Deanship of Graduate Studies

Al-Quds University

Evaluating Growth and Productivity of Heirloom Tomato Variety in Diverse Ecological Farming Approaches

Saleh Yousef Saeed Abu Lebda

M.Sc. Thesis

Jerusalem-Palestine

1445هـ / 2024 م

Evaluating Growth and Productivity of Heirloom Tomato Variety in Diverse Ecological Farming Approaches

Prepared by:

Saleh Yousef Saeed Abu Lebda

B. Sc. Food Technology / Al-Quds University, Palestine

Supervisor: Prof. Dr. Jehad Abbadi

Co- Supervisor: Dr. Iba’ Farrah

A thesis submitted in partial fulfillment of requirement for the degree of Master of Agriculture Extension, Institute of Sustainable Development, Al-Quds University.

2024 م / 1445هـ

Al-Quds University
Deanship of Graduate Studies
Applied and Industrial Technology

Thesis Approval

Evaluating Growth and Productivity of Heirloom Tomato Variety in Diverse Ecological Farming Approaches

Prepared by: Saleh Yousef Saeed Abu Lebda

Registration Number: 21712743

Supervisor: Prof. Dr. Jehad Abbadi

Co- Supervisor: Dr. Iba' Farrah

Master thesis submitted and accepted, Date: 4/1/2024

The names and signatures of the examining committee are as follows:

1- Head of Committee: Prof. Dr. Jehad Abbadi Signature: ....
2- Co- Supervisor: Dr. Iba' Farrah Signature ....
3- Internal Examiner: Dr.Thamin Hijawi Signature: ....
4- External Examiner: Dr. Samer Jarrar Signature....................

Jerusalem- Palestine

1445 / 2024

Dedication

I humbly dedicate this thesis to the cherished memory of my father, whose unwavering support, boundless love, and ceaseless encouragement have been guiding lights along my academic journey. Though he may no longer walk beside us, his enduring presence and influence continue to shape every facet of my life.

To my beloved mother, whose enduring love, unwavering support, and countless sacrifices have paved the way for my growth and success. This dissertation stands as a tribute to your resilience and a humble token of gratitude for being my unwavering source of guidance.

In profound reverence, I honor the spirits of the Palestinian martyrs, whose noble sacrifices transcend our understanding. They laid down their lives for the existence of our nation, the dignity of its people, and the prosperity of its future generations.

The Researcher

Saleh Abu Lebda

Declaration

I certify that this thesis submitted for the degree of master, is the result of my own research, except where otherwise acknowledged, and this thesis has not been submitted for the higher degree to any other university or institution.

Saleh Yousef Saeed Abu Lebda

Signed: …………………….

Date : 4/1/2024

Acknowledgments

I am profoundly grateful to Allah, the Most Merciful and Compassionate, whose boundless guidance, blessings, and strength enabled me to complete this thesis. His unwavering support has been the cornerstone of my perseverance and success throughout this academic endeavor. I am deeply indebted to His grace and mercy for granting me the wisdom, resilience, and opportunities to accomplish this milestone.

I extend my heartfelt appreciation to the Sustainable Development Study institute at Al Quds University for providing an enriching academic environment that nurtured my passion for sustainable development. I am profoundly grateful to the faculty members and teaching staff whose dedication, guidance, and expertise have been instrumental in shaping my knowledge and scholarly growth. Their unwavering support, insightful mentorship, and encouragement have been invaluable throughout my academic journey. Moreover, I extend my sincere gratitude to Al Quds University for providing a platform for learning and growth. The university's commitment to academic excellence and resources offered have significantly contributed to my educational experience. I am deeply appreciative of the opportunities and resources provided by Al Quds University that have facilitated the completion of this thesis.

I extend my sincere appreciation to my primary supervisor, Prof. Dr. Jehad Abbadi, whose unwavering support, encouragement, and exceptional patience were invaluable throughout this research journey. My heartfelt thanks also go to my second supervisor, Dr. Iba’ Farrah, for her efforts in guiding and assisting me in this scholarly endeavor. I am equally grateful to Mr. Sameh Nusseibeh, the laboratory technician, for his invaluable assistance. Together, we formed a cohesive team dedicated to the successful completion of this research.

I extend my thanks to the Union of Agricultural Work Committee (UAWC), represented by Eng. Fouad Abu Seif, for providing a grant that supported this research. Gratitude is also extended to the Palestinian Agricultural Academic Cooperation (PAAC) for their financial assistance. Finally, I acknowledge and appreciate the contributions of my institute, EJ-YMCA's Vocational Training Center, and specifically the Director of the Centre, Mrs. Samah Al-Naber, for her steadfast support in ensuring the success of this research, especially in the practical work.

ABSTRACT

Background: The escalating global population has brought unprecedented demands for resources, amplifying strains on natural reserves, and pressuring agriculture to amplify output. In Palestine, the agricultural sector's decline in contribution to the GDP, coupled with land constraints and water scarcity due to geopolitical factors, has significantly impacted food security. The solution lies in sustainable and urban agriculture, especially when heirloom seeds are used.

Objectives: To analyze and compare the growth patterns and yield performance of Heirloom Tomato plants across different cultivation systems, including aquaponics, ecoponics, raised beds, and hydroponics.

Methods: The experiment was initiated in 2019, utilizing a greenhouse for the growth of young tomato plants, which were subsequently transferred to distinct farming systems. Harvesting and analytical procedures encompassed a comprehensive assessment of plant parts, including stem, leaves, roots, and fruits. Laboratory tests were conducted to evaluate chlorophyll content, pH, total dissolved salts, nutrient levels (NPK), and soil characteristics in the raised bed system. Statistical analyses performed using SAS software. Pearson correlations were calculated to explore relationships between traits and fruit yield, further complemented by subsequent multiple regression studies to validate findings.

Results: The SPAD measurements revealed varied chlorophyll content, showcasing higher values in the raised bed system compared to aquaponics at the end of the production cycle. Stem diameter was notably larger in raised beds, followed by hydroponics, while internode length and plant height exhibited differences across systems. Raised beds displayed the highest total dry weight, while the NFT section of the aquaponics showed maximum root dry weight. Leaves dry weight was highest in raised beds and lowest in hydroponics. Analysis of fruit yield parameters indicated significant variations among systems. Raised beds yielded the highest number of fruits per plant, while hydroponics produced the least. However, the NFT section of the aquaponics exhibited the highest number of fruits per cluster and highest fruit weight per plant, and lowest in hydroponics. Fruit color index was highest in the ecoponic system and lowest in hydroponics. Pearson correlation analysis highlighted positive relationships between fruit yield and certain growth and yield parameters across systems. Total fruit yield showed positive correlations with total dry weight, leaves dry weight, and several fruit-related characteristics. Nutrient content showed varying associations with fruit yield across systems, with notable correlations observed in specific components of aquaponics, hydroponics, and raised beds.

Conclusion and Recommendations: The raised bed system generally showed superior growth metrics, while aquaponic systems displayed better fruit dimensions. Nutrient content significantly affected yield but varied across systems. Recommendations include further exploration of nutrient management strategies tailored to different cultivation systems to optimize yield while maintaining fruit quality.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

GDP	Gross Domestic Product
pH	Power of Hydrogen (measure of acidity)
NPK	Nitrogen , Phosphorus and Potassium
SAS	Statistical Analysis System
GLM	General Linear Models
SPAD	Soil Plant Analysis Development
YMB	Young Mature Blade
TDS	Total Dissolved Solids
DAP	Days After Planting
FAO	Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
IFAD	International Fund for Agricultural Development
PCBS	Palestinian Central Bureau of Statistics
UNCTAD	United Nations Conference on Trade and Development
AAE	Ammonium Acetate
CAL	Calcium Acetate
TGH	Temperature of Greenhouse
HGH	Humidity of Greenhouse
APSA	Aquaponic System section A
APSB	Aquaponic System section B
APSC	Aquaponic System section C
RBS	Raised Bed System
EPS	Ecoponics System
HPS	Hydroponics System
TDW	Total Dry Weight
NFT	Nutrient Film Technique

LIST OF TABLES

LIST OF FIGURES

Chapter One : INTRODUCTION AND LITERATURE REVIEW

Human population has been steadily increasing over the years. Up-to-date, it is around 8.0 billion **(United States Census Bureau, 2023).** This growth is primarily due to advancements in healthcare, sanitation, and food production, which have led to longer lifespans and lower mortality rates. Population growth varies across regions, with some areas experiencing rapid expansion while others have stabilized or are declining **(Pelletier, 2020).**

This increasing population creates a continuous demand for resources like food, water, energy, and land. As more people inhabit the planet, there is an amplified strain on natural resources. Agriculture must produce more food to feed the growing population, leading to increased land use and potential environmental consequences like deforestation and habitat loss. Additionally, the rising demand for energy and water puts pressure on these limited resources, leading to concerns about sustainability and conservation **(Lee *et al.*, 2023; Rees *et al.*, 2023).**

Efforts to address these challenges involve advancements in technology, sustainable practices, and resource management. Innovation in agriculture, renewable energy, water conservation, and waste management are crucial to meet the needs of a growing population without depleting resources or causing irreparable harm to the environment. Balancing population growth with resource availability remains a significant global challenge for governments, organizations, and societies worldwide **(Carlsen and Bruggemann, 2022).**

The global agricultural sector encounters multifaceted challenges in meeting global food demand. As highlighted by the United Nations Food and Agriculture Organization (FAO) and the Intergovernmental Panel on Climate Change (IPCC), population growth strains agricultural productivity amidst limited arable land, water scarcity, and the destabilizing impact of climate change on crop yields. Climate-related extremes, documented in reports like the IPCC's Assessment Reports, exacerbate food production challenges through droughts, floods, and changing weather patterns conservation **(Lee *et al.*, 2023)**.

Furthermore, the World Bank's publications underscore resource scarcities like water for irrigation and soil degradation, intensifying the need for sustainable agricultural practices. The issue of food waste and distribution inefficiencies, emphasized by studies in journals such as "Food Policy" and "Nature Food," poses a significant obstacle to achieving food security. Moreover, the International Fund for Agricultural Development (IFAD) notes concerns about rural-urban migration, an aging farming population, and the limited economic access for small-scale farmers, necessitating policy reforms and investments in rural development to address these structural challenges **(Woodhill *et al.*, 2022).**

The agricultural sector in Palestine played a major role in the formation of the Palestinian GDP over long periods of time, as the agricultural sector is the major source of income for almost 40% of households **(PCBS, 2017).** It was the vital sector that contributed to the provision of food to the Palestinian people and the absorption of a large part of the labor force. However, the deterioration has hit this sector since many years **(Temper, 2009).** The agricultural sector's contribution to Palestine's GDP had declined from 36% in the 1970s to about 3% in 2018. Moreover, the agricultural sector's budget remains the least across sectors **(Marzin *et al.*, 2019).** Increasing agricultural production and productivity and improving livelihoods of the farmers is much needed. The total area of Palestine covers 6,023,510 dunums, distributed between the West Bank (5,660,820 dunums, forming 94% of the total area of Palestine) and the Gaza Strip (362,690 dunums, forming 6% of the total area).

Palestine is considered as an arid to semi-arid region, where the lack of sufficient water has constrained sustainable development **(Palestinian Water Authority, 2011).** The situation has worsened due to population growth and the expansion of agricultural activities, adding additional burden on the limited available and uncertain water supply **(Shadeed *et al.*, 2020).** 45% of owned lands are cultivated, 11.9% is arable but uncultivated, 8.5% is suitable for reclamation, 5.5% is unsuitable for reclamation, 0.4% is being used as grazing land, while 17.2% includes urban areas used for construction.

11.5% of owned land has been confiscated by Israel for the purposes of building new colonies, constructing by pass roads and building the separation wall **(Qaddoha, 2016).**

During 1984–2016, the agricultural land area in Palestine including the West Bank and Gaza Strip, decreased by 0.65% each year due to the annexation of parts of the occupied West Bank lands by the occupation. The land of the Jordan Valley which is exposed to annexation is estimated at 26% of the West Bank, and that constitutes 50% of the food basket of the Palestinian people, contains groundwater basins, and is rich in mineral salts.

In the Gaza Strip, the Israeli occupation denied access to 18% of the arable land on the eastern and northern borders of the Gaza Strip under the pretext of security **(PCBS, 2020; Marzin *et al.*, 2019).**

There are over 5.2 million Palestinians living in West Bank and Gaza (59.8% in the West Bank and 40.2% in Gaza Strip) struggle to survive against ongoing Israeli occupation. Therefore, the population is more dependent on aids, less able to produce food, and more reliant on imported goods, which is estimated to reach 90 % of primary commodities. Agriculture production is limited by the access of land, water and natural resources, with severe restrictions on movement. Over time agricultural imports increased to exceed exports significantly **(PCBS, 2020).** The total area of agricultural land currently used by Palestinians covers 30.5% of the Palestinian land area and 54.4% of the total suitable lands for cultivation (**Alataweneh, 2013).** Rain-fed agriculture is practiced in 87.0% of the total cultivated area, while only 13.0% is irrigated agriculture. Regular access to most of the Palestinian land is not granted as a result of Israeli Settlements, military areas and the separation wall, thus, only a low percentage of Palestinian agricultural land remains as open rangeland for grazing. The average annual rainfall varies between 100-250 mm, epically in the southern pastures of the West Bank **(Ghattas *et al.*, 2002).**

According to the Palestinian Central Bureau of Statistics (PCBS), there is a constant decline in the percentage of workers in agricultural activity. The agricultural sector recorded the lowest daily wage rate in West Bank and Gaza Strip. This is weakening the agricultural sector, and it is leading to the inability of food sovereignty as part of the right to self-determination. This is considered as the leading cause of poverty, unemployment, and food insecurity **(UNCTAD, 2020).**

More than 54% of the world's populations live in urban regions and it is expected to reach 66% by 2050 **(Leeson, 2018).** Cities account for 70–90% of all economic activities, and over 75% of total resources use **(Sodiq *et al.*, 2019).** This increase in urbanization has led to resources depletion, increased waste and food insecurity **(Wiskerke, 2015).** Urbanization in Palestine has been growing steadily, reaching about 75%, with a high urban residents' growth rate (3.2%) compared to a 2.5% in the Middle East region **(Raddad, 2022).** Due to the high rate of urbanization in Palestine and the negative impact of geopolitical obstacles, such as Israeli settlements, bypass roads, and the separation wall, Palestinian cities have witnessed a huge loss of farming area in urban and peri-urban areas in recent years **(Raddad, 2010).** These obstacles, in addition to other global challenges of agriculture, have direct impact on food security whether affecting food availability, economic access to food, or food utilization **(Raddad, 2022).**

For these reasons, sustainable and urban agriculture has become important at the global level, and can play a highly significant role in sustainable development and achieving sustainable development goals **(UN-Habitat, 2018).** These goals include control of poverty in all its forms (Goal 1), ending hunger, realizing food security and enhancing nutrition and promoting sustainable farming (Goal 2), ensuring sustainable consumption and production models (Goal 12), and preserving, healing and supporting sustainable use of earthly ecosystems (Goal 15) **(Game and Primus, 2015).**

Urban agriculture is defined as the processing and delivery of food through plant cultivation and/or raising livestock in cities or around cities for feeding local residents. Hunger issue is one of the main challenges facing global development especially in developing countries, with similar proportions in rural and urban areas **(Artmann *et al.*, 2020).** Therefore, there is a need to increase food production while at the same time decreasing the negative impacts of agriculture on land, water, and climate **(Foley *et al.*, 2011).** Global climate change is expected to cause altered patterns of weather and drought. Drought and salinity stress due to global climate change, as well as the development of new pest and pathogen problems, are predicted to be a burden on growth and yields of crops **(Tester and Langridge, 2010).** Another concern is the fast growth of plants at higher temperatures, while leaving less time to accumulate human nutrients such as sugars, fat, and protein and lowering the nutritional quality **(Fedoroff *et al.*, 2010).**

Competition for land use with urbanization, and the lass loss due to salination and desertification will reduce agricultural land and agricultural production **(Hossain *et al.*, 2020).** Additionally, conversion of land to agricultural production has serious environmental consequences. Transforming natural ecosystems to land in agricultural production impacts the global carbon and hydrological cycles, habitat biodiversity, and soil conditions **(Myers *et al.*, 2014).**

Food production has doubled around the world over the last few decades; due to the use of chemical fertilizers, pesticides, and irrigation. However, to increase productivity of current production systems to meet the demands of future populations, there is a need to change the agricultural methods **(Foley *et al.*, 2011)**. The use of Nitrogen and phosphorus fertilizers in agriculture has increased dramatically, of about 800% from 1960 to 2000, with nitrogen use efficiencies below 40% leading to loss of nitrogen into the environment **(Fowler *et al.*, 2013).** The overuse of phosphorus fertilizers also resulted in negative environmental impacts, causing eutrophication of water systems **(Bouwman *et al.*, 2013).**

Pesticide use has also increased dramatically over the past few decades by 15 to 20 times **(Tudi *et al.*, 2021).** Chemical pesticides used in agriculture are hazardous to human health and harm biodiversity, with some pesticides accumulating in food chains **(Selim, 2019).** Advancement in irrigation resulted in doubling the land used for agriculture over the past five decades, where 70% of freshwater is used to irrigate cropland **(Foley *et al.*, 2011, Mishara, 2023)**. Irrigation can also result in nutrient loading into water systems and the salinization of arable land. Therefore, agricultural intensification over the past decades has had negative impacts, which included increased soil erosion and decreased soil fertility, pollution of ground water and increased atmospheric constituents. All these negative impacts, led to global climate change and water resources scarcity with dramatic consequences on food production **(de Graaff *et al.*, 2019).**

Conventional crop production systems are the most common in agriculture worldwide in which synthetic fertilizers and pesticides are used, while organic production systems that use natural sources for maintaining soil fertility and pest control are less common. Conventional production systems can be further categorized into tillage and no-till/ reduced-tillage systems. Conventional no-till systems are considered more sustainable than conventional tillage systems due to their benefits in sequestering more carbon, having better soil erosion prevention, improving water and fertilizer use efficiency. Conventional no-till systems also have better soil nutrient cycling, enhanced soil biological activity, and can also reduce energy, labor, and machinery inputs **(Roberts and Mattoo, 2018).**

Organic and chemical-free production systems are designed to be less causing harm to humans and the environment than the conventional systems. This is due to the greater emphasis on reducing and eliminating inputs that are harmful to human health and the environment such as synthetic fertilizers and synthetic pesticides. Organic and sustainable production systems have greater emphasis on managing ecological processes **(Seufert *et al.,* 2012).** The building of soil organic matter is a major principle of organic agriculture. This is done by the use of cover crops and animal manures. Organic soils with higher organic matter levels have higher capacity to mineralize, capture, and store essential nutrients and water resources **(Spargo et al., 2011).** Higher soil organic matter also results in higher soil aggregate stability. This is associated with richer food webs and higher biological activities that drive beneficial soil processes **(Kamau *et al.,* 2019).**

The increasing demand for food and the need to save freshwater, made it urgent to increase food production efficiency. Currently, more than 70% of the world's freshwater resources are used for agricultural purposes **(Mishra, 2023)**, which means that there is an increasing need for improved water use efficiency as well as the need for recycling water in farming. Food provision has also significant impact environmentally through greenhouse gas emissions, phosphorus depletion, use of land and water resources, and chemical pollution **(Tukker *et al.,* 2016).**

Sustainable agriculture is the science of applying environmental concepts and principles to sustainable farming systems in terms of design, development and management. It aims to achieve sustainability in agricultural systems through a balance between social and environmental aspects even in urban spaces **(Velten *et al.,* 2015).** Urban agriculture not only can produce food locally, but can also use resources very efficiently with minimum negative impact on the environment **(de Zeeuw and Drechsel, 2015).** Food production faces many challenges, of which, the production of a wide variety of high-quality foods with good nutritional value. Therefore, it is important to find and evaluate sustainable food production systems that can be used in lands and in urban areas.

Conventional and sustainable production systems have been compared in many studies. Differences are found in crop yields, impact on the environment, and levels of sustainability **(Reganold and Wachter, 2016).** It was found that yield averages associated with sustainable production systems were lower. However, these differences in yield were contextual, varying between 5% and 34% lower depending on crop, conditions, region and management practices **(Seufert *et al.*, 2012).** Numerous studies showed that sustainable farming generally had lower negative impacts on the environment per unit land area, and not necessarily per unit product due to lower yields. For example, sustainable farms have higher soil organic matter and lower nutrient loss per unit field area but higher NH_4 and N_2O emissions per unit product. Sustainable production systems also had higher eutrophication potential per unit product **(Tuomisto *et al.*, 2012).**

Raised beds are sustainable production systems commonly used in urban agriculture. According to numerous studies, raised bed media have higher pH, organic matter, and nutrient concentrations due to the presence of compost. Raised beds with compost have 20 times higher rate of water infiltration rate compared to regular soil. Mixing soil with compost in raised beds reduced nutrient concentrations and water infiltration rate compared to compost-only beds, as mixing soil with compost in raised beds reduced irrigation demand by 32%. Raised beds reduced grass and weed abundance by over 90% **(Miernicki *et al.*, 2018).** Figure 1 shows the raised beds system used in this study.

Figure 1: Sustainable Raised Beds system, YMCA, Jericho

In addition to raised beds, there are new sustainable production systems that have emerged in the last few decades. Aquaponics is one of the most promising sustainable food production systems that combines hydroponic systems with recirculating aquaculture systems. It has the potential to play a major role in food provision and tackling global challenges such as water scarcity, food security, water pollution, high energy use and excessive food transport miles (**Graber and Junge, 2009).** The Aquaculture farming and hydroponics are of the innovative methods of agriculture without the need for soil. That is, depending on water by providing all the plant's needs for growth. This method was created for households and stakeholders that do not have soil, or have salty soil or in cases of severe desertification **(AlShrouf, 2017).**

If the aquaponics system is operated in a closed water loop, it has little environmental impact because the food is produced with low water consumption **(Enduta *el al.*, 2011).** Plant production yields in aquaponics have been reported to be higher than for crops grown in soil **(Rakocy *et al.*, 2004),** however data are scarce. In aquaponics, nutrients enter the system in the form of fish feed. The feed is ingested and metabolized by the fish. The remains of the feed and the metabolic products from the fish dissolve in the water creating an aquaculture effluent that provides most of the nutrients required for plant growth in a hydroponics part of the system. Microorganisms in the biofilter, on plant roots, and in the recirculating water release and convert the nutrients (e.g., phosphates from the debris, and ammonium to nitrate) and the plants assimilate them, thus treating the water, which flows back to the aquaculture component of the system **(Graber and Junge, 2009).** In aquaponics, fish, plants, and bacteria coexist in the same water, albeit in different compartments of the system **(Al-Hafedh *et al.*, 2008).** In aquaponics, there are different modes of cultivating plants and crops. One is the tuff (volcanic stone) cultivation culture. Another cultivation culture in the aquaponics is the Nutrient Film Technique (NFT). Another is the deep-water culture. Figure 2 shows the aquaponic system used in this study with its different cultivation cultures; the tuff stone culture, the NFT pipes culture, and the deep-water culture.

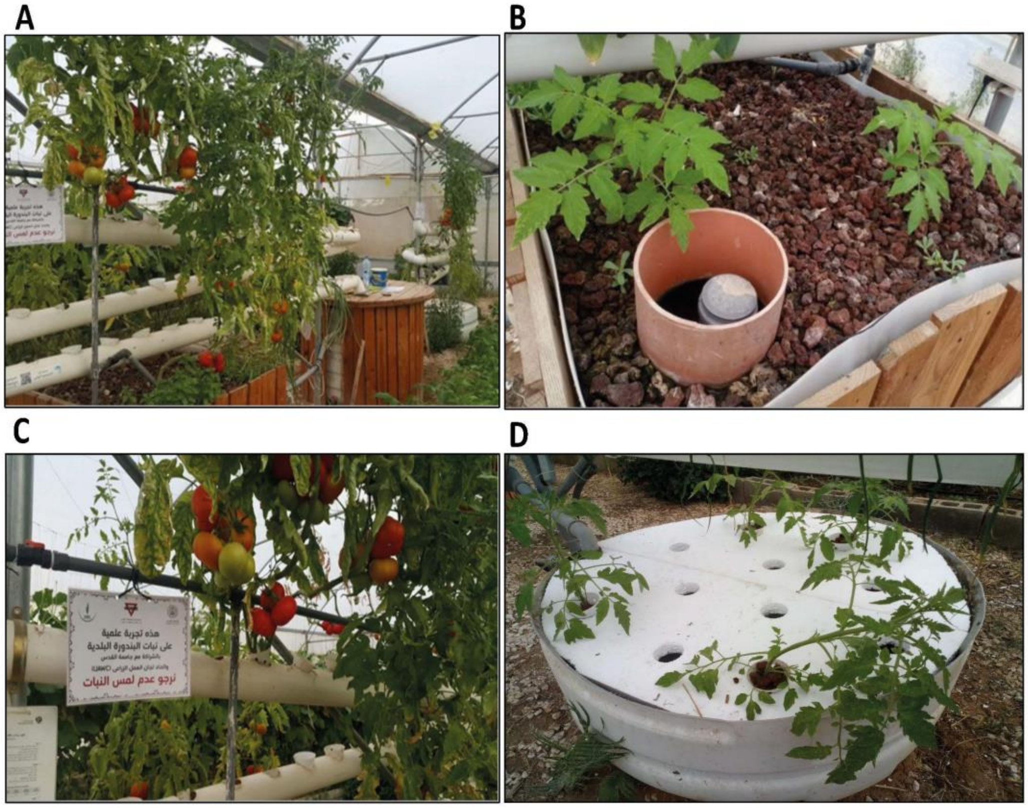


Figure 2: Aquaponics system, YMCA, Jericho. A: Aquaponics system, B: Aquaponics section A in Tuff (volcanic) stone culture (APSA), C: Aquaponics section B in Pipes culture (NFT) (APSB), D: Aquaponics section C in Deep water culture (APSC)

Hydroponic system is a plant cultivation system without soil using formulated nutrient solutions of water containing fertilizers with or without the use of an inert medium. Inert media, such as sand, gravel and vermiculite, can be used to provide mechanical support **(Sharma *et al.*, 2018).** Crops that can be grown using hydroponics, include leafy vegetables, tomato, cucumber, pepper and strawberry **(Prakash *et al.*, 2020)**. Change in growing medium can be a promising alternative approach for sustainable farming and conservation of depleting land and available water resources. Hydroponics cultivation systems have numerous advantages over conventional cultivation system, of which, allowing crops to grow up to 50% faster than soil cultivation systems when providing constant and nutrition. It also provides higher yield than conventional methods. The interest of hydroponics in sustainable agriculture has increased dramatically, and the hydroponics cultivation systems are becoming increasingly widespread around the globe for growing sufficient food to feed the world's growing population sustainably **(Swain *et al.*, 2021).** The hydroponic system used in this study is showed in figure 3.

Figure 3: Hydroponic system, YMCA, Jericho.

Organic hydroponics refers to the use of organic nutrient solutions in hydroponics. Bioponics is another term for organic hydroponics, which also implies that microorganisms are added to the organic nutrient **(Szekely and Jijakli, 2022).** In In organic hydroponics, organic nutrients instead of synthetic and chemical fertilizers are used to provide nutrients to plants, such as compost tea, fish emulsion, seaweed extract and other waste and natural products. In 2018, the first ecological hydroponics was established in the YMCA model eco-farm, named ecoponics, using innovative approaches to substitute chemical fertilizer with organic and biofertilizers. The ecoponics is a novel chemical-free hydroponic system in Palestine, that uses worm compost (vermicompost) by breeding red wiggler worms in an attached worm factory, as well as and compost tea, as shown in figure 4. Future technologies are being developed to repurpose organic-grade municipal solid waste compost products as nutrient sources.

Figure 4: The ecoponics system, YMCA, Jericho

Heirloom crops are traditional cultivars that have been grown for hundreds of years (>50 years), with a preserved heritage regionally and ethnically. Heirlooms are known for their unique appearance, taste, uses, and cultural and historical significance to local cuisine, and their role in sustainable food production **(Dwivedi *et al.*, 2019).** There is an urgent need to know more about the traits available in heirloom cultivars, particularly for productivity and proximate composition grown in sustainable farming models compared to chemical farming.

Therefore, it is important to study the effectiveness of heirloom tomato in sustainable agriculture compared with other chemical farming models. This will have impact socially, economically and environmentally to reduce dependency on expensive commercial seeds and restore our agricultural heritage, as well as preserving the environment by chemical-free farming.

Tomato (*Solanum lycopersicum*) is originally from the Andean region, now including parts of Chile, Boliva, Ecuador, Colombia and Peru. The time and place of domestication of tomato are not known with certainty. It had reached a certain stage of domestication before reaching Europe in the 15th century and further domestication on a much more intense level occurred throughout Europe in the 18th and 19th centuries **(Sims, 1979).**

Since the 20th century, there have been morphologically different cultivars and forms from the single species *S. lycopersicum* via plant breeding.

Tomatoes are of the high value crops rich in health-beneficial compounds, including carotenoids and vitamin C **(Li *et al.*, 2021).** Beyond favorable health-related substances, the quality of tomatoes is given by several compounds defining the overall soluble solids content and the acidity, both underlying the taste and flavour of fruits **(Tigist *et al.*, 2013).**

The plant tomato, belongs to the Solanaceae family, which includes over 3000 species **(Knapp, 2002).** The phylogenetic classification of Solanaceae recently re-integrates the genus *Lycopersicon* into the *Solanum* genus with its new nomenclature. *Solanum* section *Lycopersicon* includes the cultivated tomato (*S. lycopersicum*) and 12 additional wild relatives **(Peralta *et al.*, 2006; Egashira *et al.*, 2000).**

Heirloom tomatoes are varieties that have been passed down through generations due to their valued characteristics, such as unique flavors, diverse colors, and often, historical significance. These tomatoes are open-pollinated, meaning insects, birds, wind, pollinate them naturally or other natural mechanisms, and their seeds can be saved and replanted year after year while maintaining their distinct traits **(Dwivedi *et al.*, 2019).**

Characterized by their diversity in size, color, shape, and taste, heirloom tomatoes come in a wide range of hues such as red, yellow, orange, green, purple, and even striped or bi-colored patterns. They may be larger, smaller, or differently shaped compared to typical commercial varieties found in supermarkets **(Joseph *et al.*, 2017).**

Despite the broad range of tomato diversity, there has been an increased popularity and demand of heirloom tomatoes in the late 20^{th} century. This has been attributed to the return to organic, local, and ‘‘authentic’’ foods **(Jordan, 2007).** Figure 5 shows morphological differences between commercial tomatoes found in the Palestinian market and heirloom tomatoes available in Palestine.

A **B**

Figure 5: Differences in tomato fruits between A: commercial tomatoes, B: heirloom tomatoes

Heirloom tomatoes are cherished for their rich and nuanced flavors, often perceived as more complex and robust compared to some hybrid or commercial tomatoes. Additionally, they often have a reputation for being well suited to specific climates or regions and are favored by gardening enthusiasts and organic growers for their unique attributes and historical value **(Joseph *et al.*, 2017).** Organically grown produce is thought to be more nutritious, as some studies suggest that the content of vitamin C, carotenoids, and polyphenol contents of organically produced tomatoes was higher than conventionally grown tomatoes **(Caris-Veyrat *et al.*, 2004).**

Pieper and Barrett (2009) reported that organic production systems may delay maturity and alter total and soluble solids of processing tomatoes compared with conventional systems, but nutrient content was not significantly different between production systems.

Sustainable and eco-friendly tomato production systems can be more profitable than conventional systems **(Clark *et al.*, 1999),** as they have been found to use less energy than conventional systems **(Turhan *et al.*, 2008).** One of the major challenges to eco-friendly and organic production of tomatoes is disease management. There have been established strategies to minimize disease in sustainable agriculture. Disease incidence was reduced by using composted cotton gin trash, swine manure, and rye-vetch green manure compared with bare soil and incorporated synthetic fertilizers **(Bulluck and Ristaino, 2002).**

Fruit quality of tomato cultivar in conventional tomato production systems was higher than organic, although yields were similar **(Colla *et al.*, 2000).** Although yields of heirloom tomatoes are often less than modern commercial hybrids, consumer demand and premium prices for heirlooms and organically produced produce and the relaxed grade standards may provide a viable source of additional revenue for tomato producers.

In Palestine, seed collectors seek local varieties, drawing on the knowledge of local farmers to identify heirloom "baladi" seeds; baladi, as a synonym for local. It connotes a similar array of associated, yet contested values: community, tradition and ownership. In a biological context, "baladi" refers generally to a population comprised of numerous heterogeneous lines with their own individual characteristics. Characteristics might encompass resistance to drought, pests, and rusts, as well as traits related to content and yield **(Nadar, 2018).**

Despite the challenges posed by climate change and occupation, Palestine has one of the highest concentrations of agrobiodiversity in the world, consisting of wild pulses, grains, woody plants, and trees that humans began to modify and domesticate about 12,000 years ago **(Tesdell *et al.*, 2020).** It is a center of diversity for the crops of the Neolithic (wheat, barley, chickpea, lentil, flax, and oat) as well as numerous legume species and tree crops. Drylands in Palestine's host plants and crop varieties adapted to drought, salinity, and high temperatures **(Zohary and Feinbrun-Dothan, 1966).** These qualities make them objects of interest in the face of global climate change.

There is limited research on Palestinian heirloom varieties. There is even less research on the production of heirloom tomatoes in sustainable chemical-free systems and conventional chemical systems, especially in Palestine. This study was conducted to comprehensively evaluate and compare the growth and productivity of Palestinian heirloom tomato varieties when cultivated using various ecological farming approaches. Evaluating and comparing growth of the different parts of the tomato plants, shown in figure 6, cultivated in the different systems can give an indication of the variances of yield in each system. The aim is to identify the most effective and sustainable method that maximizes tomato yield while ensuring adaptability to challenging environmental conditions.

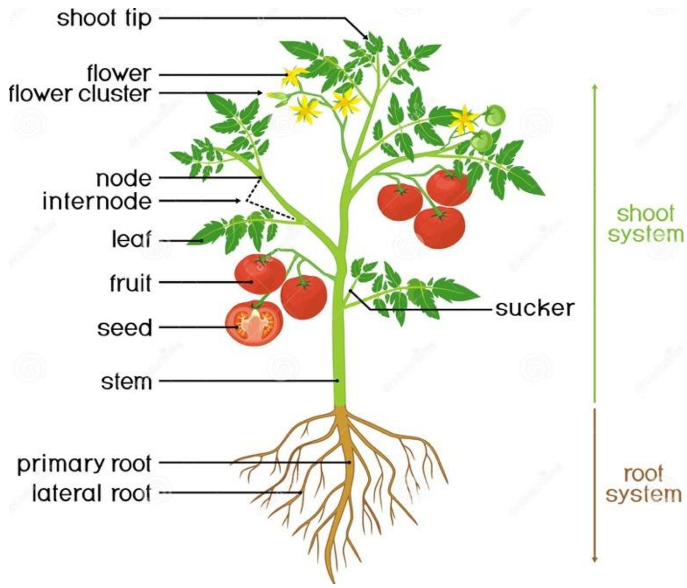


Figure 6: Tomato plant parts

Purpose of the Study

The study's primary objective is to conduct a comparative analysis of heirloom tomato growth and productivity across diverse farming methods, including ecological and non-ecological approaches. The ecological farming methods under examination are the raised beds farming system, aquaponics, and ecoponics (organic hydroponics). Notably, the third model under investigation introduces a novel chemical-free hydroponic system in Palestine, relying on worm compost (vermicompost) and compost tea.

This research holds significant importance as it seeks to identify the strengths and challenges of cultivating heirloom tomatoes in Jericho. Furthermore, it aims to assess the effectiveness of ecological farming models in enhancing the growth and productivity of heirloom tomatoes compared to conventional non-organic hydroponic methods.

The study tests the growth of heirloom tomato in three different ecological farming methods compared to chemical hydroponics farming. In Palestinian agriculture, hybrid and commercially introduced tomato varieties have become prevalent, posing a threat to the continued existence of heirloom seeds. In Jericho, ecological farming has been replaced by chemical farming, resulting in a decreased use of heirloom seeds. Therefore, this study aims to test the effectiveness of heirloom tomato farming using sustainable agriculture compared with other chemical farming methods in order to promote ecological farming using heirloom seeds. This transition will exert social, economic, and environmental effects by diminishing reliance on costly commercial seeds, reviving Palestinian agricultural traditions, and safeguarding the environment through chemical-free farming practices.

The research aims to ascertain the efficacy of ecological farming methods on heirloom tomatoes, supporting the hypothesis that employing ecological farming practices will yield superior outcomes in terms of overall production and quality for heirloom tomatoes.

Objectives

The main objective of this research was to evaluate growth and productivity of heirloom tomato variety in sustainable and ecological production systems as compared to chemical hydroponics production system.

Specific objectives:

1. To examine and compare the growth parameters of heirloom tomato in three ecological farming systems, in comparison with a chemical hydroponic system.
2. To examine and compare the yield parameters of heirloom tomato in three ecological farming systems, in comparison with a chemical hydroponic system.
3. To determine the correlation between growth parameters and yield of heirloom tomato in the studied four different farming systems.

Chapter Two: METHODOLOGY

An experiment was conducted to evaluate the performance of tomato (*Solanum lycopersicum*, variety heirloom) growth and yield in different growing systems (aquaponics, ecoponics, raised beds, and hydroponics).

The study was designed to identify the advantages or disadvantages of ecological farming on heirloom tomatoes, considering the hypothesis that ecological farming for heirloom tomatoes might be more effective in the aspects of growth, yield, quality, and seed production.

The experiment was conducted in January 2019 by growing young plants in soil inside a greenhouse. After about 40 days, these plants were moved to the aquaponics, where they continued growing without the soil. About 20 days later, the first flowers appeared. Two weeks after that, a hive of bumblebees was introduced into the greenhouse to help with pollination. Around 98 days after planting, the first batch of tomatoes was collected. After six months, which included three months of growing tomatoes, the plants were taken out of the system to be dried, weighed, and studied. Measurements of how the plants grew and produced tomatoes were taken in groups during April and May 2019, about three to four months after planting. Every month throughout the six-month experiment, samples of water from the aquaponics system were collected and studied.

In March 2019, young plants for the ecoponics system were planted after carefully taking off the peat moss from their roots and placing them directly into the system. The first flowers started to show up about 42 days later. To help with pollination, a hormone was used every four days when a new set of flowers bloomed. After 38 days, the tomatoes were ready to be picked, and then, 45 days later, the plants were taken out of the system for drying and sampling, where necessary measurements were taken. The harvesting of the fruit was done in five batches, one batch each week.

The raised bed system's seedlings were initially placed in the greenhouse and regularly watered. After 26 days, the first flowers started showing up. To aid in pollination, a bumblebee hive was introduced into the greenhouse where the system was set up. About

99 days later, the first set of tomatoes was harvested. Following this, the plants were taken out of the system 39 days after the harvest for drying and sampling, and essential data and coding were gathered. The harvesting took place in four batches, spaced out weekly.

The hydroponics system had its seedlings planted without any soil. After about 24 days, the initial flowers started to bloom. To aid in pollination, a hormone was applied every four days when new flowers emerged. About 49 days later, the first batch of produce was harvested. Then, 34 days following the harvest, the plants were taken out of the system for drying and sampling, during which necessary plant readings were recorded. The fruit harvesting was completed in two batches, with one batch collected every week.

Growth parameters studied include:

1. SPAD measurement corresponding to chlorophyll content in plant leaves.
2. Stem diameter (mm).
3. Internodes length (cm).
4. Height of tomato plants (cm).
5. Dry weight (g) of tomato whole plants.
6. Root dry weight (g) of tomato plants.
7. Stem dry weight (g) of tomato plants.
8. Leaves dry weight (g) of tomato plants.
9. Number of leaves per tomato plant.
10. Number of branches per tomato plant.

Productivity (agronomic yield) parameters studied include:

1. Number of fruits per plant.
2. Number of fruits per cluster.
3. Fruit yield (weight of fruits per plant).
4. Fruit color.
5. Fruit dimensions (mm).
6. Seed weight (g) per tomato plant.

Harvesting and analytical procedures

The plants were harvested at various times to collect their fruits; the initial harvest occurred roughly 70-80 days post-planting. The complete plants were harvested during the final harvest, approximately 180 days after they were planted.

At the final harvest, the dry weight of plant parts (stem, leaves, roots) was measured (g) after drying at 60 C till constant weight. Plant materials were grinded to pass a 1.5mm sieve, of which, after thorough mixing, a subsample of 5 g was ball-milled to a fine powder for further preparation for nutrient status content (N, P, and K). The plant samples were prepared for P and K analyses using wet microwave digestion using concentrated tri acid mixture (HNO_3, $HClO_4$, and H_2SO_4 with a volumetric ratio of 8:2:1). Total K of the plant material digest was measured using flame photometer. Total contents of P of the plant material digest were measured using spectrophotometric method. Total N of plant materials was determined as ammonium by Olson method **(Johnston and Poulton, 2019)** after Kjeldal digestion using concentrated H_2SO_4.

Water samples were collected from each system (except raised beds) in different times during the experiment and analyzed for nutrients content (N, P, and K) using the same analytical procedures used for plant materials.

<u>Aquaponics (APS):</u> 16 plants were used for the study. Fruits, seeds, stems, leaves and roots from each plant were dried and grinded. Each part was given a specific code for lab tests. The plants were distributed in 3 sections; the tuff stone culture section (APSA), the NFT pipes section (APSB), and the deep-water culture section (APSC).

<u>Ecoponics</u>: 18 splants were used for the study. Fruits, seeds, stems, leaves and roots from each plant were dried and grinded. Each part was given a specific code for lab tests.

<u>Raised Beds</u>: 16 plants were used for the study. Fruits, seeds, stems, leaves and roots from each plant were dried and grinded. Each part was given a specific code for lab tests.

<u>Hydroponics</u>: 17 plants were used for the study. Fruits, seeds, stems, leaves and roots from each plant were dried and grinded. Each part was given a specific code for lab tests.

Figure 7 shows some of the methodology procedures described in this section.

Figure 7: Documentation of some of the experimental settings and procedures

Laboratory tests encompassed various assessments, outlined as follows:

YMB-Chlorophyll: This test evaluated the chlorophyll percentage in leaves across 67 plants within four distinct agricultural systems. It targeted the first leaves emerging after the initial fruit cluster (young mature leaves). The SPAD meter facilitated this examination, considering chlorophyll's pivotal role in photosynthesis.

pH Test for Water Samples: Regular pH examinations were conducted on water samples from all experimental systems. Weekly assessments occurred during the setup phase for each system. Monitoring water pH is crucial for optimizing nutrient absorption by plant roots. Utilizing a pH meter, measurements are detailed in Tables 1, 2, and 3.

TDS Test for Water Samples: Evaluation of total dissolved salts in water mediums preceded the experiment across all systems. Weekly assessments gauged the concentration of dissolved salts, providing insights into nutrient requirements and provisioning in the mediums.

Table 1: pH and TDS measurements in water for all aquaponic system

Day after planting (DAP)	PH	TDS (ppm)
62	6.85	1150
72	7.17	1350
83	6.9	1230
93	7.1	1200
106	7.05	1150

Table 2: PH and TDS measurements in the water of the Ecoponics system

Day after planting (DAP)	PH	TDS (ppm)
17	7.07	875
24	6.62	920
38	6.48	950
52	6.5	950
65	6.7	875

Table 3: PH and TDS measurements in the water of the hydroponics system

Day after planting (DAP)	PH	TDS (ppm)
10	8.11	795
17	5.45	780
31	6.05	755
45	6.34	735
58	6.5	893

NPK level in each water media system: Throughout the experiment, the water content of NPK was consistently monitored to gauge the accessibility of vital macronutrients crucial for plant growth and the general health of the water system. Laboratory tests were carried out to assess these levels, and the resulting data are presented in the following tables (Tables 4, 5, and 6) for reference and analysis.

Table 4: NPK content of water in each section of the aquaponic system

Day after planting (DAP)	NO_3 ppm	P ppm	K ppm
3	9.28	48.05	12.79
11	66.55	59.02	6.40
57	3.28	47.56	2.56
74	68.23	60.00	9.50
88	18.67	51.95	0.73
102	17.52	55.12	1.28
108	17.01	53.17	1.1
122	25.81	57.07	2.38
138	67.06	49.27	4.75

Table 5: NPK content in water of the Ecoponics system

Day after planting (DAP)	NO_3 ppm	P ppm	K ppm
47	11.30	60.00	31.62
35	13.91	64.15	36.55
14	6.38	62.44	47.52
30	4.93	62.20	51.36
44	4.64	59.27	53.91
58	3.71	69.27	60.31
64	6.38	68.54	60.86
78	5.84	66.10	66.34
93	4.68	48.05	72.37

Table 6: NPK content of the water used in the hydroponic system

Day after planting (DAP)	NO_3 ppm	P ppm	K ppm
14	63.08	36.22	28.51
31	81.21	62.32	53.09
45	75.05	62.07	56.47
54	12.86	60.61	43.59
60	11.13	60.73	56.75
63	5.89	61.11	58.21
64	73.28	64.15	36.37
81	82.00	50.98	34.45
95	29.19	59.76	44.68

Soil analysis: it focused on the Raised Bed system aimed to assess the availability of macronutrients within the experiment's soil. While phosphorus and potassium measurements were successfully conducted in the laboratory using the CAL and AAE methods, nitrogen assessment was hindered by the high organic matter content in the soil samples. Please refer to Table 7 below for the obtained results.

Table 7: soil data for the raised beds system

# Sample	**CAL soil**		**AAE soil**	
	K ppm	P ppm	K ppm	P ppm
1	1.88	1.68	3.45	0.99
2	1.87	1.77	3.21	0.96
3	1.52	169	2.74	0.96
4	1.96	1.00	3.45	1.00

Stem Measurements: In all systems included in the experiment, we conducted measurements of both stem diameter and the internodal distance of each plant. These metrics were key indicators of plant growth and overall health across the various systems. The measurements were taken using a caliper tool.

Weight of Dry Plants and Parts Pre-Grinding: Using a high-precision electronic scale, we measured the total dry weight of each plant and the dry weight of its three primary parts (stem, leaves, roots). This comprehensive assessment encompassed all 67 plants in the study, providing insights into differences in total plant dry weights among the systems. These measurements offered indications of plant health and the concentrations of stored substances within their tissues.

Fruit Dimensions: For each fruit produced in the four systems, we measured the length, width, and height using a caliper. This allowed us to assess fruit quality and the potential impact of size on both seed quality and quantity across all produced fruits.

Fruit Weight: Employing an electronic scale, we measured the weight of all fruits across the four systems. Fruit weight is an indicator of fruit quality and expected seed yield.

Fruit Color: Assessment of tomato color in all systems was conducted visually. The color grading provided insights into fruit ripeness and its influence on seed quantity and quality.

Seed Yield (Weight): The weight of seeds per fruit and per plant was recorded, constituting a fundamental test offering insights into overall seed production quality.

Weather Conditions: Throughout the research conducted in the greenhouses, we monitored temperature and humidity. Measuring devices were installed from the experiment's commencement to its conclusion. This allowed us to understand the atmospheric conditions within the greenhouses, with the aquaponics and raised bed systems housed together, while the hydroponics and ecoponics systems were located separately. Table 8 shows the weather conditions.

Table 8: Weather conditions within the greenhouses of the experiment

System type	TGH / C			HGH / %		
	Beginning	**Middle**	**end**	**Beginning**	**middle**	**end**
APS	34	45	56	58	30	16
RBS	34	45	56	58	30	16
HPS	43	52	53	36	16	16
EPS	43	52	53	36	16	16

Data statistical analysis

All statistical analyses were carried out using SAS (SA Institute Inc., Cary, USA, Release 8.02, 2001). Comparisons of means between different treatments were carried out using the GLM procedure considering a fully randomized design. With multiple t-test, the Bonferoni procedure was employed to maintain an experiment-wise a of 5%. Initially Pearson correlations were calculated to test the relation between individual traits (morphological parameter or yield components) and fruit yield. The NOMISS option was used in order to obtain results consistent with subsequent multiple regression studies.

Chapter Three: RESULTS

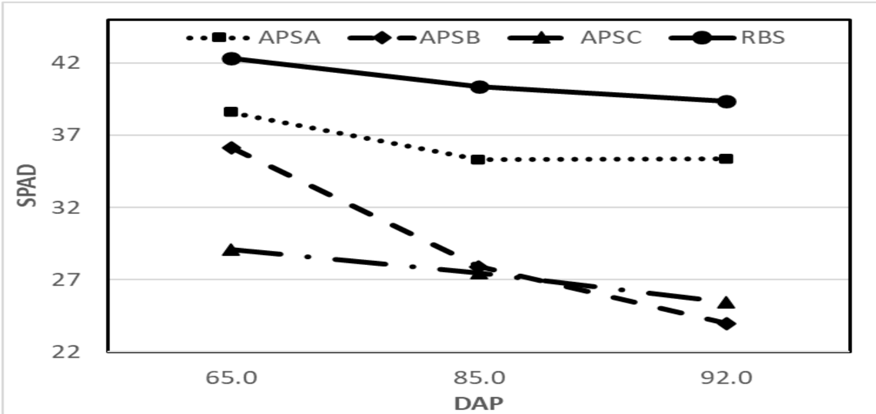
3.1 Growth parameters of Heirloom Tomato:

3.1.1 SPAD measurement:

The data presented in part (A) of Figure 7, featuring the raised bed system (RBS) and the aquaponic system divided into three sections (APSA, APSB, APSC), illustrate varying average values over time. At the initial reading (DAP 65) post-planting, the highest average SPAD value was observed in RBS at 42, while the lowest was in APSC at 29. Moving to the reading during the production phase (DAP 85), RBS recorded the highest average value of 40, contrasting with APSC's lowest average value of 27.5. Finally, at the end of the production cycle (DAP 92), RBS maintained the highest average value of 39, while APSB recorded the lowest average at 24. Notably, the number of duplicates for each system was distributed as follows: RBS = 16 plants, APSA = 4 plants, APSB = 8 plants, APSC = 4 plants.

The findings depicted in part (B) of Figure 8, encompassing the hydroponics system (HPS) and the Ecoponics system (EPS), exhibit the evolving average SPAD values over time. Initially, at the first reading post-planting (DAP 35), HPS displayed the highest average value of 37.8, whereas EPS showed the lowest at 32. Advancing to the second reading (DAP 42), HPS peaked with the highest average value of 42, while EPS maintained the lowest at 32. Transitioning to the onset of production (DAP 53), HPS again recorded the highest average value at 38.7, contrasting with EPS, which marked the lowest average value of 31. Notably, the number of duplicates for each system was identical, with HPS and EPS both having 18 plants.

Part (A)



Part (B)

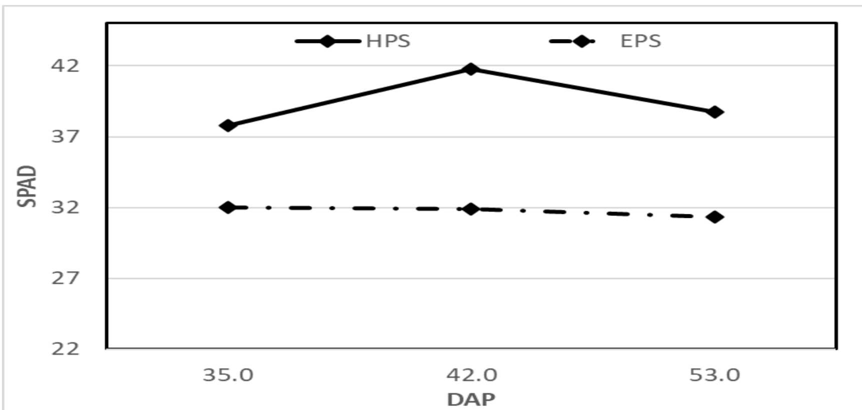


Figure 8. The impact of days after planting (DAP) on the SPAD test, measuring the chlorophyll content in young, mature leaves (YMB), was assessed. Part (A) of the figure illustrates variations in SPAD test readings among the three segments of the aquaponics system and the raised bed system examined simultaneously. Meanwhile, Part (B) of the figure demonstrates SPAD test values for both the hydroponics and Ecoponics systems analyzed within the same timeframe.

In the first set of results (part A), at the final reading (DAP 92), the raised bed system (RBS) had the highest average SPAD value of 39, while the aquaponic system section B (APSB) had the lowest average value of 24. In the second set of results (part B), at the start of production (DAP 53), the hydroponics system (HPS) had the highest average SPAD value of 38.7, while the Ecoponics system (EPS) marked the lowest average value of 31.

Comparing the final readings between the two sets, the raised bed system (RBS) in part A had a higher average SPAD value compared to the hydroponics system (HPS) at the start of production in part B. Additionally, the aquaponic system section B (APSB) in part A had a lower average SPAD value compared to the Ecoponics system (EPS) at the start of production in part B.

3.1.2 Stem diameter (mm):

The maximum average stem diameter attained by plants across the experimental systems was measured, as depicted in Figure 9. The raised bed system (RBS) exhibited the highest statistically significant average stem diameter at 21.3 mm, while the lowest average was observed in the APSC system, measuring 11.5 mm. Moreover, among the three sections constituting the aquaponic system, APSB demonstrated the largest average stem diameter (APSA= 12 mm, APSB=13.5 mm, APSC= 11.5 mm). Additionally, the results indicated that the average stem diameter in the HPS system reached 19.4 mm, surpassing that of the EPS system, which measured 14.3 mm. Notably, the number of duplicates for each system stood as follows: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

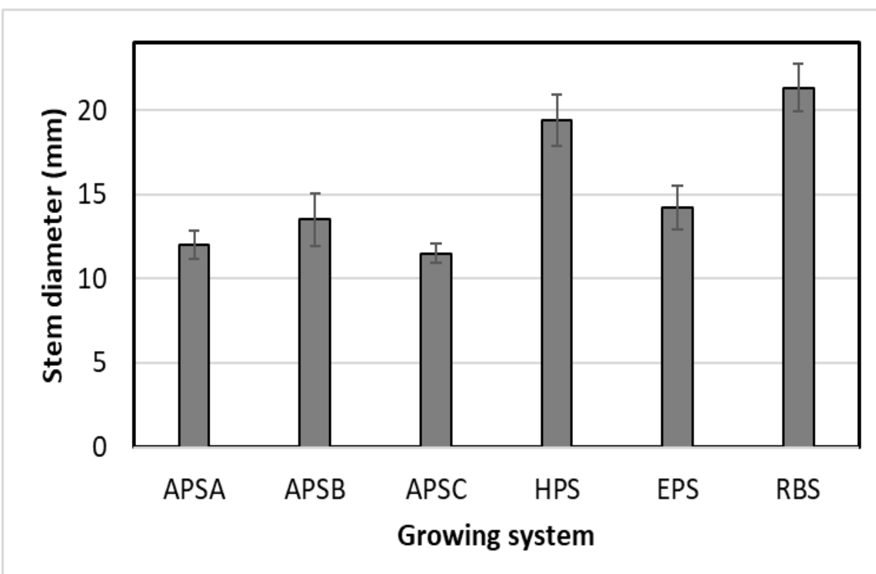


Figure 9: The stem diameters (mm) of tomato plants measured across four distinct growing systems: the aquaponic system (comprising three parts), hydroponic system, Ecoponic system, and raised bed system.

3.1.3 Internodes length (cm):

The maximum average internode length between every two mature leaves of each plant was measured within the experimental systems, as illustrated in Figure 10. The hydroponics system (HPS) displayed the highest average internode length at 11.3 cm, while the APSC system had the lowest at 6.25 cm. Furthermore, among the three sections comprising the aquaponic system, APSA showcased the longest average internode length (APSA= 6.88 cm, APSB=6.81 cm, APSC= 6.25 cm). Additionally, the results highlighted that the average internode length in the RBS system measured 10.5 cm, surpassing the EPS system, which recorded 8.5 cm. Duplicates for each system was as follows: (RBS =16 plant , APSA = 4 plant, APSB = 8 plant, APSC = 4 plant, HPS =18 plant , EPS = 18 plant).

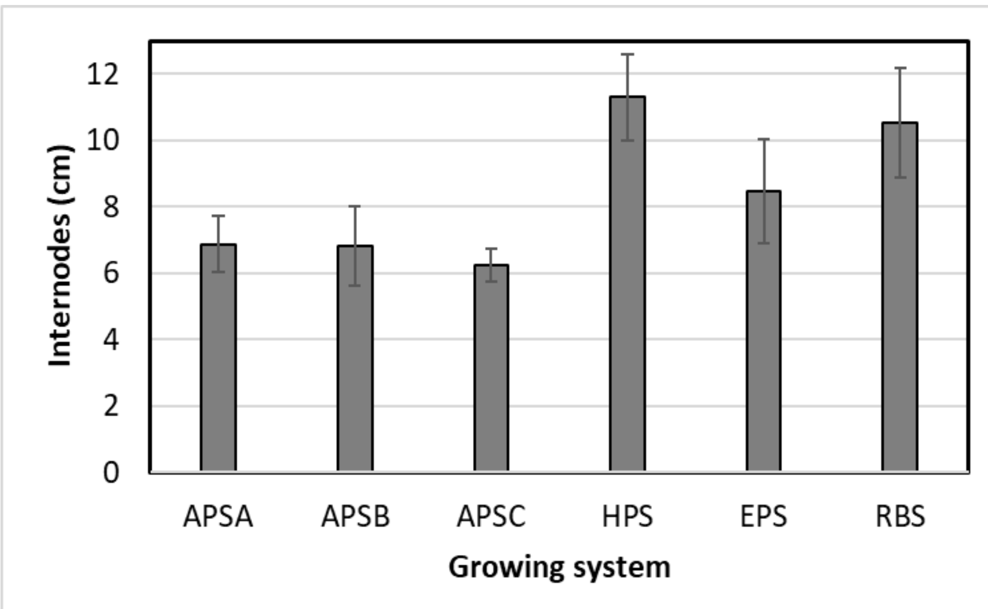


Figure 10. The internode length of tomato plants assessed across four distinct growing systems: the aquaponic system (comprising three parts), hydroponic system, Ecoponic system, and raised bed system.

3.1.4 Plant height (cm):

The maximum average height attained by plants within each system of our experiment was assessed, as depicted in Figure 11. Notably, the hydroponics system (HPS) displayed the tallest average height for tomato plants, reaching 131 cm, while the Ecoponic system (EPS) registered the shortest average height at 73 cm. Among the aquaponic system sections, APSA showcased the greatest average height for tomato plants (APSA=119 cm, APSB=114 cm, APSC=100 cm). Additionally, the average height of tomato plants in the RBS system measured 118.7 cm. These measurements were conducted with the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

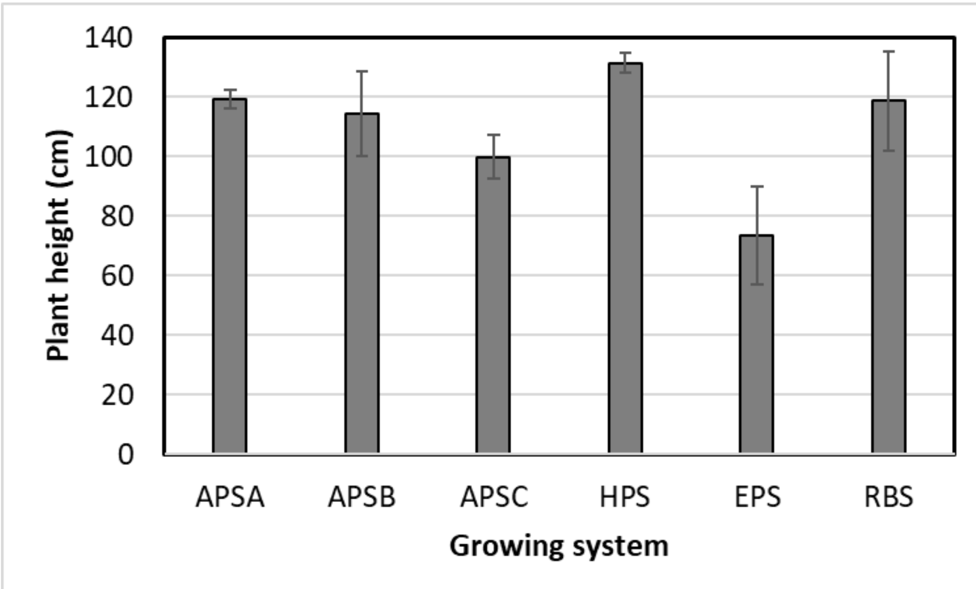


Figure 11: The heights of tomato plants (measured in centimeters) were evaluated across four distinct growing systems: the aquaponic system (comprising three parts), hydroponic system, Ecoponic system, and raised bed system.

3.1.5 Total dry weight (TDW, g) :

The average total dry weight (TDW in grams) of whole tomato plants within each system of our experiment was measured, as depicted in Figure 12. Remarkably, the raised bed system (RBS) highlighted the highest average dry weight for tomato plants, reaching 622 grams. In contrast, the APSA system exhibited the lowest average dry weight at 132 grams. Moreover, among the aquaponic system sections, APSB displayed the greatest average dry weight for tomato plants (APSA=132 g, APSB=408 g, APSC=167 g). Additionally, the EPS system yielded an average dry weight of 249 grams for tomato plants, surpassing that of the HPS system, which measured 142 grams. These assessments were conducted based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

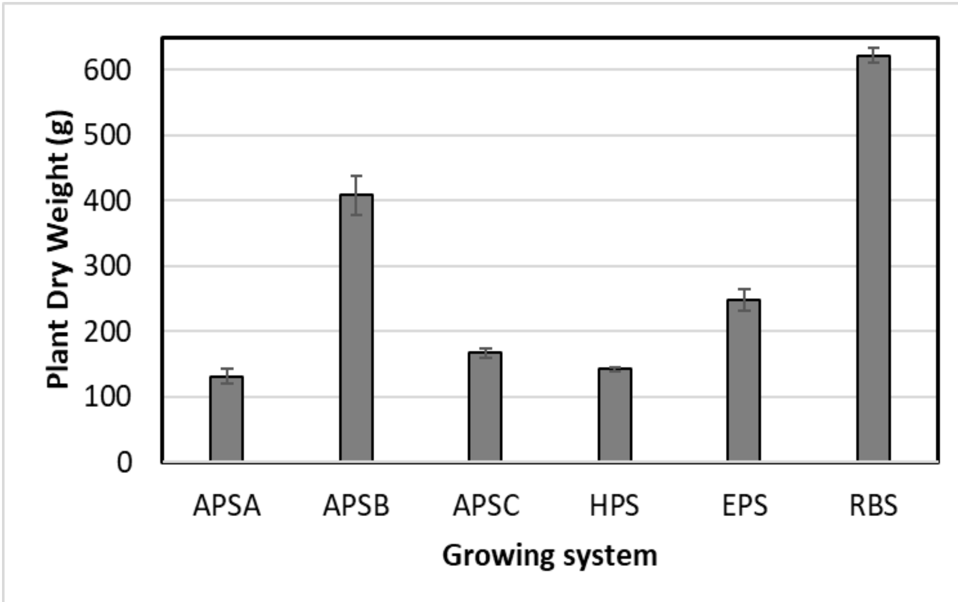


Figure 12: The dry weight (measured in grams) of entire tomato plants assessed across four distinct growing systems: the aquaponic system (comprising three parts), hydroponic system, Ecoponic system, and raised bed system.

3.1.6 Root dry weight (g) of tomato plants:

Measurements of the average root dry weight (in grams) of tomato plants within each system of our experiment was conducted, detailed in Figure 13. Strikingly, the APSB system demonstrated the highest average root dry weight for tomato plants, reaching 48 grams. Conversely, the APSA system exhibited the lowest average root dry weight at 2.4 grams. Additionally, for the last section (APSC) of the aquaponic system, the average root dry weight was recorded at 23.4 grams. Comparatively, the EPS system yielded an average root dry weight of 24 grams for tomato plants, surpassing the HPS system, which measured 11 grams. Lastly, the average root dry weight of tomato plants in the RBS system was 7.5 grams. These assessments were conducted based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

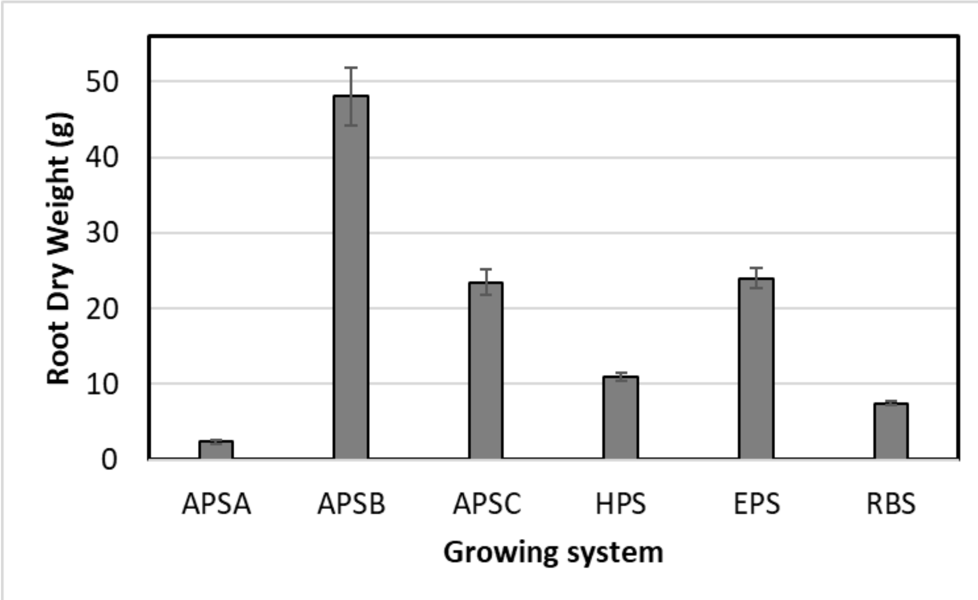


Figure 13. The dry weight (measured in grams) of tomato plant roots was analyzed across four distinct growing systems: the aquaponic system (comprising three parts), hydroponic system, Ecoponic system, and raised bed system.

3.1.7 Stem dry weight (g) of tomato plants:

The average stem dry weight (in grams) of tomato plants within each system of our experiment was assessed, outlined in Figure 14. Impressively, the raised bed system (RBS) exhibited the highest average stem dry weight for tomato plants, reaching 242 grams. Conversely, the APSC system displayed the lowest average stem dry weight at 39 grams. Among the aquaponic system sections, APSB displayed the greatest average stem dry weight for tomato plants (APSA=45.5 g, APSB=149.5 g, APSC=39 g). Additionally, the EPS system demonstrated an average stem dry weight of 112.6 grams for tomato plants, surpassing the HPS system, which recorded 53.1 grams. These evaluations were based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

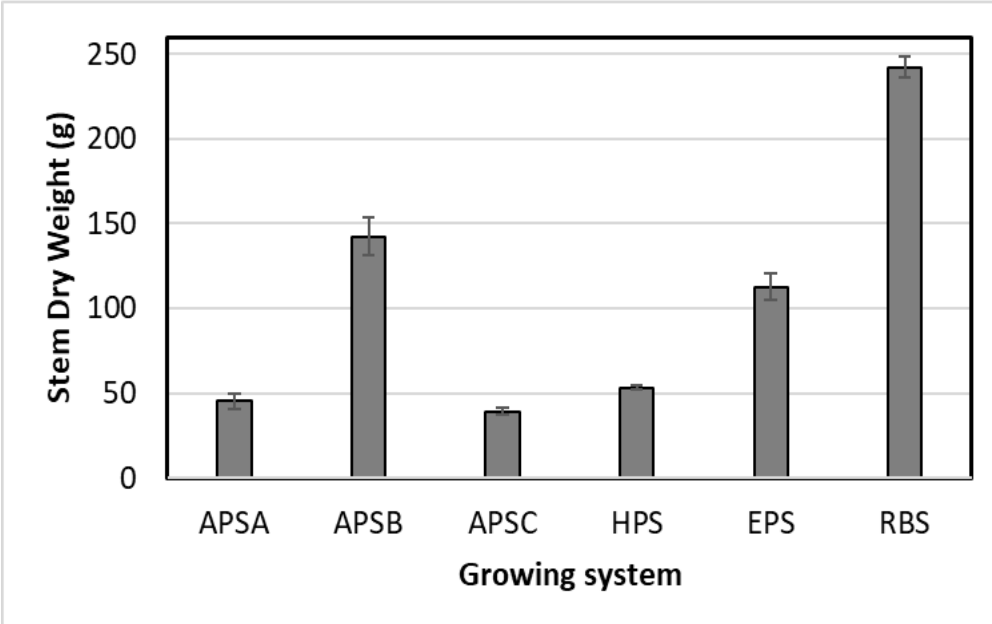


Figure 14. The dry weight (measured in grams) of tomato plant stems was examined across four distinct growing systems: the aquaponic system (comprising three parts), hydroponic system, Ecoponic system, and raised bed system.

3.1.8 Leaves dry weight (g) of tomato plants:

The average dry weight of leaves (in grams) of tomato plants across the experimental systems was measured, as depicted in Figure 15. Strikingly, the raised bed system (RBS) displayed the highest average dry weight of leaves for tomato plants, reaching 372 grams. In contrast, the hydroponic system (HPS) showcased the lowest average dry weight at 77 grams. Among the aquaponic system sections, APSB demonstrated the greatest average dry weight of leaves for tomato plants (APSA=82 g, APSB=216 g, APSC=103 g). Additionally, the EPS system exhibited an average dry weight of 116 grams for tomato plant leaves. These evaluations were based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

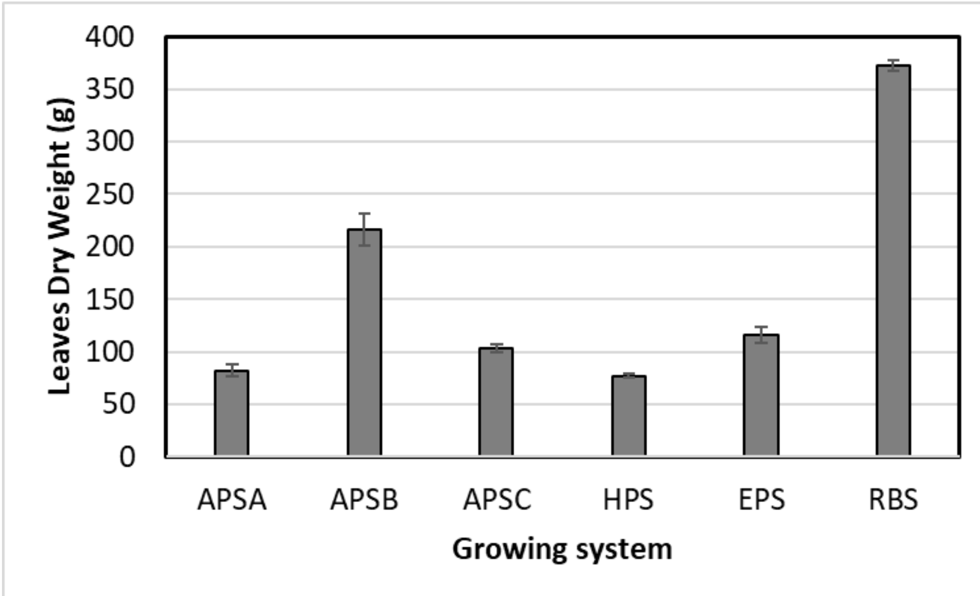


Figure 15. The grams of dry weight in tomato plant Leaves underwent analysis within four unique growth systems: the aquaponic system, consisting of three parts, alongside the hydroponic, Ecoponic, and raised bed systems.

3.1.9 Number of leaves per tomato plant:

The measurements of the average number of leaves per tomato plant within the systems of our experiment conducted, outlined in Figure 16. Notably, the raised bed system (RBS) exhibited the highest average number of leaves for tomato plants, reaching 50 leaves. In contrast, the hydroponic system (HPS) displayed the lowest average number of leaves at 16. Among the aquaponic system sections, APSB highlighted the greatest average number of leaves per tomato plant (APSA=30 leaves, APSB=34 leaves, APSC=20 leaves). Additionally, the EPS system presented an average of 21 leaves per tomato plant. These assessments were based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

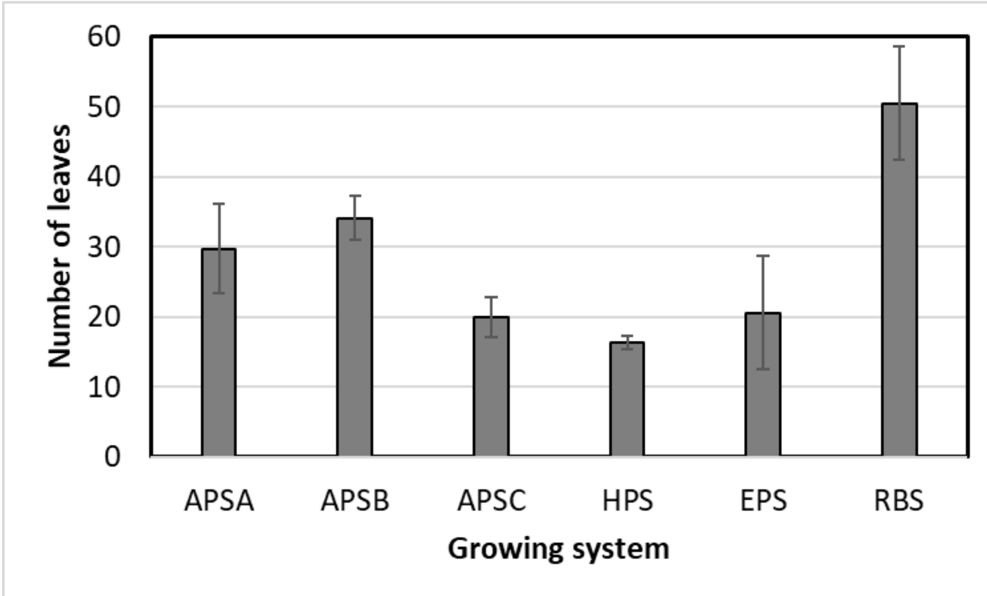


Figure 16. Number of Leaves for tomato plants in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system).

3.1.10 Number of branches per tomato plant:

The average number of branches per tomato plant across the systems in our experiment was recorded, as illustrated in Figure 17. Notably, the raised bed system (RBS) displayed the highest average number of branches per tomato plant, reaching 3.5 branches. In contrast, the hydroponic system (HPS) exhibited the lowest average number at one branch per plant. Among the aquaponic system sections, APSB presented the greatest average number of branches per tomato plant (APSA=1.75 branches, APSB=2.13 branches, APSC=2 branches). Additionally, the EPS system showed an average of 2.06 branches per tomato plant. These assessments were conducted with the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

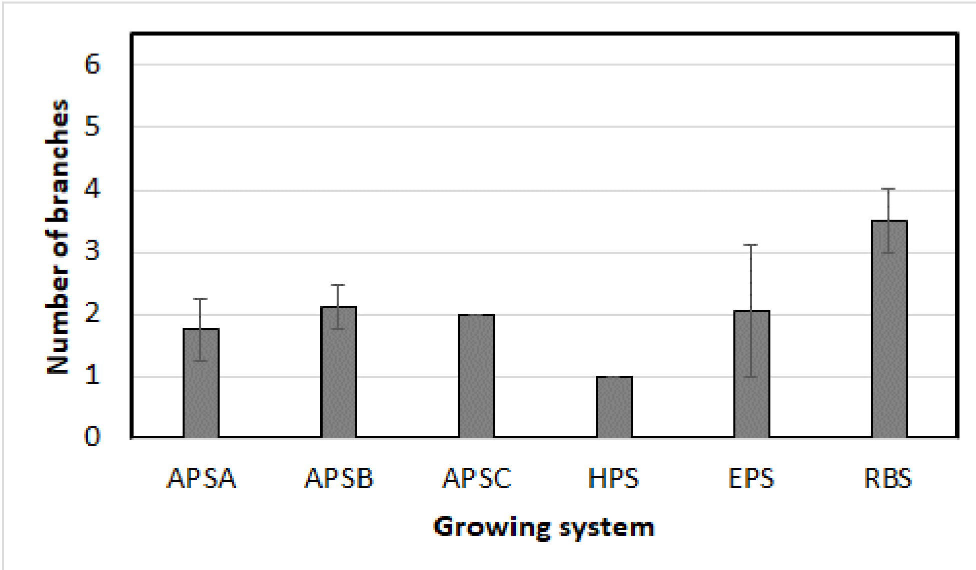


Figure 17. Number of branches for tomato plants in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system).

3.2 Yield parameters of Heirloom Tomato:

3.2.1 Total number of fruits per plant:

The average total number of fruits per plant across the systems within our experiment was collected, showcased in figure 18. Remarkably, the raised bed system (RBS) displayed the highest average number of fruits per plant, reaching 13 fruits. In contrast, the hydroponic system (HPS) showed the lowest average number with just one fruit per plant. Among the aquaponic system sections, APSB presented the greatest average number of fruits per plant (APSA=10.5 fruits, APSB=12.25 fruits, APSC=5.75 fruits). Additionally, the EPS system demonstrated an average of 4.7 fruits per plant. These assessments were based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

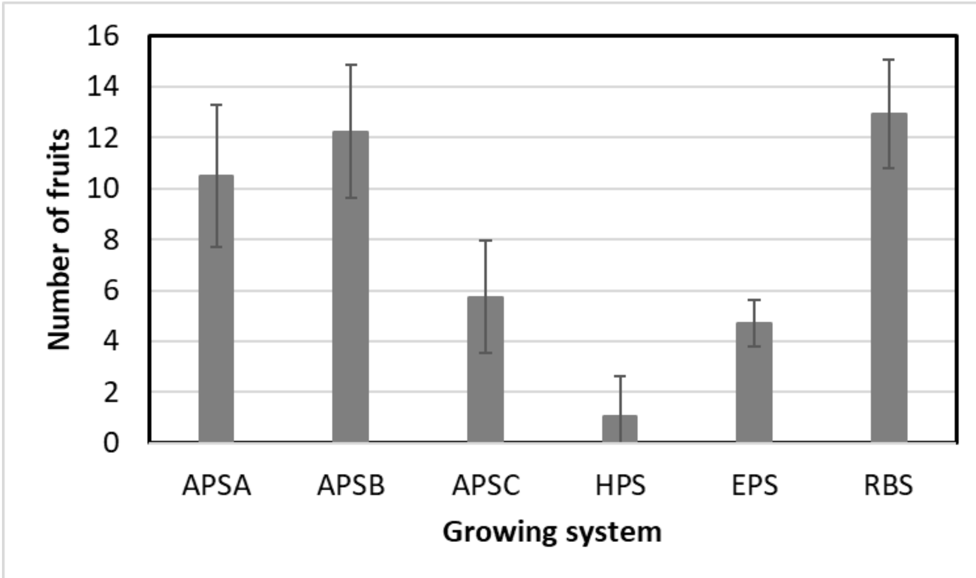


Figure 18. Number of fruits for tomato plants in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system

3.2.2 Number of fruits per cluster:

The average number of fruits per cluster across the systems within our experiment was measured, detailed in Figure 19. Strikingly, the APSA system exhibited the highest average number of fruits per cluster, reaching 3.75 fruits. Conversely, the hydroponic system (HPS) showcased the lowest average number with just one fruit per cluster. Among the aquaponic system sections, APSC displayed the least average number of fruits per cluster (APSA=3.75 fruits, APSB=3.41 fruits, APSC=2.13 fruits). Moreover, the RBS system demonstrated an average of 3.66 fruits per cluster, surpassing the EPS system, which recorded 1.89 fruits. These assessments were based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

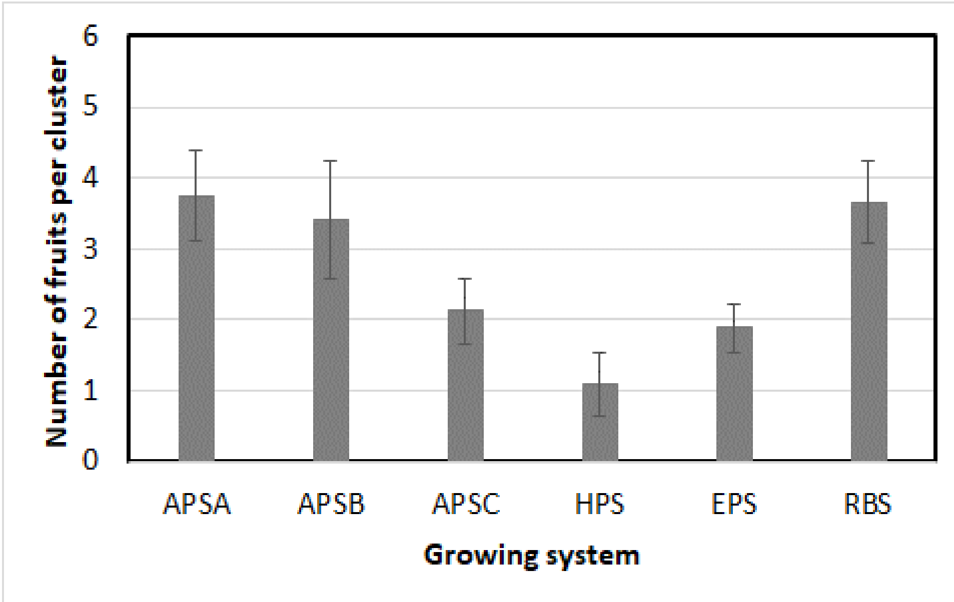


Figure 19. Number of fruits per cluster of tomato plants in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system).

3.2.3 Fruits weight per plant:

The average weight of fruits per plant across the systems within our experiment was measured, as illustrated in Figure 20. Impressively, the APSB system displayed the highest average weight of fruits per plant, reaching 143 grams. Conversely, the hydroponic system (HPS) highlighted the lowest average weight at 81 grams per plant. Among the aquaponic system sections, APSC demonstrated the least average weight of fruits per plant (APSA=134 g, APSB=143 g, APSC=95 g). Additionally, the RBS system presented an average of 140 grams per plant, surpassing the EPS system, which recorded 93 grams. These assessments were conducted based on the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

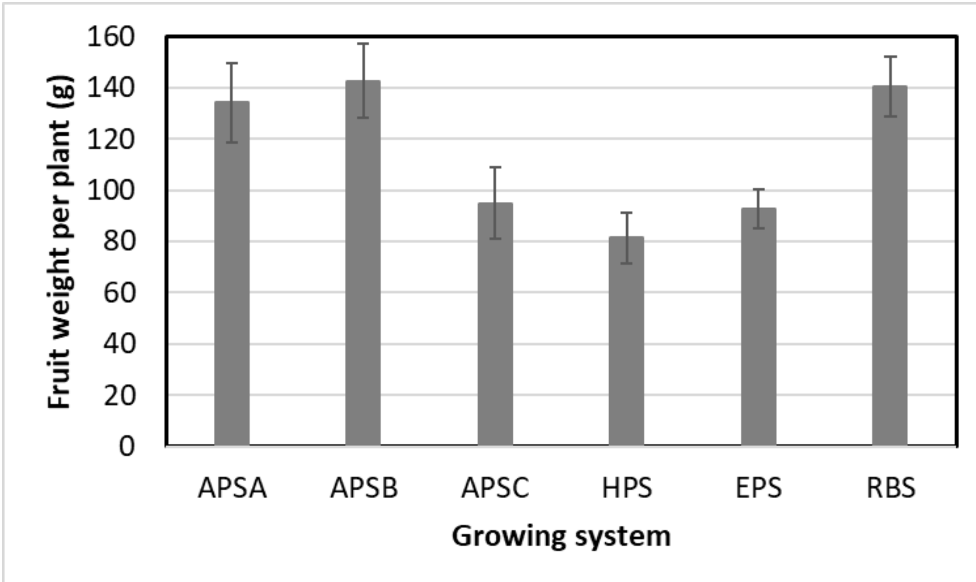


Figure 20. Fruits Weight per tomato plants (g) in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system).

3.2.4 Fruit color index:

The average fruit color index per plant across the systems within our experiment was assessed, as presented in figure 21. Impressively, the EPS system showcased the highest average fruit color index per plant, reaching 2.27. In contrast, the hydroponic system (HPS) displayed the lowest average index at 1.06. Among the aquaponic system sections, APSB demonstrated the largest average number of fruits per plant (APSA=1.98, APSB=2.24, APSC=2.20). Additionally, the RBS system presented an average of 2.17 fruits per plant. These evaluations were conducted with the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

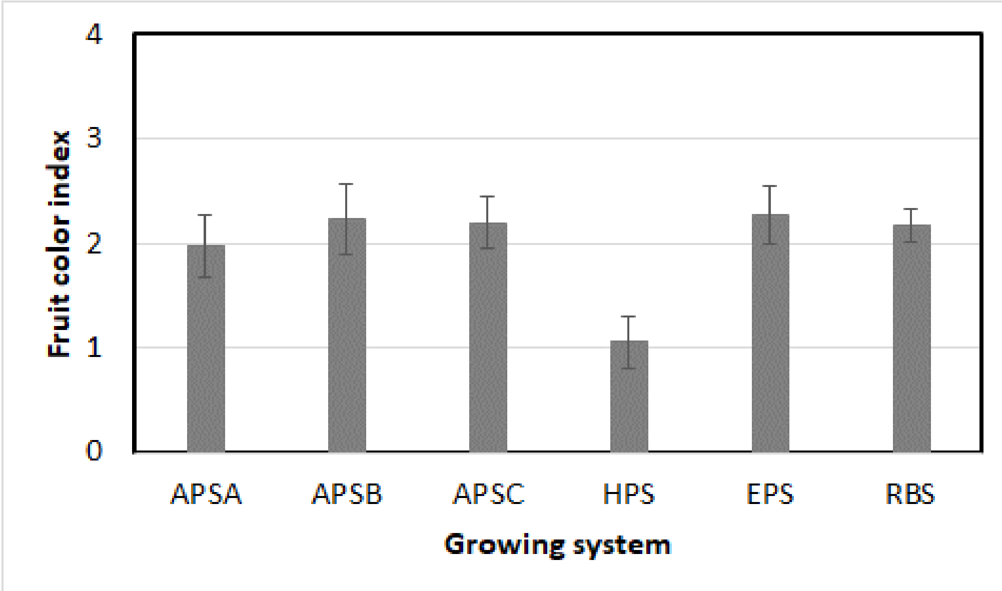


Figure 21. Fruits color index for tomato plants in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system) . In which the index was divided into three color grades : (1 : Dark Red , 2: Light Red , 3 : Yellowish red).

3.2.5 Dimensions (mm) of tomato fruits:

The average three dimensions (A, B, and C) of tomato fruits per plant within the systems of our experiment were recorded, detailed in figure 22. Remarkably, the APSB system displayed the highest average three dimensions of tomato fruits per plant: (73 mm, 65 mm, 44 mm). In contrast, the hydroponic system (HPS) exhibited the lowest average dimensions: (36 mm, 32 mm, 22 mm). Among the aquaponic system sections, APSC demonstrated the least average dimensions: {APSA=(68 mm, 61.4 mm, 42.9 mm), APSB=(73 mm, 65 mm, 44 mm), APSC=(67.5 mm, 60 mm, 42.8 mm)}. Additionally, the RBS system presented larger dimensions: (71 mm, 63 mm, 43 mm) compared to the EPS system: (49 mm, 42 mm, 32 mm). These evaluations were conducted with the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

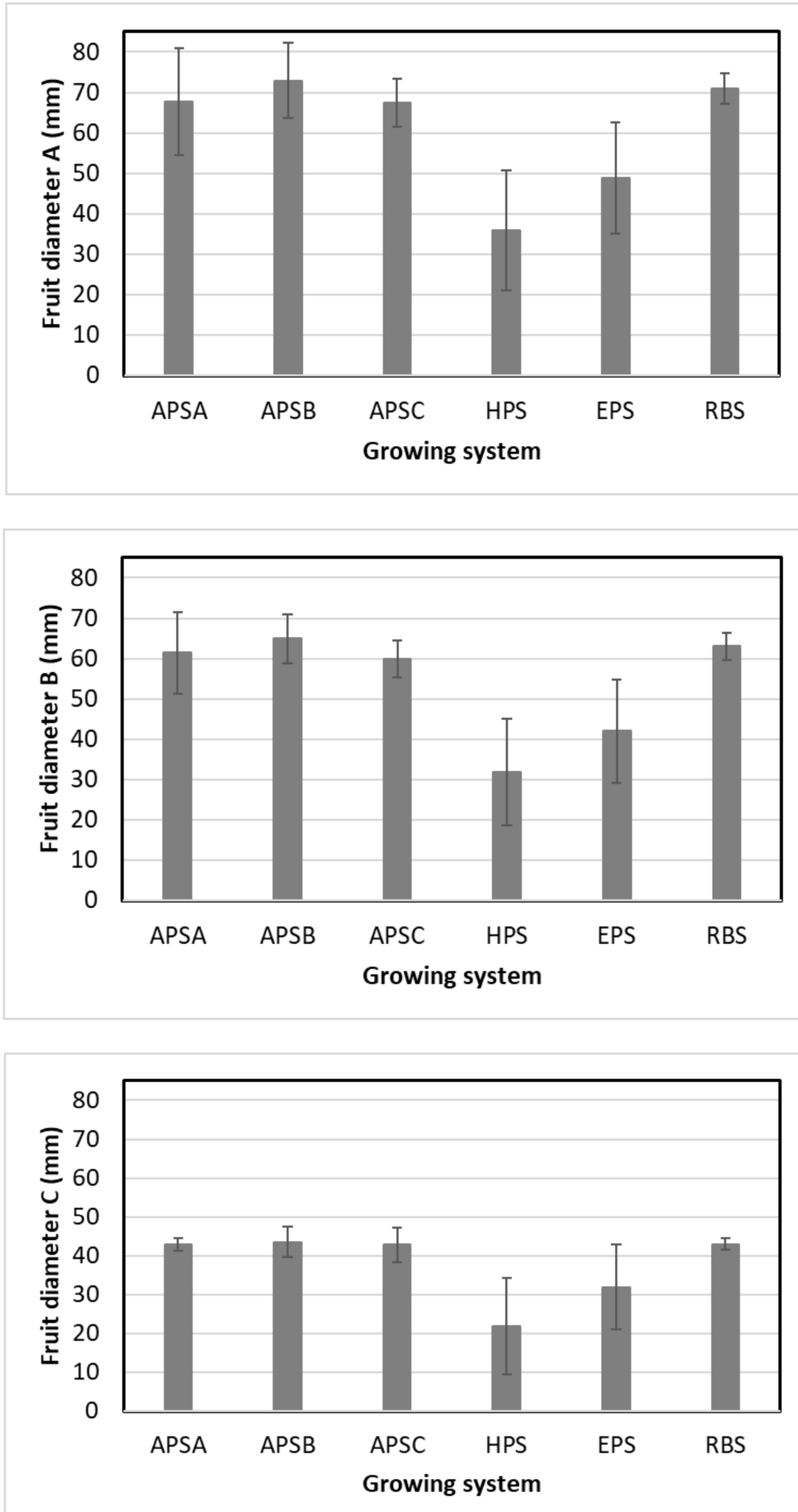


Figure 22. The three dimensions (mm) of tomato fruits (A,B,and C), which show that the fruits are irregular in shape in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system.

3.2.6 Seed weight per tomato plant:

The average seed weight per tomato plant across the systems in our experiment was recorded, as illustrated in figure 23. Notably, the APSA displayed the highest average seed weight per tomato plant, reaching 0.84 grams. In contrast, the raised bed system (RBS) and the APSB systems exhibited the lowest average seed weight per tomato plant, where they both reaching 0.80 grams . And the APSC system comes in second place after the APSA system (APSA=0.84 g, APSB=0.80 g, APSC=0.81 g). It is noteworthy that no significant values were obtained for both the hydroponic system (HPS) and the EPS system. These assessments were conducted with the following numbers of duplicates for each system: RBS=16 plants, APSA=4 plants, APSB=8 plants, APSC=4 plants, HPS=18 plants, and EPS=18 plants.

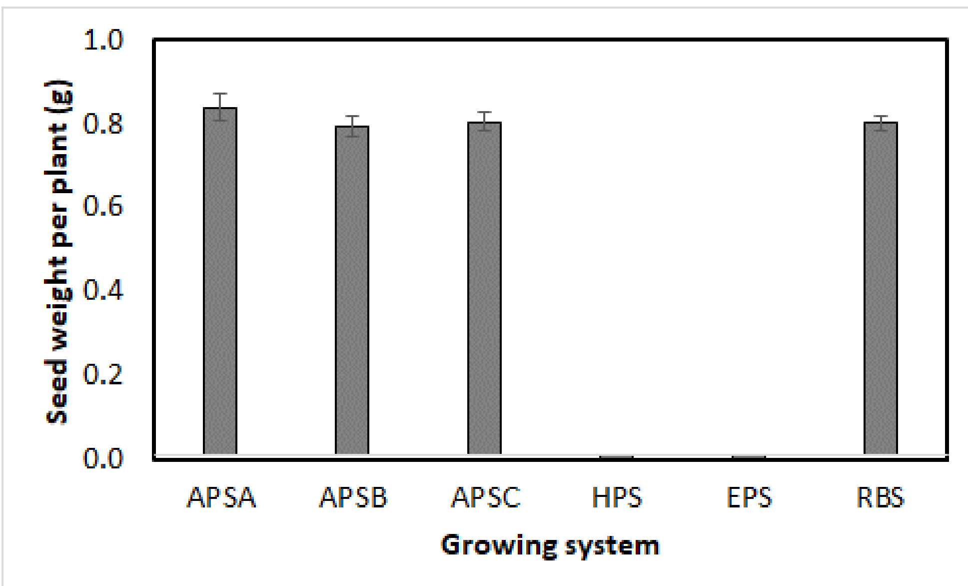


Figure 23. seed weight per tomato plant (g), in the four different growing systems (aquaponic system with its three parts, hydroponic system, the Ecoponic system, and raised bed system). Where the average seed weight per plant ranged between 0.80 and 0.84 grams approximately .

Table 9 shows a comprehensive summary of all the previously described results of the four systems, expressed in numerical scores. This allows for an overall view of the comparative effectiveness of the farming models in enhancing the growth and productivity of heirloom tomatoes.

Table 9: A comprehensive summary of the results of the four systems expressed in numerical scores

Parameters	Growing system					
	APSA	**APSB**	**APSC**	**EPS**	**HPS**	**RBS**
SPAD measurement	4	3	1	2	5	6
Stem diameter (mm)	2	3	1	4	5	6
Internodes length (cm)	3	2	1	4	6	5
Height of tomato plants (cm)	5	3	2	1	5	4
Dry weight (g) of tomato whole plants	1	5	3	4	2	6
Root dry weight (g) of tomato plants	1	6	4	5	3	2
Stem dry weight (g) of tomato plants	2	5	1	4	3	6
Leaves dry weight (g) of tomato plants	2	5	3	4	1	6
Number of leaves per tomato plant	4	5	2	3	1	6
Number of branches per tomato plant	2	5	3	4	1	6
Number of fruits per plant	4	5	3	2	1	6
Number of fruits per cluster	6	4	3	2	1	5
Fruit yield (weight of fruits per plant)	4	6	3	2	1	5
Fruit color	2	5	4	6	1	3
Fruit dimensions (mm)	4	6	3	2	1	5
Seed weight (g) per tomato plant	4	2	3	0	0	1
Total scores	**50**	**70**	**40**	**49**	**37**	**78**

3.3 Pearson correlation

The Pearson correlation analysis was conducted to assess the relationship between fruit yield and various growth, yield, and nutrient parameters. In the overall dataset, tomato yield showed a positive correlation with total dry weight and leaves dry matter. However, there was no correlation found with stem or root dry matter. Additionally, total fruit yield exhibited significant positive correlations with several factors including the number of fruits per plant, fruits per cluster, fruit diameters (A, B, and C), number of seeds per plant, and fruit color.

Regarding nutrient content, fruit yield showed significant positive correlations with phosphorus (P) content in stems and leaves, and potassium (K) content in roots. However, there was no correlation with nitrogen (N) content in any plant parts (leaves, stem, roots).

When focusing on specific systems, in the APS system, fruit yield correlated significantly with fruit diameters A and B, P content in leaves, and seed weight per plant. APSA showed correlations between tomato yield and fruit diameters A and B, as well as P content in roots. Conversely, APSB displayed positive correlations between tomato yield and fruit diameters (A, B, and C), and nitrogen content in leaves, while showing a negative correlation with P content in leaves.

In APSC, tomato fruit yield exhibited a negative correlation with SPAD readings throughout the experiment. It positively correlated with the length between internodes but negatively correlated with the number of leaves per plant. Furthermore, it showed positive associations with the number of fruits per plant and per cluster but displayed negative correlations with P content in stem and roots, as well as K content in the stem.

In the EPS, tomato fruit yield was highly positively correlated with the number of fruits per cluster, fruit diameters (A, B, and C), and fruit color. The HPS system demonstrated a positive and strong correlation between fruit yield and the number of fruits per plant, fruits per cluster, fruit diameters (A, B, and C), fruit color, and nitrogen content in the stem. However, in the RBS system, the yield was significantly and highly correlated solely with fruit diameters (A, B, and C), without significant correlations with other growth, yield, or nutrient parameters.

Table 10 : Pearson correlation between growth parameters and yield of tomato:

System	Correlated parameters
All systems pooled	TDW (0.28*), leaves dry weight (0.28*), number of fruit per plant (0.35040*), number of fruit per cluster (0.62***), Fruit diameter A (0.93***), Fruit diameter B (0.92***), Fruit diameter C (0.89***), fruit colour (0.72***), P% stem (0.25*), P% leaves (0.31*), K% roots (-0.25*), seeds weight per plant (0.38**)
APS pooled	Fruit diameter A (0.80***), Fruit diameter B (0.89***), P% leaves (-0.71**), seeds weight per plant (0.60*)
APSA	Fruit diameter A (0.98459),Fruit diameter B (0.97674), P% in roots (-0.97910)
APSB	Fruit diameter A (0.88**), Fruit diameter B (0.95**), Fruit diameter C (0.72*), N% in leaves (0.73*), P% in leaves (-0.69*)
APSC	SPAD at the beginning (-0.66*), SPAD at the middle (-0.86224*), SPAD at the end (-0.72*), internodes (0.76*), number of leaves (-0.75*), number of fruits per plant, (0.88**), number of fruits per cluster (0.96***)
EPS	Number of fruits per cluster (0.79***), fruit diameter A (0.94***), fruit diameter B (0.92***), fruit diameter C (0.89***), fruit colour (0.68**)
HPS	Number of fruits per plant (0.74***), number of fruits per cluster (0.84***), fruit diameter A (0.98***), fruit diameter B (0.97***), fruit diameter C (0.97***), fruit colour (0.95***), N content in stem (0.48*)
RBS	Fruit diameter A(0.93***), Fruit diameter B(0.88***), Fruit diameter B(0.50*)

Chapter Four: DISCUSSION

Various observations related to growth and productivity parameters of heirloom tomatoes, such as fruit size, fruit weight, root dry weight, total dry weight, leaf dry weight, stem height, seed weight and chlorophyll content, were recorded and compared among the various farming systems. However, there are very few studies that compare various systems including all four growing systems used in this study, and less studies are found to be investigating growth and productivity of heirloom species in those systems.

Therefore, comparisons of some results with other studies from literature cannot be possible, as most studies, for example, compare commercial tomato yields between aquaponics and hydroponics, and rarely compare between aquaponics and soil cultivation systems, or have more than two different systems under investigation in the same study.

The SPAD value which was under study in this experiment, can reveal the photosynthetic rate of tomato plants in each cultivation system, and therefore, it can be an indicator for plant growth, and can be associated with yield. SPAD measurement is an indirect estimate of N status of tomato leaves, and SPAD was found to be positively correlated with individual fruit weight, total yield, and marketable yield (**Pattillo *et al.*, 2020).**

Comparing SPAD readings between the four system, the RBS had a higher average SPAD value compared to the HPS at the start of production. APSB had a lower average SPAD value compared to the EPS at the start of production, and higher values in the RBS compared to the APS at the end of the production cycle. Some studies showed that aquaponics reduced SPAD value in tomato leaves compared to hydroponics **(Yang and Kim, 2020).** In a study by **Schmautz *et al.*, 2016,** SPAD measurements showed significant differences between aquaponics and hydroponics, where the aquaponics had the highest values and NFT system had significantly higher values than the raft culture growing system in aquaponics. These results are compatible with our findings, however, there are no studies comparing SPAD values of plants in soil cultivation systems and soilless cultivation systems.

In other studies, it was shown that the values of SPAD observed, indicated a good photosynthetic rate reached under organic cultivation **(Güler and Büyük, 2004).** Organic cropping systems reported having higher SPAD values in early production time, while showed lower values in later stages **(Ronga et al., 2015).**

Higher SPAD values are directly related to nitrogen uptake and photosynthesis rate, and using biofertilizers in organic cultivation systems result in higher SPAD values compared to chemical cultivation systems. It is suggested that compost and biofertilizers may supply the adequate amount of nutrients to plants at different stages, with numerous photosynthesis-related proteins upregulated in plants, which may increase photosynthetic capacity of the plants leading to yield and quality of crops **(Khan *et al.*, 2017).**

When observing the average stem diameter of plants across the experimental systems, the RBS exhibited the highest statistically significant average stem diameter at 21.3 mm, while the lowest average was observed in the APSC system, measuring 11.5 mm. This is compatible with studies of the effect of soilless cultures on stem height, shoot biomass, and other growth parameters **(Madusanka *et al.*, 2023; Deer *et al.*, 2023)**. **Deer *et al.*, 2023** suggested that the type of system can affect growth and nutrient uptake of tomatoes and should not be used in a soilless system because of excessive fruit splitting, leading to unmarketable fruit and low yield, unless environmental conditions can be managed.

The three studied sections of the aquaponic system, demonstrated close average stem diameter (APSA= 12 mm, APSB=13.5 mm, APSC= 11.5 mm), confirming the effect of soilless culture on stem diameter. However, the average stem diameter in the HPS and EPS reached 19.4 mm and 14.3 mm, respectively. This differs than what was found in the same study of **Madusanka *et al.*, 2023**. It was found that aquaponics system provided the opportunity to produce higher tomato yields compared to those obtained by the conventionally used hydroponic system, with longer stems and higher plant height grown in the hydroponics system. No studies were found comparing tomato plants in soil cultivation systems with soilless ones.

The HPS displayed the highest average internode length at 11.3 cm, while the APSC system had the lowest at 6.25 cm, with no huge differences among its different sections (ranging from 6.25 to 6.88 cm). The average internode length in the RBS system measured 10.5 cm while in the EPS system was 8.5 cm. According to literature, internodal length are much affected by space and plant geometry and no studies are present studying the effects of various farming systems on the internode length.

In a study by **Singh *et al.*, 2017,** it was found that plant geometry and space had significant effect on number of nodes per plant, internodal length and plant height in tomato production. This could be due to increase in a number of stems per plant and due to sufficient light intensity. The minimum internodal length recorded in that study was when plants were spaced at 70 × 60 cm and was statistically superior to 70 × 30 cm geometry. **Papadopoulos and Ormrod, 1990,** also recorded less internodal length in wider spacing plants. This was favored due to increased availability of growth favouring components, nutrients, air and moisture at wider spacing. These findings are compatible with the findings of this study, as the APS has better conditions regarding space, moisture and light intensity compared with RBS.

Regarding the average heights of tomato plants, the HPS displayed the highest average height for tomato plants, reaching 131 cm, while EPS plants had the lowest average height at 73 cm. The aquaponic system sections, and the RBS had plants with average heights ranging from 100 cm to 119 cm. Similar to these results, **Yang and Kim, 2020**, found that aquaponics reduced plant height and leaf length in tomato compared to aquaponics. **Deer *et al.*, 2023** also found that hydroponic plants had greater stem heights than aquaponic 2 months after plantation. No literature was found comparing tomato plant height grown in raised beds with tomato grown in the different aquaculture systems. However, some studies have shown the difference in plant heights among heirloom plants and non-heirloom ones. Plant height was significantly higher among heirloom tomato plants compared to modern tomato genotypes, and was also higher in organic farming systems compared to conventional ones **(Ronga *et al.*, 2021).**

Regarding the average total dry weight (TDW in grams), the RBS highlighted the highest average dry weight for tomato plants, reaching 622 grams, with APSA system as the lowest (at 132 grams). Surprisingly, there was a huge difference between TDW of plants in APSB (408 g) compared to APSA (132 g) and APSC (167 g). The TDW of plants of the HPS measured 142 grams. In one study by **Schmautz *et al.*, 2016**, studying tomato productivity and quality in aquaponics and hydroponics, no significant differences were observed in the dry matter between the different systems.

Bernard *et al.*, 2009, found that tomatoes grown in aquaponics had significantly lower dry matter and more moisture than those that were grown in hydroponics. It was suggested that there might be a connection between nitrogen level and moisture content, as the higher nitrogen supply may result in lower dry matter content. It is hypothesized that the aquaponic tomatoes had higher and more consistent access to nitrogen than the other system due to fish waste, but that does not explain the high TDW in APSB, despite the low TDW in the other 2 sections. The high TDW of tomatoes in NFT aquaponics, might be due to the vey thin line of water flow through the tomato plant roots which might explain the higher TDW (and less moisture) in APSB plants compared to APSA and APSC or even RBS where moisture is at the lowest level among all water-based cultivation systems.

Measurements of the average root dry weight of showed that the APSB system demonstrated the highest average root dry weight for tomato plants, at 48 grams. Conversely, the APSA system exhibited the lowest average root dry weight at 2.4 grams. The APSC section of the aquaponic system, had an average root dry weight of 23.4 grams, similar to the EPS tomato plants, and surpassing the HPS at 11 grams. The average root dry weight of tomato plants in the RBS system was 7.5 grams. This shows that soilless cultures are better for root growth, but in the case of APSA, the solid tuff culture might have similar limiting environment as in raised beds. In the study by **Deer *et al.*, 2023** on growing tomatoes using different hydroponics systems, it was found that plants grown using a hydroponic system had increased root dry weights. It was also found that aquaponics resulted in greater root fresh weight than hydroponics. This is compatible with results in this study showing that aquaponics resulted in higher root dry weight compared to hydroponics and raised beds, however, the tuff culture in aquaponics had an adverse effect on root mass similar to soil in raised beds.

The average stem dry weight of tomato plants, the RBS was the highest reaching 242 grams, while the APSC system displayed the lowest average stem dry weight at 39 grams. Among the aquaponic system sections, APSB displayed the greatest average stem dry weight at 149.5 g. The APSB stem dry weights were much higher compared with APSA at 45.5 g and APSC at 39 g, but were similar to the HPS at 53.1 grams. The EPS system demonstrated an average stem dry weight of 112.6 g. **Madusanka *et al.*, 2023** showed that there were no significant differences between the hydroponics and aquaponics systems regarding the stem dry weight, despite a slightly higher stem dry weight in hydroponics.

The average dry weight of leaves of tomato plants was the highest in the RBS reaching 372 g, and the lowest in the HPS at 77 grams. Among the aquaponic system sections, APSB demonstrated the greatest average dry weight of leaves for tomato plants (APSA=82 g, APSB=216 g, APSC=103 g). Additionally, the EPS system exhibited an average dry weight of 116 grams for tomato plant leaves. In a study by **Danaher *et al.*, 2016**, tomato plants watered with inorganic fertilizer had greater leaf dry matter, root dry matter, and total dry matter compared to plants watered with municipal water. However, tomato plant growth in substrate partially replaced with 10% dewatered aquaculture effluent was similar irrespective of water source, providing optimal physical and chemical properties along with sufficient nutrients for tomato transplants without the need for commercial, inorganic fertilizer. This contradicts observations of the root dry weight and leaf dry weight in this study, which show much higher dry root and leaf weight values in aquaponics compared to hydroponics.

The average number of leaves per tomato was the highest in the RBS, reaching 50 leaves, while the HPS displayed the lowest average number of leaves at 16 leaves. Among the aquaponic system sections, the number of leaves varied between 20 and 34 leaves with the NFT section (APSB) having the highest average number of leaves per tomato plant. The EPS system presented an average of 21 leaves per tomato plant. **Madusanka *et al.*, 2023** showed that there were no significant differences between the hydroponics and aquaponics systems although the hydroponics system had 2 more leaves compared to plants in the aquaponics. No studies compare soilless farming with soil conventional farming.

The average number of branches per tomato was the highest in the RBS reaching 3.5 branches, while the HPS exhibited the lowest average number at one branch per plant.

Among the aquaponic system sections, similar close values were present, around 2 branches per plant, similar to the EPS. There were no studies comparing number of branches between the different systems, however, a study by **(Gajbhiye *et al.,* 2003).** found that biofertilizers in combination with chemical fertilizers were the best treatment and significantly influenced plant height, number of primary branches per plant, number of fruits per plant, weight of fruits per plant and fruit size compared to chemical fertilizer treatment alone.

The average total number of fruits per plant was the highest in the RBS, reaching 13 fruits per plant, while the HPS showed the lowest average number with just one fruit per plant. Among the aquaponic system sections, a significant variation is observed with 10.5 fruits in APSA, 12.5 fruits in APSB and 5.57 fruits in APSC, and EPS had an average of 4.7 fruits per plant. In a study by **Schmautz *et al.,* 2016**, it was found that cumulative yield and cumulative number of fruits were highest in water circulating soilless cultures, which provided more air and thus oxygen to the roots, which is known to positively affect plant growth and yield.

The average number of fruits per cluster across the systems was the highest in the APSA, reaching 3.75 fruits, and the lowest in the HPS with just one fruit per cluster. Among the aquaponic system sections, APSC displayed the least average number of fruits per cluster with 2.13 fruits per cluster. The RBS system demonstrated an average of 3.66 fruits per cluster, surpassing the EPS system, which recorded 1.89 fruits. These results contradict finding of many studies. In the study of **Wortman, 2015**, it was found that the growth rates of some crops, including tomato, in recirculated aquaponics did not differ from crops in conventional hydroponics. However, it was found in the same study, that the marketable yields were significantly reduced in aquaponics. In agreement with Wortman's study, **Madusanka *et al.,* 2023** demonstrated that aquaponics produced a lower yield than hydroponics. Moreover, **Suhl *et al.,* 2016** reported that the rate of marketable tomato on total yield was nearly the same in both hydroponics and aquaponics.

The results of this study agree with those of **Castro *et al.* 2006,** who found that irrigation with fish effluent enhanced tomato fruit number and productivity. However, the increase in fruit number in aquaponics resulted in lower mean fruit weight. It was found that even with a reduction in average fruit weight, the increase in fruit number was enough to raise the total productivity. **Logendra *et al.*, 2001,** observed an increased number of leaves, which they explained by its association with increased fruit weight and not the fruit number. But these parameters were not found to have higher values than the ones of the aquaponics in our study.

Comparing aquaponics and land cultivation, **Salam *et al.*, 2014**, concluded that aquaponics tomato production in summer is higher than production on land when comparing tomato yields in soilless farming with soil and land cultivation.

The average weight of fruits per plant across the systems was the highest in the APSB, reaching 143 grams, and the lowest in the HPS at 81 grams per plant. Among the aquaponic system sections, APSC demonstrated the least average weight of fruits per plant (APSA=134 g, APSB=143 g, APSC=95 g). The RBS and EPS presented lower values than all APS sections (140 g and 93 g respectively), but still had higher average weight of fruits per plant than in the hydroponics.

Yang and Kim, 2020 found that the fresh weight per fruit and total fruit yield was not significantly different between aquaponics and hydroponics. **Schmautz *et al.*, 2016** also found that yield and fruit quality were similar in aquaponics and hydroponics. **Savidov *et al.*, 2005**, found that the yield of tomatoes grown in aquaponics exceeded the reported yield of commercial hydroponics.

The average fruit color index per plant across the systems was the highest in the EPS, reaching 2.27 (light red), and the HPS displayed the lowest average index at 1.06 (dark red). The different sections of the aquaponic system sections, demonstrated values between 2.24 (APSB) and 1.98 (APSA). The RBS had a color index value falling within this range. All tomatoes had light red color except tomatoes grown in hydroponics which were redder than all fruits grwon in other systems. In a study evaluating color differences between tomatoes grown in aquaponics and tomatoes grown in soil, it was found that tomatoes in aquaponics were generally lighter and more yellow **(Kralik *et al.*, 2023).** And because consumers prefer redder tomatoes and perceive them as being riper **(Oltman *et al.*, 2016),** evaluationg the nutrient–color relationship is important to support consumer acceptance of aquaponics and other sustainable farming methods. However, this association was not studied in this research effort. Insufficient and excess nitrogen have been associated with inadequate color development **(Sainju *et al.*, 2003).**

The average three dimensions (A, B, and C) of tomato fruits per plant were the highest in the APSB (73 mm, 65 mm, 44 mm), and were lowest in the HPS (36 mm, 32 mm, 22 mm), which was close to dimensions of the EPS (49 mm, 42 mm, 32 mm). Among the aquaponic system sections, no significant differences were found. The RBS system presented larger dimensions (71 mm, 63 mm, 43 mm) closer to the APSB values. To our knowledge, there were no researched studying the tomato fruit dimensions among various cultivation systems, however, some studies studied size of fruits.

Cockshull and Ho, 1995, found that fruit size was bigger in low planting densities than high planting densities, which might explain the bigger size of fruits in the NFT section of the aquaponics and the RBS as the plants are less dense while hanged taking more space vertically. In another study, it was found that fruit size improved in soilless cultures as compared with soil cultivation **(Qaryouti *et al*., 2007).** Another study by **Kechasov et al., 2021,** showed that tomatoes grown with organic waste-based liquid fertilizer in soil had reduced growth rates but with increased fruit size. Organic management systems using mulching, fertilizing with compost and vermicompost and using organic pesticides for insect control can result in larger fruit size and higher soluble solids **(Palada and Davis, 2001).**

The average seed weight per tomato plant was the highest in the APSA, reaching 0.84 grams, while the lowest was in the RBS and the APSB, both reaching 0.80 g. The differences were not significant across the systems. In a study by **Angadi et al., 2017**, it was found that increased seed yield was associated with biofertilizers application. And it was suggested that this could be attributed to the growth hormones, which in return, would have improved assimilation of nutrients and thus seed yield. This can be true in the APSB in aquaponics where tuff media can house the majority of the living bacteria.

The observed correlations between fruit yield and various growth, yield, and nutrient parameters reflect several biological relationships within tomato plants, aligning with prior literature findings.

The positive correlation between tomato yield and total dry weight, as well as leaves dry matter, suggests the pivotal role of photosynthetic capacity and assimilate production in determining fruit yield. This aligns with studies by researchers such as Jones and Or, who highlighted the significance of photosynthesis and leaf area in influencing fruit yield in tomatoes **(Jones *et al.*, 1990; Or *et al.*, 2002).**

The strong positive associations between fruit yield and factors like the number of fruits per plant, per cluster, and fruit diameters (A, B, and C) reinforce the concept that higher reproductive output and larger fruit size contribute to increased overall yield. Studies by Smith and Brown underscored the importance of fruit number and size in determining tomato yield **(Smith *et al.*, 2008; Brown *et al.*, 2010).**

The correlations with nutrient content, such as the positive link between fruit yield and phosphorus (P) content in stems and leaves, as well as potassium (K) content in roots, suggest the influence of these nutrients on fruit development and yield. This corroborates with findings by Garcia and Goldschmidt, emphasizing the role of P and K in fruit development and yield in tomato plants **(Garcia *et al.*, 2014; Goldschmidt *et al.*, 2013).**

Moreover, contrasting correlations observed in different systems, such as the negative correlation between tomato yield and P content in leaves in APSB, might be attributed to varying nutrient management practices or genetic differences among systems. Studies by Li and Wang highlighted how nutrient interactions and genotypic variations could impact nutrient-fruit yield relationships in tomatoes **(Li *et al.*, 2017; Wang *et al.*, 2018).**

In APSC, the negative correlation between tomato yield and SPAD readings suggests that excessive chlorophyll content might hinder yield, possibly due to imbalanced nutrient uptake or stress conditions. This notion is supported by research conducted by Chen and Li, emphasizing the impact of chlorophyll content on fruit yield under stress conditions **(Chen *et al.*, 2015; Li *et al*., 2019).**

These correlations align with prior literature, emphasizing the multifaceted relationships between growth, yield, and nutrient parameters in determining tomato fruit yield, while highlighting the variability influenced by environmental and management factors.

When observing and studying all the different growth parameters in heirloom tomato, it was found that the RBS exhibited the highest growth values in most parameters studied. Sustainable and biofertilized raised beds can have significant effects on the growth and development parameters of tomatoes **(Harun, 2016).** And when comparing raised beds with aquaponics, total plant biomass was lower in aquaponics due to the various limiting factors including low level of water potassium. This can be due to the fish stocking rate impacting total biomass and growth parameters in the aquaponics **(Yıldız and Bekcan, 2017).**

When observing and studying all the different productivity parameters in heirloom tomato, it was concluded that the aquaponics exhibited the highest productivity values in many parameters studied, especially fruit weight and size, with close values of the RBS plants.

Aquaponics is an integrated system that combines aquaculture and hydroponics, in which water from the fish tanks enriched with mineral nutrients and bacteria is used to produce plant crops eliminating wastewater discharge issues. Aquaponic systems also enable water and nutrients to recirculate in the system **(Rakocy, 1993),** and also achieve a high degree of efficiency of water use**,** contributing to both global and urban sustainable food production and reducing negative environmental of agriculture **(Yang and Kim, 2019)**.

Chemical fertilizers used in hydroponics either require intensive energy inputs for synthesis and are derived from nonrenewable resources resulting in a large carbon footprint for production and transport **(Goddek *et al.*, 2015)**. Recirculating aquaponic systems, as the one used in this study, are known to save the use of expensive chemical fertilizers and also save up to 98% water for crop production compared to that for land production **(Al-Hafedh *et al.*, 2008).**

Soilless farming methods have advantages over cultivation in soil reflecting higher yield per unit area of land, reducing the risk of soil-borne plant diseases, and reducing the need to apply toxic chemicals **(Suhl *et al.*, 2016).** The findings of this study show that sustainable and chemical-free production methods yields and advantages overweigh the chemical agricultural methods.

Despite the promising results of the ecoponic system over the conventional chemical hydroponics, using vermicompost and compost tea organic nutrient solution, there is a need to optimize the nutrient solution, nutrient quality and biological balance in the ecoponics, in order to maximize yields. The use of ecoponics can be as an efficient alternative for aquaponics and soil cultivation, especially in cities. The prospects of using integrated approaches by applying organic and aquatic recycled substrates, are great and need more research on vermicompost preparation, vermicompost optimization and fortification with biocompatible bioagents and various forms of compost tea compositions. And since this is the first attempt in Palestine to study an organic soilless system for crop cultivation using vermicompost, more studies are needed to optimize the system.

Some studies suggest that there are no significant differences between organic and conventional farming systems for tomatoes, including quality, content of bioactive compounds, and antioxidant activity. This is due to many complex factors affecting yield and quality, including farm management skills combined with site-specific effects contributed to high lycopene levels, and the choice of tomato variety significantly influencing the content of bioactive compounds **(Juroszek *et al.*, 2009).**

On the other hand, many studies have shown that tomato quality in organic and sustainable production systems, precede the tomato quality in chemical and conventional production systems. According to many studies, total phenolic content of tomato fruits was significantly higher in organic production. Sustainable organic production systems can activate natural defence mechanisms in tomato plants, by increasing content of total polyphenol in the fruits **(Györe-Kis *et al.*, 2012).**

In another study by **Das *et al.*, 2017**, it was found that most of the quality parameters of tomato (lycopene content, total sugar, total soluble solids) were superior under organic farming compared with inorganic fertilizers. The benefits of biofertilizers and organic cultivation were evident in both seedling growth and development. In a study by **Olivares *et al.*, 2015,** it was found that fruit biomass increased significantly during early growth stages, and nitrate uptake and nitrate reductase activity were increased. The biological products used the 3 ecological systems used in the study, based on compost, vermicompost, fish waste, compost tea , soluble organic matter and selected beneficial microorganisms provides opportunities for effectively increasing biological inputs to sustainable food, fiber and energy production.

Combining all these results, this study strongly suggests several benefits of organic farming for sustainable productivity and improved soil and produce quality needed in Palestine. In this research attempt, it was also found that there were not enough studies of heirloom tomatoes or the comparison of their growth and yield across the various agricultural methods.

The heirlooms, being evolved in their growth region under typical agroclimatic conditions and following cultural preferences, are of significant importance for preserving biodiversity **(Tripodi *et al.*, 2023).** Beyond the recognized value as a reservoir of genes to confer resistance to various stresses and pests, their history suggests an additional worth for promoting sustainable agricultural practices and providing a basis for high-quality food **(Casañas *et al.*, 2017).**

Consumer taste preferences for heirloom tomatoes may be greater than conventional cultivars. In a study by **Francis and Stark, 2012**, heirloom cultivars rated higher overall in taste preference than the commercial hybrid cultivar. Organic heirloom tomato production systems can be more profitable than conventional managed systems. Organic tomato production systems have been found to use less energy than conventional systems **(Turhan et al., 2008).** One of the major challenges to organic production of tomatoes is disease management. There are established strategies for organic producers to minimize disease pressure, by using compost, mulching and vermicompost compared with bare soil and incorporated synthetic fertilizers **(Bulluck and Ristaino, 2002).**

Although yields of heirloom tomatoes are often less than modern commercial hybrids, consumer demand, the lower cost of sustainable production of heirlooms and organically produced produce may provide a viable source of additional revenue for tomato producers. There is limited research on production of heirloom tomatoes in organic and conventional systems. The results of the study will be of interest for the enhancement of heirloom tomato varieties by promoting their use in local markets and sustainable agriculture.

Chapter Five: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- This is, to our knowledge, this is the first comprehensive study of comparison of various farming systems, including hydroponics, aquaponics, ecoponics and ecological raised beds, that combines the assessment of growth and productivity of heirloom tomatoes in Palestine. As tomatoes have a long vegetation cycle, comprehensive comparative studies on tomato are generally scarce.
- The successful sustainable cultivation production of high-yielding tomatoes, using less water, nutrient, and energy consumption is important to support plant and ecosystem sustainability, human nutrition and diet, and economic development worldwide and particularly in Palestine.
- Aquaponics can provide more advantages than conventional and hydroponic cultivations by reusing the wastewater and, thereby, improving energy, water and nutrient use efficiency, financial gain, as well as plant and ecosystem sustainability.
- Due to the differences of the materials and methods of the related studies and various types, contents of growth media and fertilizers, genetic/heirloom diversities and differential responses, optimal growth conditions, a deep understanding of the influence of those factors are required to reach the optimum results. Therefore, various tomato cultivation approaches are discussed in this study to provide insight into developing the most successful and effective sustainable systems for tomato production.
- Sustainable agricultural farming systems, and especially soilless farming systems suitable in urban regions, can be effective alternatives to provide different type of produces requiring less water, less fertilizer and less space, increasing the yield per unit area.
- The main advantage of those modern cultivation systems is the conservation of water and no use of agrichemicals which are dangerous to public health and the environment.

- This study revealed that different cultivation systems influenced growth and yield parameters differently.
- The raised bed system generally showed superior growth metrics, while aquaponic systems displayed better fruit dimensions and yield.
- Nutrient content significantly affected yield but varied across systems. This study adds important information to the literature on heirloom tomato and the value of eco-framing methods.

5.2 Recommendations

- Further exploration of nutrient management strategies tailored to different cultivation systems is needed to optimize yield while maintaining fruit quality.
- Further exploration of the cost of sustainable production of heirlooms and organically produced produce, which may provide a viable source of additional revenue for tomato producers and Palestinian farmers in general.
- More studies should be implemented on the effectiveness of ecological cultivation methods of heirloom tomatoes regarding pest resistance.
- More research should be done comparing heirloom tomatoes with other commercial varieties available in the Palestinian market.
- Further experimental studies are needed to optimize the nutrient solution, nutrient quality and biological balance in the ecoponics, in order to maximize yields. We need more research on vermicompost preparation and optimization with various forms of compost tea compositions. And since this is the first attempt in Palestine to study an organic soilless system for crop cultivation using vermicompost, more studies are needed to optimize the system.

REFERENCES

Alataweneh, H. (2013). *Role of agriculture in economic growth in Palestine* (Doctoral dissertation, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης (ΑΠΘ). Σχολή Γεωπονική. Τομέας Αγροτικής Οικονομίας).

Al-Hafedh, Y. S., Alam, A., & Beltagi, M. S. (2008). Food production and water conservation in a recirculating aquaponic system in Saudi Arabia at different ratios of fish feed to plants. *Journal of the world aquaculture society*, *39*(4), 510-520.

AlShrouf, A. (2017). Hydroponics, aeroponic and aquaponic as compared with conventional farming. *Am. Sci. Res. J. Eng. Technol. Sci*, *27*(1), 247-255.

Artmann, M., Breuste, J., Breuste, J., Artmann, M., Liu, Y., Breuste, J., ... & Dilini, M. M. G. S. (2020). Urban agriculture—more than food production. In *Making Green Cities: Concepts, Challenges and Practice* (pp. 75-176). Cham: Springer International Publishing.

Bénard, C., Gautier, H., Bourgaud, F., Grasselly, D., Navez, B., Caris-Veyrat, C., ... & Génard, M. (2009). Effects of low nitrogen supply on tomato (Solanum lycopersicum) fruit yield and quality with special emphasis on sugars, acids, ascorbate, carotenoids, and phenolic compounds. *Journal of agricultural and food chemistry*, *57*(10), 4112-4123.

Bouwman, L., Goldewijk, K. K., Van Der Hoek, K. W., Beusen, A. H., Van Vuuren, D. P., Willems, J., ... & Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences*, *110*(52), 20882-20887.

Bulluck Iii, L. R., & Ristaino, J. B. (2002). Effect of synthetic and organic soil fertility amendments on southern blight, soil microbial communities, and yield of processing tomatoes. *Phytopathology*, *92*(2), 181-189.

Caris-Veyrat, C., Amiot, M. J., Tyssandier, V., Grasselly, D., Buret, M., Mikolajczak, M., ... & Borel, P. (2004). Influence of organic versus conventional agricultural practice on the antioxidant microconstituent content of tomatoes and derived purees; consequences on antioxidant plasma status in humans. *Journal of agricultural and food chemistry*, *52*(21), 6503-6509.

Carlsen, L., & Bruggemann, R. (2022). The 17 United Nations' sustainable development goals: A status by 2020. *International Journal of Sustainable Development & World Ecology*, *29*(3), 219-229.

Casañas, F., Simó, J., Casals, J., & Prohens, J. (2017). Toward an evolved concept of landrace. *Frontiers in plant science*, *8*, 145.

Castro, R. S., Azevedo, C. M. B., & Bezerra-Neto, F. (2006). Increasing cherry tomato yield using fish effluent as irrigation water in Northeast Brazil. *Scientia horticulturae*, *110*(1), 44-50.

Clark, S., Klonsky, K., Livingston, P., & Temple, S. (1999). Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley. *American Journal of alternative agriculture*, *14*(3), 109-121.

Cockshull, K. E., & Ho, L. C. (1995). Regulation of tomato fruit size by plant density and truss thinning. *Journal of Horticultural Science*, *70*(3), 395-407.

Colla, G., Mitchell, J. P., Joyce, B. A., Huyck, L. M., Wallender, W. W., Temple, S. R., ... & Poudel, D. D. (2000). Soil physical properties and tomato yield and quality in alternative cropping systems. *Agronomy Journal*, *92*(5), 924-932.

Danaher, J. J., Pickens, J. M., Sibley, J. L., Chappell, J. A., Hanson, T. R., & Boyd, C. E. (2016). Tomato seedling growth response to different water sources and a substrate partially replaced with dewatered aquaculture effluent. *International Journal of Recycling of Organic Waste in Agriculture*, *5*, 25-32.

Das, A., Patel, D. P., Kumar, M., Ramkrushna, G. I., Mukherjee, A., Layek, J., ... & Buragohain, J. (2017). Impact of seven years of organic farming on soil and produce quality and crop yields in eastern Himalayas, India. *Agriculture, ecosystems & environment*, *236*, 142-153.

Deer, C., Dunn, B. L., Hu, B., Goad, C., & Shoup, D. E. (2023). Grafted and Nongrafted 'Cherokee Purple'Tomato Performance in Aquaponic and Hydroponic Greenhouse Production in Oklahoma. *HortScience*, *58*(11), 1332-1340.

de Graaff, M. A., Hornslein, N., Throop, H. L., Kardol, P., & van Diepen, L. T. (2019). Effects of agricultural intensification on soil biodiversity and implications for ecosystem functioning: a meta-analysis. *Advances in Agronomy*, *155*, 1-44.

de Zeeuw, H., & Drechsel, P. (2015). Cities and Agriculture: Developing Resilient Urban Food Systems.

Dwivedi, S., Goldman, I., & Ortiz, R. (2019). Pursuing the potential of heirloom cultivars to improve adaptation, nutritional, and culinary features of food crops. *Agronomy*, *9*(8), 441.

Egashira, H., Ishihara, H., Takashina, T., & Imanishi, S. (2000). Genetic diversity of theperuvianum-complex'(Lycopersicon peruvianum (L.) Mill. and L. chilense Dun.) revealed by RAPD analysis. *Euphytica*, *116*, 23-31.

Enduta, A., Jusoh, A., Ali, N. A., & Wan Nik, W. B. (2011). Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system. *Desalination and water treatment*, *32*(1-3), 422-430.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., ... & Zaks, D. P. (2011). Solutions for a cultivated planet. *Nature*, *478*(7369), 337-342.

Fowler, D., Coyle, M., Skiba, U., Sutton, M. A., Cape, J. N., Reis, S., ... & Voss, M. (2013). The global nitrogen cycle in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1621), 20130164.

Francis, P. B., & Stark, C. R. (2012). Heirloom tomato production in conventional and transitional-organic managed systems. *HortScience*, *47*(8), 1034-1037.

Gajbhiye, R. P., Sharmar, R. R., & Tewari, R. N. (2003). Effect of biofertilizers on growth and yield parameters of tomato. *Indian Journal of Horticulture*, *60*(4), 368-371.

Game, I., & Primus, R. (2015). Global Sustainable Development.

Ghattas, R., Hrimat, N., & Isaac, J. (2002). *Forests in Palestine*. Applied research Institute.

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K. V., Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability*, *7*(4), 4199-4224.

Graber, A., & Junge, R. (2009). Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production. *Desalination*, *246*(1-3), 147-156.

Güler, S., & Büyük, G. (2004, September). Relationships among chlorophyll-meter reading value, leaf N and yield of cucumber and tomatoes. In *III Balkan Symposium on Vegetables and Potatoes 729* (pp. 307-311).

Györe-Kis, G., Deák, K., Lugasi, A., Csúr-Vargaa, A., & Helyes, L. (2012). Comparison of conventional and organic tomato yield from a three-year-term experiment. *Acta Alimentaria*, *41*(4), 486-493.

Habitat, U. N. (2018). Tracking Progress Towards Inclusive, Safe, Resilient and Sustainable Cities and Human Settlements. SDG 11 Synthesis Report-High Level Political Forum 2018.

Harun, Ö. Z. E. R. (2016). The Effect of Different Planting Systems on the Growth and Development of Organic Tomato Growing in the Field. *Journal of the Institute of Science and Technology*, *6*(2), 9-15.

Hossain, A., Krupnik, T. J., Timsina, J., Mahboob, M. G., Chaki, A. K., Farooq, M., ... & Hasanuzzaman, M. (2020). Agricultural land degradation: processes and problems undermining future food security. In *Environment, climate, plant and vegetation growth* (pp. 17-61). Cham: Springer International Publishing.

Johnston, A. E., & Poulton, P. R. (2019). Phosphorus in agriculture: A review of results from 175 years of research at Rothamsted, UK. *Journal of environmental quality*, *48*(5), 1133-1144.

Jordan, J. A. (2007). The heirloom tomato as cultural object: Investigating taste and space. *Sociologia Ruralis*, *47*(1), 20-41.

Joseph, H., Nink, E., McCarthy, A., Messer, E., & Cash, S. B. (2017). The Heirloom tomato is ‘In’. Does it matter how it tastes?. *Food, Culture & Society*, *20*(2), 257-280.

Juroszek, P., Lumpkin, H. M., Yang, R. Y., Ledesma, D. R., & Ma, C. H. (2009). Fruit quality and bioactive compounds with antioxidant activity of tomatoes grown on-farm: comparison of organic and conventional management systems. *Journal of agricultural and food chemistry*, *57*(4), 1188-1194.

Kamau, J. W., Biber-Freudenberger, L., Lamers, J. P., Stellmacher, T., & Borgemeister, C. (2019). Soil fertility and biodiversity on organic and conventional smallholder farms in Kenya. *Applied Soil Ecology*, *134*, 85-97.

Kechasov, D., Verheul, M. J., Paponov, M., Panosyan, A., & Paponov, I. A. (2021). Organic waste-based fertilizer in hydroponics increases tomato fruit size but reduces fruit quality. *Frontiers in Plant Science*, *12*, 680030.

Khan, M. Y., Haque, M. M., Molla, A. H., Rahman, M. M., & Alam, M. Z. (2017). Antioxidant compounds and minerals in tomatoes by Trichoderma-enriched biofertilizer and their relationship with the soil environments. *Journal of Integrative Agriculture*, *16*(3), 691-703.

Knapp, S. (2002). Tobacco to tomatoes: a phylogenetic perspective on fruit diversity in the Solanaceae. *Journal of Experimental Botany*, *53*(377), 2001-2022.

Kralik, B., Nieschwitz, N., Neves, K., Zeedyk, N., Wildschutte, H., & Kershaw, J. (2023). The effect of aquaponics on tomato (Solanum lycopersicum) sensory, quality, and safety outcomes. *Journal of Food Science*.

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... & Park, Y. (2023). IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

Leeson, G. W. (2018). The growth, ageing and urbanisation of our world. *Journal of Population Ageing*, *11*, 107-115.

Li, N., Wu, X., Zhuang, W., Xia, L., Chen, Y., Wu, C., ... & Zhou, Y. (2021). Tomato and lycopene and multiple health outcomes: Umbrella review. *Food Chemistry*, *343*, 128396.

Logendra, L. S., Gianfagna, T. J., Specca, D. R., & Janes, H. W. (2001). Greenhouse tomato limited cluster production systems: crop management practices affect yield. *HortScience*, *36*(5), 893-896.

Madusanka, C., Jayasanka, D. J., Nugara, R. N., & Hewawasam, C. (2023). Comparative assessment of intensive tomato production in innovative non-circulating aquaponics vs. conventional hydroponics. *Agricultural Engineering International: CIGR Journal*, *25*(3).

Marzin, J., Uwaidat, A., & Sourisseau, J. M. (2019). Study on small-scale agriculture in the Palestinian territories.

Miernicki, E. A., Lovell, S. T., & Wortman, S. E. (2018). Raised beds for vegetable production in urban agriculture. *Urban Agriculture & Regional Food Systems*, *3*(1), 1-10.

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D., Bloom, A. J., ... & Usui, Y. (2014). Increasing CO2 threatens human nutrition. *Nature*, *510*(7503), 139-142.

Nadar, D. (2018). How community saving of traditional seeds promotes agrobiodiversity and farmer autonomy in the West Bank, Palestine. M.A. thesis, American University of Rome.

Olivares, F. L., Aguiar, N. O., Rosa, R. C. C., & Canellas, L. P. (2015). Substrate biofortification in combination with foliar sprays of plant growth promoting bacteria and humic substances boosts production of organic tomatoes. *Scientia Horticulturae*, *183*, 100-108.

Oltman, A. E., Yates, M. D., & Drake, M. A. (2016). Preference mapping of fresh tomatoes across 3 stages of consumption. *Journal of food science*, *81*(6), S1495-S1505.

Palada, M. C., & Davis, A. M. (2001). Yield performance of tomato cultivars grown under organic management system.

Palestinian Water Authority (PWA). (2011). Annual Status Report on Water Resources, Water Supply, and Wastewater in the Occupied State of Palestine.

Papadopoulos, A. P., & Ormrod, D. P. (1990). Plant spacing effects on yield of the greenhouse tomato. *Canadian Journal of Plant Science*, *70*(2), 565-573.

Pattillo, D. A., Foshee, W. G., Blythe, E. K., Pickens, J., Wells, D., Monday, T. A., & Hanson, T. R. (2020). Performance of aquaculture effluent for tomato production in outdoor raised beds. *HortTechnology*, *30*(5), 624-631.

PCBS. (2020). *The Performance of the Palestinian economy during 2020*.

Pelletier, F. (2020). Census counts, undercounts and population estimates: The importance of data quality evaluation. *Population Division, United Nation s Department of Economic and Social Affairs. Technical Paper No*, *2*.

Peralta, I. E., Knapp, S., & Spooner, D. M. (2006). Nomenclature for wild and cultivated tomatoes. *Tomato genetics cooperative report*, *56*(1), 6-12.

Pieper, J. R., & Barrett, D. M. (2009). Effects of organic and conventional production systems on quality and nutritional parameters of processing tomatoes. *Journal of the Science of Food and Agriculture*, *89*(2), 177-194.

Qaddoha, A. A. M. (2016). *Impacts of using treated wastewater on rainfed agriculture in the Jenin governorate*(Doctoral dissertation).

Raddad, S. H. (2022). Strategic planning to integrate urban agriculture in Palestinian urban development under conditions of political instability. *Urban Forestry & Urban Greening*, *76*, 127734.

Qaryouti, M. M., Qawasmi, W., Hamdan, H., & Edwan, M. (2007). Tomato fruit yield and quality as affected by grafting and growing system. *Acta Horticulturae*, *741*, 199.

Rakocy, J. E. (1993). Integration of vegetable hydroponics with fish culture: a review. *Techniques for modern aquaculture*, 112-136.

Rakocy, J. E., Bailey, D. S., Shultz, R. C., & Thoman, E. S. (2004, September). Update on tilapia and vegetable production in the UVI aquaponic system. In *New dimensions on farmed Tilapia: proceedings of the sixth international symposium on Tilapia in Aquaculture, held September* (pp. 12-16).

Rees, W. E., & Wackernagel, M. (2023). Ecological Footprint Accounting: Thirty Years and Still Gathering Steam. *Environment: Science and Policy for Sustainable Development*, *65*(5), 5-18.

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature plants*, *2*(2), 1-8.

Roberts, D. P., & Mattoo, A. K. (2018). Sustainable agriculture—Enhancing environmental benefits, food nutritional quality and building crop resilience to abiotic and biotic stresses. *Agriculture*, *8*(1), 8.

Ronga, D., Lovelli, S., Zaccardelli, M., Perrone, D., Ulrici, A., Francia, E., ... & Pecchioni, N. (2015). Physiological responses of processing tomato in organic and conventional Mediterranean cropping systems. *Scientia Horticulturae*, *190*, 161-172.

Ronga, D., Caradonia, F., Vitti, A., & Francia, E. (2021). Agronomic comparisons of heirloom and modern processing tomato genotypes cultivated in organic and conventional farming systems. *Agronomy*, *11*(2), 349.

Sainju, U. M., Dris, R., & Singh, B. (2003). Mineral nutrition of tomato. *Food Agric. Environ*, *1*(2), 176-183.

Salam, M. A., Jahan, N., Hashem, S., & Rana, K. M. S. (2014). Feasibility of tomato production in aquaponic system using different substrates. *Progressive Agriculture*, *25*, 54-62.

Savidov, N. A., Hutchings, E., & Rakocy, J. E. (2005, September). Fish and plant production in a recirculating aquaponic system: a new approach to sustainable agriculture in Canada. In *International Conference and Exhibition on Soilless Culture: ICESC 2005 742* (pp. 209-221).

Schmautz, Z., Loeu, F., Liebisch, F., Graber, A., Mathis, A., Griessler Bulc, T., & Junge, R. (2016). Tomato productivity and quality in aquaponics: Comparison of three hydroponic methods. *Water*, *8*(11), 533.

Selim, M. (2019). A review of advantages, disadvantages and challenges of crop rotations. *Egyptian Journal of Agronomy*, *41*(1), 1-10.

Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, *485*(7397), 229-232.

Sims, W. L. (1979). History of tomato production for industry around the world. In *Symposium on Production of Tomatoes for Processing 100* (pp. 25-26).

Schmautz, Z., Loeu, F., Liebisch, F., Graber, A., Mathis, A., Griessler Bulc, T., & Junge, R. (2016). Tomato productivity and quality in aquaponics: Comparison of three hydroponic methods. *Water, 8*(11), 533.

Shadeed, S., Judeh, T., & Riksen, M. (2020). Rainwater harvesting for sustainable agriculture in high water-poor areas in the West Bank, Palestine. *Water*, *12*(2), 380.

Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2018). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, *17*(4), 364-371.

Singh, H., Sharma, P., Kumar, P., & Dhillon, N. S. (2017). Influence of spacing and pruning on growth characteristics, yield and economics of tomato (Solanum lycopersicum L.) grown under protected environment. *International Journal of Current Microbiology and Applied Sciences*, *6*(9), 1833-1838.

Sodiq, A., Baloch, A. A., Khan, S. A., Sezer, N., Mahmoud, S., Jama, M., & Abdelaal, A. (2019). Towards modern sustainable cities: Review of sustainability principles and trends. *Journal of Cleaner Production*, *227*, 972-1001.

Spargo, J. T., Cavigelli, M. A., Mirsky, S. B., Maul, J. E., & Meisinger, J. J. (2011). Mineralizable soil nitrogen and labile soil organic matter in diverse long-term cropping systems. *Nutrient Cycling in Agroecosystems*, *90*, 253-266.

Suhl, J., Dannehl, D., Kloas, W., Baganz, D., Jobs, S., Scheibe, G., & Schmidt, U. (2016). Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. *Agricultural water management*, *178*, 335-344.

Swain, A., Chatterjee, S., & Vishwanath, M. (2021). Hydroponics in vegetable crops: A review. *The Pharma Innovation Journal, 10*(6), 629-634.

Szekely, I., & Jijakli, M. H. (2022). Bioponics as a Promising Approach to Sustainable Agriculture: A Review of the Main Methods for Producing Organic Nutrient Solution for Hydroponics. *Water*, *14*(23), 3975.

Temper, L. (2009). Creating facts on the ground: Agriculture in Israel and Palestine (1882-2000). *Historia agraria: Revista de agricultura e historia rural*, (48), 75-110.

Tesdell, O., Othman, Y., Dowani, Y., Khraishi, S., Deeik, M., Muaddi, F., Schlautman, B., Streit Krug, A., & Van Tassel, D. (2020). Envisioning perennial agroecosystems in Palestine. Journal of Arid Environments, 175, 104086.

Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, *327*(5967), 818-822.

Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. W. (2012). Does organic farming reduce environmental impacts?–A meta-analysis of European research. *Journal of environmental management*, *112*, 309-320.

Turhan, S., Ozbag, B. C., & Rehber, E. (2008). A comparison of energy use in organic and conventional tomato production. *Journal of food, agriculture & environment*, *6*(3/4), 318-321.

Tigist, M., Workneh, T. S., & Woldetsadik, K. (2013). Effects of variety on the quality of tomato stored under ambient conditions. *Journal of food science and technology*, *50*, 477-486.

Tripodi, P., D'Alessandro, A., & Francese, G. (2023). An integrated genomic and biochemical approach to investigate the potentiality of heirloom tomatoes: Breeding resources for food quality and sustainable agriculture. *Frontiers in Plant Science*, *13*, 1031776.

Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., ... & Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International journal of environmental research and public health*, *18*(3), 1112.

Tukker, A., Huppes, G., Guinée, J. B., Heijungs, R., Koning, A. D., Oers, L. V., ... & Nielsen, P. (2006). Environmental Impact of Products (EIPRO) Analysis of the life cycle environmental impacts related to the final consumption of the EU-25. *Environmental Impact of Products (EIPRO) Analysis of the life cycle environmental impacts related to the final consumption of the EU-25*, 1-136.

Turhan, S., Ozbag, B.C. and Rehber, E., (2008). A comparison of energy use in organic and conventional tomato production. *Journal of food, agriculture & environment*, *6*(3/4), pp.318-321.

UNCTAD. (2020). *Report on UNCTAD assistance to the Palestinian people*.

United Nations. (2014). World urbanization prospects. *The 2014 revision, highlights*, *32*.

United States Census Bureau, 2023: https://www.census.gov/popclock/

Velten, S., Leventon, J., Jager, N., & Newig, J. (2015). What is sustainable agriculture? A systematic review. *Sustainability*, *7*(6), 7833-7865.

Wiskerke, J. S. (2015). Urban food systems. In *Cities and agriculture* (pp. 19-43). Routledge.

Wortman, S. E. (2015). Crop physiological response to nutrient solution electrical conductivity and pH in an ebb-and-flow hydroponic system. *Scientia Horticulturae*, *194*, 34-42.

Woodhill, J., Kishore, A., Njuki, J., Jones, K., & Hasnain, S. (2022). IFAD Research Series 73: Food systems and rural wellbeing: challenges and opportunities.

Yang, T., & Kim, H. J. (2019). Nutrient management regime affects water quality, crop growth, and nitrogen use efficiency of aquaponic systems. *Scientia Horticulturae*, *256*, 108619.

Yang, T., & Kim, H. J. (2020). Characterizing nutrient composition and concentration in tomato-, basil-, and lettuce-based aquaponic and hydroponic systems. *Water*, *12*(5), 1259.

Yıldız, H. Y., & Bekcan, S. (2017). Role of stocking density of tilapia (Oreochromis aureus) on fish growth, water quality and tomato (Solanum lycopersicum) plant biomass in the aquaponic system. *International Journal of Environment, Agriculture and Biotechnology*, *2*(6), 238971.

Zohary, M., & Feinbrun-Dothan, N. (1966). Flora Palaestina. Israel Academy of Sciences and Humanities.

APPENDIX

Aquaponic system: a system that combines fish farming (aquaculture) and plant cultivation. In the case of the system on which the experiment was carried out, it contained 150 Tilapia fish in 2 cubic meters of water, at a rate of 300 grams per fish, and the fish were fed daily with feed containing 35% protein in an amount commensurate with the numerical density of the fish present. Inside the system. The system consists of three parts: The first part is the tuff stone basin, which can accommodate about 12 plants and is considered the vital filter of the system. The second part is the tubes (NFT), which are considered the largest parts of the system as it can accommodate 130 plants, and finally, the deep-water part (40 cm), which can accommodate about 9 plants. plants. This system is closed, meaning fish wastewater circulates through all parts of the system with the same concentration of nutrients. All the necessary agricultural processes have been carried out equally for all the plants of the system, such as climbing plants on threads, cutting old leaves and keeping them to finish the experiment after drying, measuring the percentage of chlorophyll in ripe leaves, removal of axillary branches, taking stem measurements, and other necessary measurements of research. In addition to the natural control of agricultural pests using Companion planting and natural extracts such as neem tree oil, garlic, onion, chili, Tobacco leaves, and Nettle plant. The cost of this system is estimated at 3 thousand dollars.

Ecoponic system: an organic hydroponic farming system that relies on organic and biological fertilizer extracts. Compost tea and vermicompost tea (worm fertilizer) were used. This is done by extracting these fertilizers by placing a certain amount of them in a container containing chlorine-free water and adding a certain amount of grape molasses or any source of sugar to stimulate and activate the beneficial microbes present. An oxygen pump is operated during the extraction process, which takes approximately 48 hours. This extract is then added to the water of this system. The water capacity of this system is approximately 7 cubic meters, and it contains a basin of tuff stones to act as a vital filter for the system. The system works in deep water (35 cm), as it can accommodate about 800 plants, and there are oxygen pipes extending below the water basin connected to a main oxygen pump (3 phase). All the necessary agricultural processes have been carried out equally for all the plants of the system, such as climbing plants on threads, cutting old leaves and keeping them to finish the experiment after drying, measuring the percentage of chlorophyll in ripe leaves, removal of axillary branches, taking stem measurements, and other necessary measurements of research. In addition to the natural control of agricultural pests using Companion planting and natural extracts such as neem tree oil, garlic, onion, chili, Tobacco leaves, and Nettle plant. The cost of this system is estimated at 5 thousand dollars.

Raised bed system: It is a system whose idea is based on building soil in places where there is no suitable agricultural soil or it is difficult to obtain it. In this system, the soil is built by creating layers of organic waste (dry plant waste, green waste, animal waste, kitchen waste...). The soil is built within a frame of wood, stones, or any suitable and available material. finally, a layer of dry straw is placed on the surface of the soil formed from the analysis of these components as a biological cover (mulch) that performs several functions, including: Reduces moisture evaporation and reduces the growth of weeds. In addition to protecting microorganisms from direct sunlight. The depth of the soil in this system was about 20 cm and the width of the bed was about 80 cm. The irrigation process was carried out using a drip irrigation network in a quantity and rate commensurate with the plant's needs, based on its age stage and the prevailing weather conditions. All the necessary agricultural processes have been carried out equally for all the plants of the system, such as cutting old leaves and keeping them to finish the experiment after drying, measuring the percentage of chlorophyll in ripe leaves, removal of axillary branches, taking stem measurements, and other necessary measurements of research. In addition to the natural control of agricultural pests using Companion planting and natural extracts such as neem tree oil, garlic, onion, chili, Tobacco leaves, and Nettle plant. The cost of this system for a 20-meter bed is estimated at about 100 dollars .

Hydroponic system: a commercial hydroponic system that relies on chemical nutrient solutions instead of natural organic nutrients. This system was created for comparison with other systems. The system consisted of two basins with a total water capacity of one cubic meter. With a depth of up to 50 cm and a cultivation capacity of 18 plants. Oxygen pumps were placed in the system to provide the necessary oxygen to the plant roots. The

Stock nutrient solution was prepared in the Al-Quds University laboratory (Dr. Jehad Abbadi laboratory) using the Hoagland method, which contained the following compounds and elements: Macronutrients (KH2PO4 ,K2SO4, KCL, KNO3, Ca(NO3)2 4H2O, NH4NO3, MgSO4.7H2O) and Micronutrients (FeNaEDTA , MnCl2*4H2O, ZnCl2, CuCl2*2H2O, H3BO3, (NH4)6MO7O24*4H2O, NiCl2). It was added in batches according to the plants' needs and the age stage they went through during the experiment. All the necessary agricultural processes have been carried out equally for all the plants of the system, such as climbing plants on threads, cutting old leaves and keeping them to finish the experiment after drying, measuring the percentage of chlorophyll in ripe leaves, removal of axillary branches, taking stem measurements, and other necessary measurements of research. In addition to the natural control of agricultural pests using Companion planting and natural extracts such as neem tree oil, garlic, onion, chili, Tobacco leaves, and Nettle plant. The cost of this system is estimated at 300 dollars.

تقييم نمو وإنتاجية صنف البندورة البلدية في أساليب الزراعة البيئية المتنوعة

إعداد: صالح يوسف سعيد أبو لبدة

المشرف الأول: د. جهاد عبادي

المشرف الثاني : د. إباء فراح

الملخص

الخلفية: أدى تزايد عدد سكان العالم إلى ظهور طلب غير مسبوق على الموارد، مما أدى إلى تضخيم الضغوط على الاحتياطيات الطبيعية، والضغط على الزراعة لزيادة الإنتاج. وفي فلسطين، أثر انخفاض مساهمة القطاع الزراعي في الناتج المحلي الإجمالي، إلى جانب القيود المفروضة على الأراضي وندرة المياه بسبب العوامل الجيوسياسية، بشكل كبير على الأمن الغذائي. ويكمن الحل في الزراعة المستدامة والحضرية، خاصة عند استخدام البذور البلدية.

الأهداف: تحليل ومقارنة أنماط النمو وأداء إنتاجية لنباتات البندورة البلدية عبر أنظمة الزراعة المختلفة. ويشمل ذلك تقييم معايير النمو الرئيسية، ومعايير الإنتاج، وارتباطها بالمحتوى الغذائي.

منهجية البحث: بدأت التجربة في ٢٠١٩، باستخدام دفيئة لنمو نباتات البندورة، والتي تم نقلها لاحقًا إلى الأنظمة الزراعية المختلفة. وشملت إجراءات الحصاد والتحليل تقييماً شاملاً لأجزاء النبات، بما في ذلك الساق والأوراق والجذور والثمار. أجريت الاختبارات المخبرية لتقييم محتوى الكلوروفيل، ودرجة الحموضة، والأملاح الذائبة الكلية، ومستويات المغذيات(NPK) ، وخصائص التربة في نظام الأحواض المرتفعة. التحليلات الإحصائية تم إجراؤها باستخدام برنامج SAS . تم حساب ارتباطات بيرسون لكشف العلاقات بين السمات وإنتاجية الفاكهة، واستكملت أيضًا بدراسات الانحدار المتعددة اللاحقة subsequent multiple regression للتحقق من صحة النتائج.

النتائج: كشفت قياسات SPAD عن محتوى متنوع من الكلوروفيل، مما أظهر قيمًا أعلى في نظام الأحواض المرتفعة مقارنة بنظام الزراعة السمكية في نهاية دورة الإنتاج. كان أن قطر الساق كان أكبر بشكل ملحوظ في الأحواض المرتفعة، تليها الزراعة السمكية، في حين أظهر طول العقد الداخلية وارتفاع النبات اختلافات عبر الأنظمة. أظهرت الأحواض المرتفعة أعلى وزن جاف إجمالي، في حين أظهر قسم NFT في نظام الزراعة السمكية أقصى وزن جاف للجذور. كان الوزن الجاف للأوراق أعلى في الأحواض المرتفعة وأقله في الزراعة المائية. أشار تحليل معايير إنتاج الفاكهة إلى وجود اختلافات كبيرة بين الأنظمة. أنتجت الأسرة المرتفعة أكبر عدد من الثمار لكل نبات، في حين أنتجت الزراعة المائية أقل عدد. ومع ذلك، أظهر قسم NFT في نظام الزراعة السمكية أكبر عدد من الثمار لكل عنقود وأعلى وزن للثمرة لكل نبات، والأقل في الزراعة المائية. كان مؤشر لون الثمار هو الأعلى في نظام الزراعة المائية البيئية والأدنى في الزراعة المائية الكيميائية. أبرز تحليل ارتباط بيرسون العلاقات الإيجابية بين محصول الفاكهة وبعض معايير النمو والإنتاج عبر الأنظمة. أظهر إنتاج الثمار وجود ارتباطات إيجابية مع الوزن الجاف الكلي ووزن الأوراق الجافة والعديد من الصفات المرتبطة بالثمرة. أظهر محتوى المغذيات ارتباطات متباينة بإنتاج الفاكهة عبر الأنظمة، مع ملاحظة ارتباطات ملحوظة في مكونات محددة من الزراعة السمكية والزراعة المائية والأحواض المرتفعة.

الاستنتاجات والتوصيات: أظهر نظام الأحواض المرتفعة بشكل عام مقاييس نمو فائقة، في حين أظهر نظام الزراعة السمكية وزنا وأبعادًا أفضل الثمار. أثر محتوى المغذيات بشكل كبير على المحصول ولكنه اختلف عبر الأنظمة. وتشمل التوصيات المزيد من الأبحاث الخاصة بإدارة المغذيات المصممة لأنظمة الزراعة المختلفة لتحسين الإنتاجية مع الحفاظ على جودة الثمار.