factor that the plant would need to produce high-quality leaves. The growth quality of basil in the soil system is depended on several aspects such as availability of proper land, a perfect drainage system, sunlight for a better part of the daytime, and other requirements that would produce the best quality basil.

1.8.4 Nutrients or Antioxidant Composition in Aquaponic/Soil system

The nutrients and antioxidants are the main benefits of basil and it is also rich in flavour, taste, calcium, and other nutrients (Maheshwari et al., 2012). The pH requirement to grow basil in the aquaponic system is between 5.5 to 6.5. Basil grown in an aquaponic system will carry certain distinguished nutrients such as vitamin k, calcium, and other several nutrients and even antioxidants (Sharma et al., 2018). Basil is a herb that is rich in various qualities and nutrients with antioxidants that give flavour to cooked dishes and is an excellent part of a healthy diet.

1.8.5 Profitability in Aquaponic/Soil System

According to Hundley et al. (2018), the world is at a phase where resources are severely depleting and the need for more sustainable options are increasing every moment. Soilless options of growing crops such as aquaponic system help in the production of crops with the use of lesser land and water, which is advantageous to farmers and producers worldwide as the population keeps on increasing the fight for land and water continue to grow (El-Kazzaz & El-Kazzaz, 2017). The lesser use of land and water give farmers a more economically favorable option of growing crops at a lesser price without compromising quality (Blidariu & Grozea, 2011).

The profitability margin is slightly lower when it comes to the soil system of producing basil as the use of land and water and all the other requirements are slightly higher in the case of soil system and for the same kind of product that is offered by aquaponic or even hydroponic production of crops (Turkmen & Guner, 2010). The soilless options of growing the same product with more sustainability and lesser use of land, water, and practically no soil, is economically profitable. The soilless options of producing basil also give a high yield per unit area to the farmers and producers, which is a better deal that most cultivators are now adopting (Barrett et al., 2016).

1.8.6 Gap Analysis

The research study conducted here is a comparative analysis between the aquaponic system and soil-system of growing and cultivating basil. The research is primarily focused on finding the difference in nutrients and antioxidants present between both production techniques. The comparative analysis is also differentiating the level of yield that is produced by both the methods of production of basil. The comparative analysis conducted in this research is between the aquaponic and soil systems of growing basil but fails to incorporate information about other methods of crop production such as hydroponics and aeroponics. The gap in the research is primarily because of a shortage of time and large portions of information that had to be fit into the research.

1.8.7 Summary

The research dives into a comparative analysis between the aquaponic system of growing and producing basil, and the soil system of producing the same. The literature review starts off with an introduction to the topics which introduces the two different systems of basil production. Further, the comparative analysis between the two systems is done on different aspects such as growing basil in the two systems, growth potential, the quality of basil, presence of nutrients and antioxidants, and lastly, the profitability in each of the systems. A gap analysis of the research has also been presented.

Chapter 2: Materials and Methods

2.1 Experiment Location

The experiment was carried out in Falaj Hazza campus unit of aquaponics (24.1860076 and 55.7066404) of the College of Agriculture and Veterinary Medicine, UAEU in Al Ain city, 160 km East of Abu Dhabi the capital city of the United Arab Emirates.

2.2 Seed Collection and Germination

The certified seeds of *Ocimum basilicum* were obtained from Agriculture materials 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 done two times per day. Plants were germinated after 4-6 days. The plants were sown along with the commencement of fish culture.

2.3 Experimental Setup

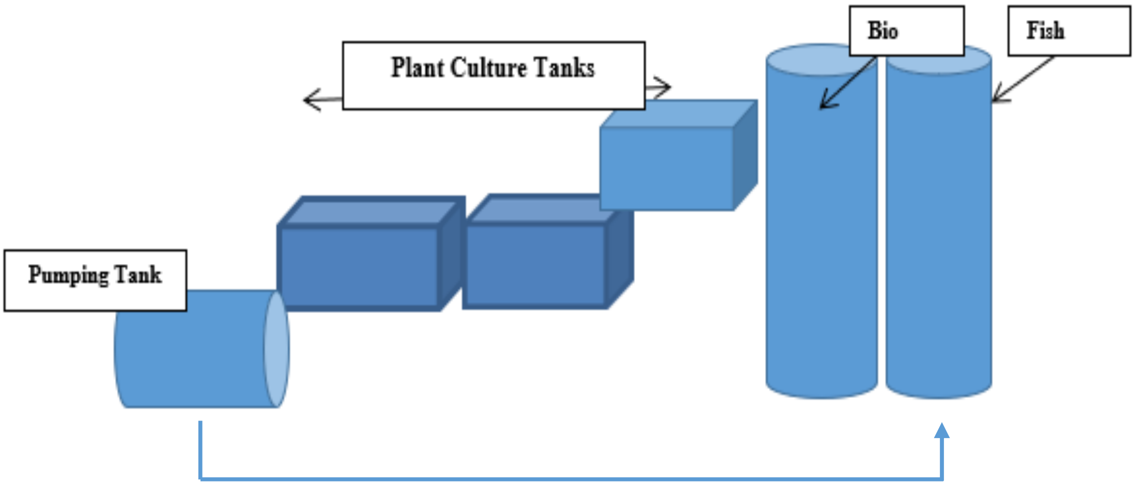

Figure 1: Experimental Set up showing Tanks, Growth Trays and Filters

The seeds/plantlets 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 plants 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 (Figure 1).

2.4 Fish Selection and Growth Conditions

Fish tanks were stocked with 50 fish m^{-3} of fingerlings of *Cyprinus rubrofuscus* var. "koi" in separate tanks with an average weight of 5 g. Fishes were fed with 36% protein commercial fish diet from Arabian Agricultural Services Company ARASCO, Saudi Arabia. They were fed three times a day.

Figure 2: Different stages during the experimental study

2.5 Plant Growth Conditions and Parameters Analyzed

Basil was harvested every 30 days and a new seed was planted to start new crop. Basil characteristics of each harvest was evaluated by measuring length (leaf to root), shoot length, root length, total weight, shoot weight, leaf weight and average leaf number per plant.

2.5.1 Plant Growth Parameters

2.5.1.1 Height of the Plant

The plant height was measured from the soil level to the tip of the shoot and the values are expressed in cm. whereas shoot average root length/plant. The plant root length was measured from the point of first cotyledonary node to the tip of longest root and expressed in cm.

2.5.1.2 Number of Leaves

The total number of leaves, which were fully developed, were counted and expressed as number of leaves per plant.

2.5.1.3 Leaf Area

The total leaf area of the plants was measured using LICOR Photo Electric Area Meter (Model LI-3100, Lincoln, USA) and expressed in cm^2 per plant.

2.5.1.4 Determination of Fresh and Dry Weights

After washing the plants in the tap water, fresh weight was determined by using an electronic balance and the values were expressed in grams. After taking fresh weight, the plants were dried at 60°C in hot air oven for 48 hours. After drying, the weight was measured and the values were expressed in grams.

2.5.2 Estimation of Photosynthetic Pigments

2.5.2.1 Estimation of Chlorophyll Contents

Chlorophyll and carotenoid were extracted from the leaves and estimated by the method of Arnon (1949).

Extraction:

Five hundred milligrams of fresh leaf material were ground with 10 ml of 80 percent acetone and centrifuged at 2500 rpm for 10 minutes at 4°C. This procedure was repeated until the residue became colorless. The extract was transferred to a graduated tube and made up to 10 ml with 80 percent acetone and assayed immediately.

Estimation:

Three milliliters aliquots of the extract were transferred to a cuvette and the absorbance was read at 645, 663 and 480 nm with a spectrophotometer (U-2001-Hitachi) against 80 percent acetone as blank. Chlorophyll content was calculated using the formula of Arnon and expressed in milligram per gram fresh weight.

Total chlorophyll (mg/ml) = $(0.0202) \times (A.645) + (0.00802) \times (A.663)$
Chlorophyll 'a' (mg/ml) = $(0.0127) \times (A.663) - (0.00269) \times (A.645)$
Chlorophyll 'b' (mg/ml) = $(0.0229) \times (A.645) - (0.00468) \times (A.663)$

2.5.2.2 Anthocyanin

Anthocyanin was extracted and estimated from the flowers by the method of Beggs and Wellmann (1985).

Five hundred milligrams of flowers were cut into small pieces and immersed in 10 ml of HCl : methanol (1 : 100 v/v) and kept in darkness at 5°C for 24 hours. The absorbance of decanted extract was measured at 525nm in spectrophotometer (U-2001-Hitachi) against HCl : methanol (1:100 v/v) as blank. The results were expressed in milligrams per gram fresh weight.

2.5.2.3 Xanthophyll

Xanthophyll was extracted and estimated from the flowers by the method of Neogy et al. (2001).

Five hundred milligrams of fresh petals was ground with 10 ml of 80 percent ethanol. The extract was centrifuged at 800 rpm for 15 minutes. The supernatant was collected and made up to 10 ml with 80 percent ethanol. The absorbance was read at 450 nm against 80 percent ethanol as blank. The results were expressed in milligrams per gram fresh weight.

2.5.3 Biochemical Analysis

2.5.3.1 Protein

Protein was estimated following the method of Bradford (1976).

Extraction:

Five hundred milligrams of fresh plant material were ground in a mortar and pestle with 10 ml of 20% trichloro acetic acid (TCA). The homogenate was centrifuged for 15 minutes at 800 g. The supernatant was discarded and to the pellet 5 ml of 0.1N NaOH was added to solubilize the protein and the solution was centrifuged at 800 g for 15 minutes. The supernatant was made up to 10 ml with 0.1N NaOH and used for the estimation of protein content.

Assay:

Protein solution containing 10 to 100 µg protein in a volume of 0.1 ml was pipetted into 12 x 100 mm test tubes. Five milliliters of Bradford's reagent was added to the test tube and the contents were mixed by vortexing. The absorbance at 595 nm was measured after 2 minutes 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 standard curve was prepared using BSA V fraction was used to determine the protein content and the results were expressed in milligram per gram dry weight.

Preparation of Bradford's Reagent:

100 milligrams of coomassie brilliant blue G-250 was dissolved in 50ml of 95 percent ethanol. To this solution, 100 ml of 85 percent (w / v) phosphoric acid was added. The resulting solution was diluted to a final volume of one litre.

2.5.3.2 Total Phenol

Total phenols were estimated by the method of Malik and Singh (1980).

Extraction:

Five hundred milligrams of fresh plant tissue was 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 to dryness. The residue was dissolved with 5 ml of distilled water and used as extract.

Estimation:

To 2 ml of the extract, 0.5 ml of Folin-Ciocalteau reagent was added. After 3 min, 2 ml of 20% $Na_2 CO_3$ solution was 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 concentration of gallic acid.

2.5.4 Non-Enzymatic Antioxidant Contents

2.5.4.1 Ascorbic Acid

Ascorbic acid content was assayed as described by Omaye et al. (1979).

Extraction:

One gram of fresh material was ground in a pestle and mortar with 5 ml of 10 percent TCA, the extract was centrifuged at 3500 rpm for 20 minutes. The pellet was re-extracted twice with 10 percent TCA and supernatant was made to 10 ml and used for estimation.

Estimation:

To 0.5 ml of extract, 1 ml of DTC reagent (2,4-Dinitrophenyl hydrazine-Thiourea-CuSO4 reagent) was added and mixed thoroughly. The tubes were incubated at 37°C for 3 hours and to this 0.75 ml of ice cold 65% H2SO4 was added. The tubes were then allowed to stand at 30°C for 30 minutes. The resulting colour 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 were expressed in mg g^{-1} fresh weight.

2.5.4.2 α-Tocopherol

α-Tocopherol content was estimated as described by Backer et al. (1980).

Extraction:

Five hundred milligrams of fresh tissue were 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 minutes and the supernatant was used for estimation of α-tocopherol.

Estimation:

To 1 ml of extract, 0.2 ml of 2 percent 2,2-dipyridyl in ethanol was added and mixed thoroughly and kept in dark for 5 minutes. The resulting red colour was diluted with 4 ml of distilled water and mixed well. The resulting colour 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.

2.5.5 Antioxidant Enzymes

Crude enzyme extract was prepared for the assay of peroxidase and catalase by the method of Hwang et al. (1999).

Extraction:

One gram of plant tissue was homogenized with 10 ml of ice cold buffer 50 mM sodium phosphate buffer containing 1 mM PMSF. The homogenate was strained through two layers of cheese cloth and centrifuged at 12,500 g for 20 minutes at 4ºC. The supernatant was made up to 10 ml with the same buffer and used as the source of enzymes. The enzyme protein was determined by Bradford (1976) method for expressing the specific activity of all the enzymes.

2.5.5.1 Catalase

Catalase activity was assayed as described by Chandlee and Scandalios (1984). 0.5 gram of frozen material 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 extract was centrifuged at 4ºC for 20 minutes at 12500 g. The supernatant was used for enzyme assay. The assay mixture contained 2.6 ml of 50 mM potassium phosphate buffer (pH 7.0), 0.4 ml of 15 mM H_2O_2 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 1 mM of H_2O_2 reduction per minute per mg protein.

2.5.5.2 Peroxidase (POX, EC 1.11.1.7)

Peroxidase was assayed by the method of Kumar and Khan (1982). 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 prepared by adding 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.

2.5.6 Microelements and Macroelements

Samples were prepared accurately by weighing 0.5 grams in the microwave digestion vessels and 10 ml of concentrated nitric acid (HNO_3) and 2 ml hydrochloric acid (HCL) were added. 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 was 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.

2.5.7 Statistical Analysis

Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Duncan’s Multiple Range Test (DMRT). The values are mean ± SD for seven samples in each group. P values ≤ 0.05 were considered as significant.

Chapter 3: Results

Economically important leafy green plant basil (*Ocimum basilicum*) belonging to the family lamiaceae was selected for the present investigation. Aquaponic and greenhouse experiments were conducted to identify the variation under both cultivation systems. In this experiment, variation in growth, photosynthetic pigments, biochemical constituents, non-enzymatic antioxidants and nutrient composition were studied from both experimental setups on 40 and 70 days after sowing (DAS).

3.1 Morphological Parameters

3.1.1 Total Height of the plants

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

3.1.2 Root Length

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

3.1.3 Number of Leaves

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

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

Growth Parameters	**DAS**	**Soilless (aquaponic) system**	**Soil (greenhouse) system**
Total plant height (cm)	40	69.42 ± 9.83^{a}	65.55 ± 9.33^{b}
	70	98.05 ± 14.21^{a}	84.21 ± 11.58^{b}
Root length (cm)	40	27.98 ± 5.89^{a}	23.21 ± 4.98^{b}
	70	59.21 ± 8.22^{a}	54.36 ± 8.25^{b}
Leaves (No.)	40	107.00 ± 22.99^{a}	99.88 ± 27.22^{b}
	70	174 ± 27.35^{a}	148 ± 24.36^{b}
Leaf area $(cm)^{2}$	40	3.78 ± 0.55^{a}	3.08 ± 0.24^{a}
	70	3.74 ± 0.25^{a}	3.66 ± 0.41^{a}
Total wet weight (g)	40	47.80 ± 13.71^{a}	45.89 ± 12.22^{b}
	70	84.31 ± 11.23^{a}	79.25 ± 11.00^{b}
Total dry weight (g)	40	4.96 ± 1.59^{a}	3.77 ± 1.25^{b}
	70	7.11 ± 0.96^{a}	6.33 ± 0.77^{b}
Root dry weight (g)	40	0.77 ± 0.34^{a}	0.44 ± 0.21^{b}
	70	1.2 ± 0.32^{a}	0.99 ± 0.39^{b}

Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT). DAS – Days after sowing.

3.1.4 Leaf Area

Total leaf area showed a decrease under greenhouse system when compared to aquaponic basil plants and it was 3.78 cm and 3.74 in aquaponic at 40 and 70 DAS respectively. In greenhouse plants, it was 3.08 and 3.66 respectively in 40 and 70 DAS.

3.1.5 Wet and Dry Weight

The fresh weight was less 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 basil plants in the system.

3.2 Photosynthetic Pigments

3.2.1 Chlorophyll Contents

3.2.1.1 Chlorophyll 'a'

The chlorophyll 'a' content of the basil leaves was extracted and estimated from the randomly selected leaves on 40 and 70 DAS (Figure 3). In contrary to the growth parameters, the chlorophyll pigment contents in basil showed an increasing trend under greenhouse cultivation system. In the case of chlorophyll 'a', it was 0.048 and 0.055 on 40 DAS in aquaponic and green house systems respectively. During the 70 DAS, the content reduced little bit and showed 0.37 and 0.49 respectively in aquaponic and greenhouse systems. In both the cases, the increase was significant in greenhouse system.

3.2.1.2 Chlorophyll ‘b’

The chlorophyll ‘b’ content of basil leaves also decreased with age in the aquaponic and greenhouse grown plants. On 40 DAS, the chlorophyll ‘b’ content was 0.068 and 0.082 in aquaponic and greenhouse plants, and it is evident that the chlorophyll ‘b’ enhancement in greenhouse system (Figure 3). On 70 DAS even though the chlorophyll content reduced slightly in both the system, but when compared to the aquaponic plants, the greenhouse plants showed an increase in content.

3.2.2 Total Chlorophyll

The total chlorophyll content of the leaves of basil increased in greenhouse cultivated plants, but the contents showed a decrease with age of plant (Figure 3). The greenhouse grown plants of harvest on 40 DAS showed higher contents (0.137) when compared to the aquaponic plants (0.116). Similar trend was observed in the case of 70 DAS harvested plants where the soil cultivated (1.15) was higher than soilless cultivated plants (0.88).

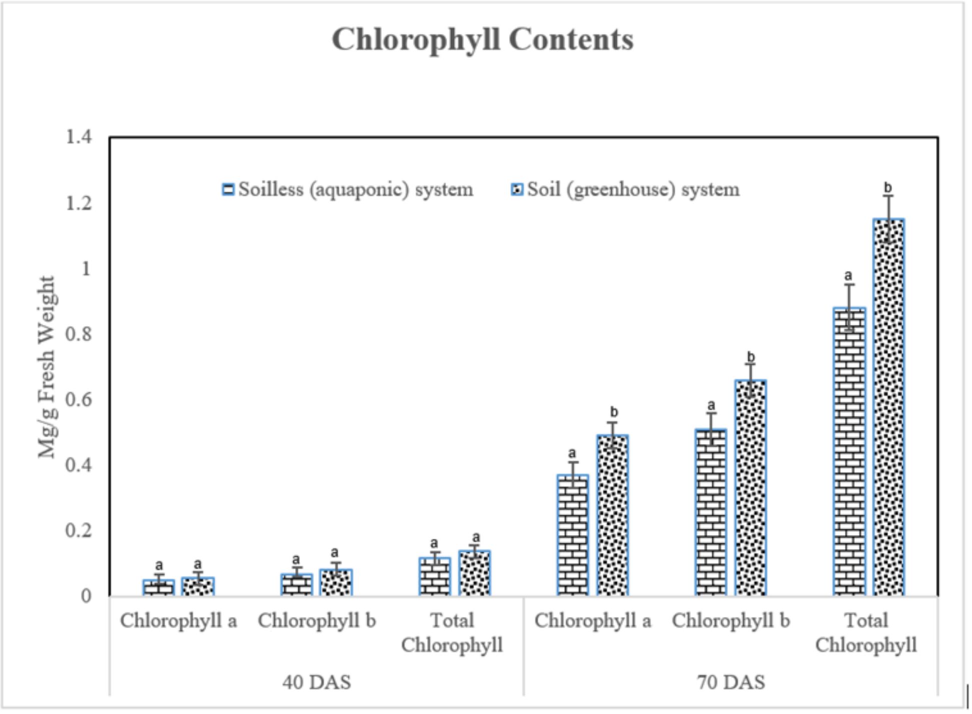

Figure 3: Chlorophyll contents of Ocimum basilicum in (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.2.3 Anthocyanin

The anthocyanin content of basil plants increased with age in both production systems. Also, in comparison with the aquaponic system, the greenhouse system showed more anthocyanin contents in the leaves. At 40 DAS, the basil plants showed 0.562 in aquaponics and 0.698 in greenhouse cultivated plants. Similarly, the basil leaves from aquaponic system on 70 DAS showed 0.59 and greenhouse system showed 0.77 anthocyanin concentration. Overall, the highest anthocyanin contents were recorded in basil leaves grown in greenhouse system on 70 DAS (Figure 4).

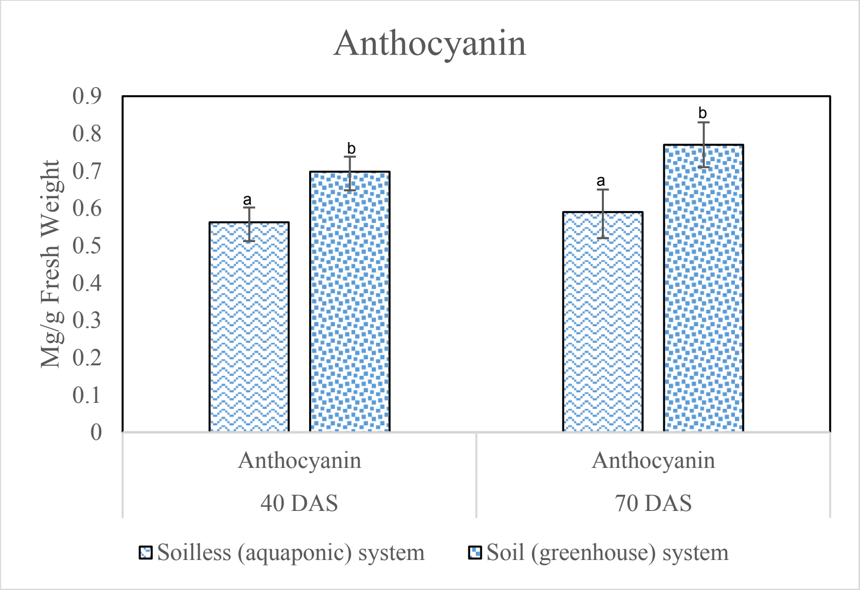

Figure 4: Anthocyanin concentrations of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.2.4 Xanthophyll

The xanthophyll concentration on 40 DAS in basil plants were 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 greenhouse system on 70 DAS (2.36) when compared to plants grown in aquaponic system (1.95).

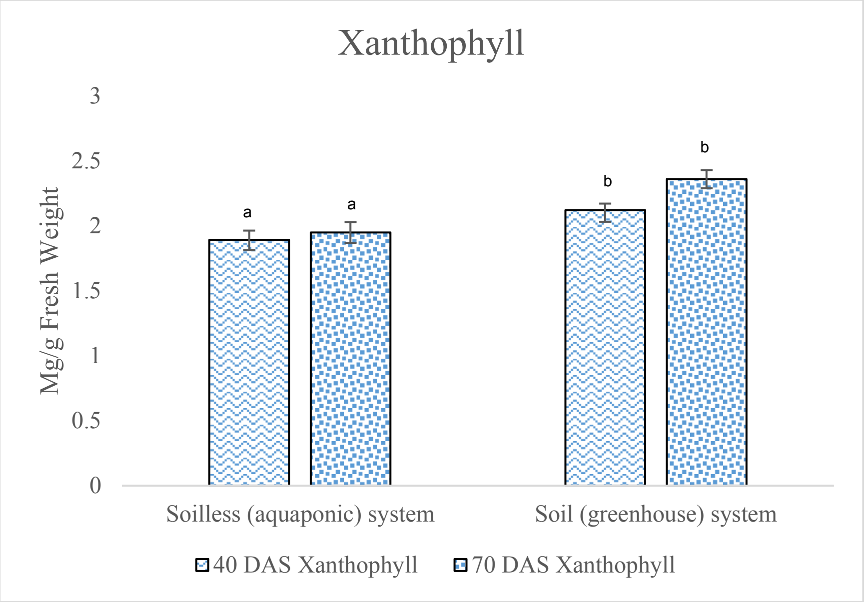

Figure 5 :Xanthophyll concentrations of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.3 Biochemical Parameters

3.3.1 Protein

The plants grown under aquaponic system showed higher content of protein (36.25) when compared to :conventional greenhouse system (29.03) on 40 DAS. Similarly, the protein content was high on 70 DAS as well in aquaponic grown plants. But the sampling days of 40 and 70 DAS didn’t influence the quantity of protein in both the aquaponic and greenhouse plants.

3.3.2 Total Phenol

The phenol concentration showed a remarkable increase in plants with age. The increase was clear in 40 and 70 DAS in both the systems. The phenol concentration at

40 DAS was 8.84 and 7.01 in aquaponic and soil systems respectively. This increased to 10.11 and 9.98 on 70 DAS.

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

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

Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.4 Antioxidants

3.4.1 Ascorbic Acid

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 plants as compared to greenhouse plants, it was 3.57 on 70 DAS when compared to 3.2 in greenhouse system (Figure 5).

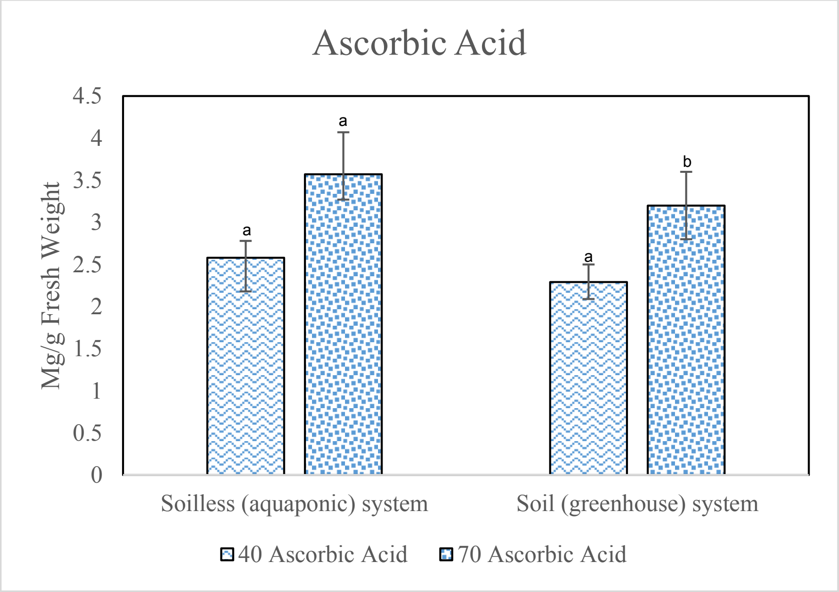

Figure 6: Ascorbic acid concentrations of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.4.2 α-tocopherol

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 plants as compared to greenhouse plants, it was 6.66 on 70 DAS when compared to 5.02 in greenhouse system (Figure 6).

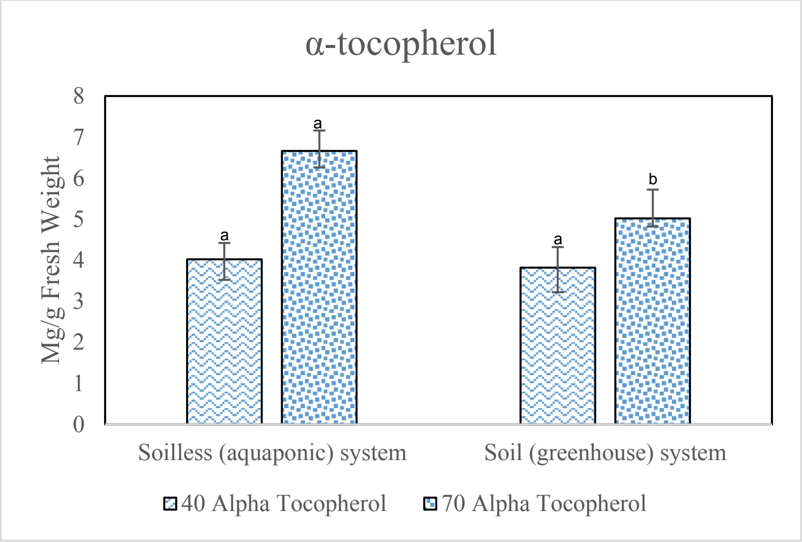

Figure 7: α-tocopherol contents of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.5 Antioxidant Enzyme Activities

3.5.1 Catalase

The antioxidant enzyme activities like catalase and peroxidase increased with age in soilless and aquaponic grown plants. The activities were higher in aquaponic grown plants when compared to soilless grown plants. On 40 DAS, the content was 7.19 in aquaponic grown plants and 4.227 in soil grown plants. The difference in activities of catalase enzyme on 40 and 70 DAS were significant between aquaponic and greenhouse plants (Figure 7).

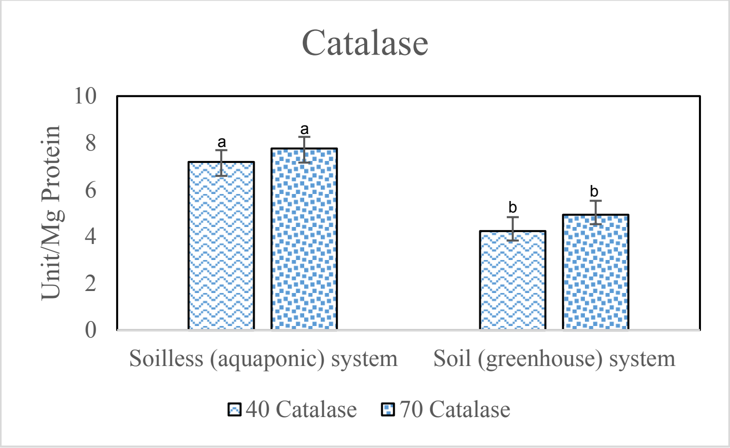

Figure 8 : Catalase activity of *Ocimum basilicum* in (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.5.2 Peroxidase

The peroxidase enzyme activity was higher in aquaponic plants when compared to greenhouse grown plants. The activity was 1.571 in aquaponic plants on 40 DAS and 1.161 in greenhouse grown plants. Similarly, the activity was higher on 70 DAS as well in aquaponic plants when compared to greenhouse grown basil plants (Figure 8).

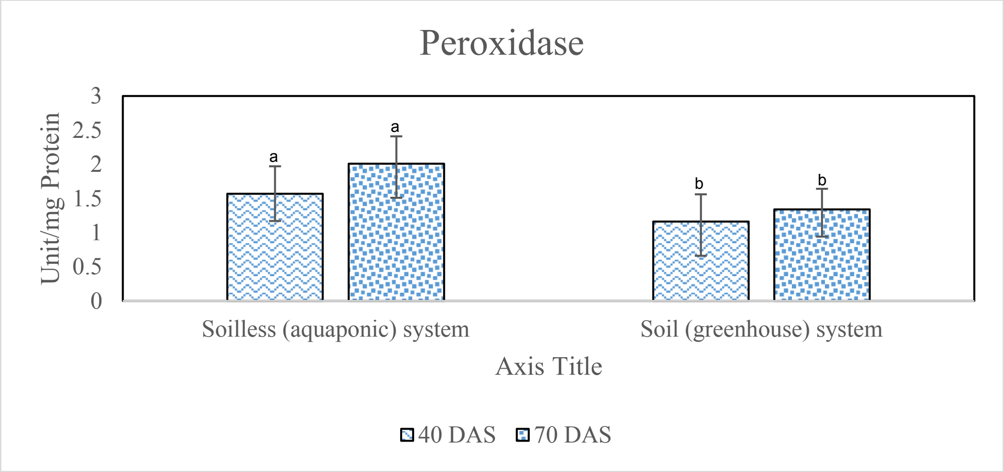

Figure 9: Peroxidase activity of *Ocimum basilicum* in soilless (aquaponic) and soil (greenhouse) systems on 40 and 70 DAS. Values are given as mean ± SD of six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

Table 3: Macronutrients (%) and micronutrients (mg kg^{-1}) in Basil leaves under soilless (aquaponic) and soil systems on 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}
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 six experiments in each group. Values, that are not sharing a common superscript (a,b) differ significantly at $P \leq 0.05$ (DMRT).

3.6 Macronutrients and Micronutrients

The analysis of elements was done only on the end of the experimental period (70 DAS). The levels of macro and micro nutrients were higher in soilless system when compared to conventional greenhouse system.

3.7 Water Parameters

The levels of water temperature, dissolved oxygen, pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), ammonia, nitrate and nitrite showed variations during different intervals in the aquaponic system. Usually the nitrate and nitrite levels increased when ammonia increased. The pH level also showed various levels during the period of experiment.

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

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

Day 70	Day 60	Day 50	**Day 40**	Day 30	Day 20	Day 10	Day 1	**Analysis Intervals**
24.21±0.03	26.01±0.04	24.84±0.02	25.24±0.03	25.02±0.02	24.02±0.03	25.09±0.03	24.01±0.03	**Temperature (°C)**
5.10±0.03	5.11±0.03	5.20±0.03	5.10±0.03	5.03±0.03	5.10±0.04	5.22±0.04	5.01±0.03	**Dissolved Oxygen (mg/l)**
6.98±0.05	6.91±0.04	7.01±0.05	6.99±0.04	6.42±0.04	6.87±0.02	6.99±0.03	6.85±0.03	**pH**
410.11±1.05	420.61±1.15	420.47±1.06	410.41±1.05	390.10±1.32	350.21±0.81	380.11±1.24	310±1.100	**TDS (ppm)**
39.01±0.02	39.98±0.03	40.14±0.04	39.99±0.03	36.40±0.02	17.90±0.04	21.33±0.04	18.09±0.04	**EC (mV)**
0.62±0.02	0.71±0.03	0.61±0.02	0.60±0.02	0.11±0.02	0.12±0.03	0.10±0.03	0.10±0.03	**Ammonia (mg/l)**
18.25±0.08	14.11±0.06	17.79±0.09	18.79±0.09	17.22±0.06	11.99±0.07	6.09±0.04	5.81±0.03	**Nitrate (mg/l)**
0.14±0.04	0.12±0.03	0.12±0.03	0.11±0.03	0.10±0.03	0.08±0.04	0.10±0.04	0.30±0.02	**Nitrite (mg/l)**

Chapter 4: Discussion

Ocimum basilicum L., commonly known as basil, is a herbal plant used for medicinal purposes in the treatment of headaches, cough, and also kidney malfunction. There are many major chemical components in the plant which are the basis for these medicinal properties. Basil has been a source of antioxidant vitamins E, A and C (Juliani & Simon, 2002). These sources of antioxidants help to elevate the health system of humans.

The present investigation was carried out to study the yield and antioxidant levels in basil grown in aquaponic and soil systems with special emphasis to nutrient content variations in these two systems. The aquaponics is based on a soilless system of growing plants. The concept is based on the nutrient-rich water, which is developed with the rearing of fishes in controlled environment (AlShrouf, 2017). The purpose of this chapter is to discuss the experiment based on analyzing the growth variation, pigments, the biochemical composition, antioxidant, elements and the water quality parameters in the study based on 40 and 70 days harvest yields.

4.1 Plant Growth Parameters

Primarily the total height of the basil plant showed an increase in length with the consequences of age. This is based on the analysis of the first DAS of aquaponics and soil systems. The plant was able to reach the maximum height in seventy days. The result of plants grown on the soil system of the greenhouse showed a distinct difference from the aquaponic growth. The root length of the plants of both systems showed a similar result as that of the height. In comparison with conventional basil cultivation, plant height in the present study was higher, which is in contrary to previous study of Pasch et al. (2021) where they reported 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. (2016) where the inoculation effect of *Azospirillum brasilense* on basil significantly increased the growth and production under aquaponics production system.

Roosta (2014) 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 ratios of hydroponic: aquaponic solutions. In aquaponics, the plants showed high growth performance and basil leaf area, fresh herbage yield, and root weight were increased up to 27, 11 and 11%, respectively (Mangmang et al., 2016). An increase in biomass and height were reported in basil plants grown in decoupled aquaponics by Rodgers et al. (2022).

4.2 Photosynthetic Pigment Contents

The chlorophyll contents of plants show defining results in both 40 and 70 DAS. The 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’ , the increase was seen more in the greenhouse plants than in aquaponic plants. Similar to that of chlorophyll, the plants showed high levels of anthocyanin in greenhouse growth and less in an aquaponic system. The contents of xanthophyll, the highest concentration, were recorded in plants grown in the greenhouse than in the aquaponic system.

There was a visible chlorosis in basil plants as reported by Roosta (2014) in basil plants under irrigation with different ratios of hydroponic: aquaponic solutions. That means the content were less in aquaponic system of growth, which is in concomitant with our studies. Leaf chlorosis can be considered as an indicator of less physiological functions under aquaponics (Yang & Kim, 2019).

There was no difference in chlorophyll content or leaf nutrients between aquaponics and hydroponics of basil plants when grown in comparison with conventional systems (Mullis & Reyes, 2019). Saha et al. (2016) also reported that the pigment concentrations were unaltered in aquaponic production of basil. Where as in contrary to our results, Ferrarezi and Bailey (2019) reported increase in chlorophyll contents in basil plants grown in aquaponics. Similarly, in one of the recent studies by Rodgers et al. (2022) reported high chlorophyll index ratios in basil plants when grown in decoupled aquaponic setup.

4.3 Biochemical Analysis

According to the result, the biochemical composition of the basil plants showed higher content of proteins in the aquaponic system than that of the conventional soil system. Also, the total phenol level was high in the aquaponic system and low in the soil system. As basil is considered as a herbal medicinal plant, the high level of phenol provides antioxidant properties (Shahrajabian et al., 2020). An increase in protein and other biochemical concentrations were reported earlier in aquaponic grown basil by Yang and Kim (2020a, 2020b).

4.4 Non-Enzymatic Antioxidant Contents

The antioxidants present in basil provide medical benefits. As per the analysis of the result, ascorbic acid contents in basil showed an increase in aquaponics the system in both the analysis of 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 (Goddek et al., 2015). 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 (Ghandar et al., 2021).

As per the results, α-tocopherol also increased in the aquaponic system with the comparison of low α-tocopherol components in the soil system. The content of alpha-tocopherol is proven to provide antioxidants activity that helps in protecting the membrane components similar to that as ascorbic acid. We can assume that the plants under aquaponic growth are probably in a type of water stress (flooding), which in turn increased the antioxidant content in the plants to fight against the stress (Yiu et al., 2009).

4.5 Antioxidant Enzymes

Antioxidant activity in basil plants is based on several activities such as catalase and peroxide. The results showed that these activities tend to increase with the age factor of the plants in both the 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 the superoxides and the hydrogen peroxide (Wang et al., 2022). Also, the survival of many plants depends on their antioxidant activities. Basically, the plants under aquaponic system are experiencing a type of flood stress in the root level, which can be the reason behind increased activities of antioxidant enzymes. Antioxidant enzyme activities are used to scavenge the potential free radicals which are produced due to the stress in plants (Ahmad et al., 2022).

4.6 Microelements and Macroelements

The results are based on the macro and micronutrients in basil plants in the analysis of 70 DAS in both aquaponic and soil systems. The major macronutrients present in basil plants are the nitrogen, phosphorus, Sisyphus, 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 have shown a lower content in the aquaponic system and higher contents in the soil system, finally, the macronutrients of Sulphur showed the presence of equal levels in both the aquaponic and soil system after 70 DAS. As per the results, the levels of micronutrients were also shown in the results. Boron, magnum and sodium showed higher levels of contents in the aquaponic system than soil system, while the level of copper, iron and zinc showed lower levels of contents in the aquaponic system and higher levels of content in the soil system of the 70 DAS.

Soil system plants have lower levels of nutrient content. Aquaponics, the water beds of recirculating water, contains more nutrients, and this helps it grow the plan of basil 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 (Rakocy et al., 2003). As per the recent data, the information on aquaponic nutrient manipulation is really scanty. Mainly the potassium and iron can be added to the system as main nutrient elements to be added as a supplement to aquaponic solution as potassium hydroxide and iron chelates or as a foliar spray (Roosta & Hamidpour, 2011).

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 keeps fluctuating from day 1-40 from 24°C to 25°C. The dissolved oxygen level was considered to be highest on the day 10 of the analysis

As per the literature, the accurate pH ranges are 6 to 9 for tilapia fish, 5.5 to 6 for plants, and 7 to 8 for nitrifying bacteria, so, we can conclude that pH 7 is considered an ideal compromise for aquaponics (Rakocy et al., 2003). In this study the EC in aquaponics was 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 (Saha et al., 2016).

Chapter 5: Conclusion

The main aim of this experiment was to standardize aquaponic production of basil plants with the help of ornamental fishes like Koi fish and to compare the growth and quality of basil plants with conventional production method like greenhouse cultivation in the UAE 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 showed significant enhancement in aquaponic grown plants when compared to standard greenhouse system. The non-enzymatic and enzymatic antioxidants showed significant increase under aquaponic system in basil plants. The conventional greenhouse system showed less antioxidant levels. Micro and macro nutrient levels also showed varied response under aquaponic cultivation.

From the results of this study, it can be concluded that basil crop can be grown in both aquaponic and greenhouse soil systems, but the quantity and quality of crop can be increased when soilless system is adopted. In soilless aquaponic system, the height, fresh and dry weight of basil increased significantly when compared to conventional soil systems. This increase may be from the additional fertilizers from the fish waste produced in the system.

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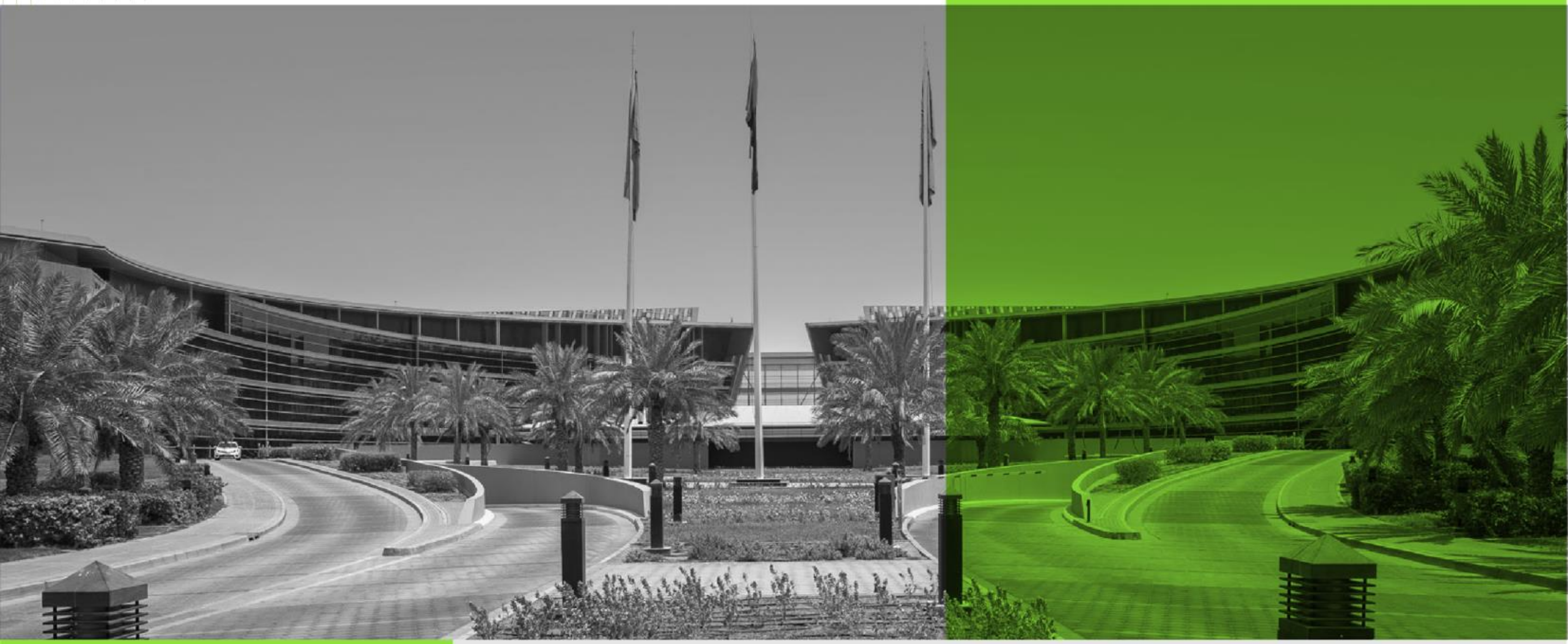

UAE UNIVERSITY MASTER THESIS NO. 2022:12

A study was conducted to evaluate the performance of Ocimum in both aquaponic and soil systems in the UAE climatic condition. The experiments were conducted under greenhouse condition. Plants were raised in aquaponic beds with ornamental fishes in different concentrations. At the same time, a set of plants were raised in pots under greenhouse set up. This study is mainly a comparative study for evaluating the growth and quality of aquaponic soilless basils in comparison to conventionally grown basils.

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