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Research Article

Cultivation of Genovese basil (*Ocimum basilicum* L. cv. *Genovese*) in aquaponic and hydroponic systems: A comparative study

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Abstract

Recently, many horticultural crops have been subjected to study under hydroponic and aquaponic conditions, with a view to enhance their productivity. Nevertheless, a comparative analysis of these two soilless cultivation systems has rarely been undertaken, despite the fact that they represent two distinct approaches. This study's objective was to compare between the aquaponic cultivation system and the hydroponic one, with the aim of identifying the most suitable soilless system for cultivating Genovese basil (*O. basilicum* L. cv. *Genovese*). For the purpose of this study, a factorial randomized complete block with three repetitions was conducted. It was carried out at the National Agronomic Institute of Tunisia under glasshouse conditions. Accordingly, the variation of the soilless cultivation systems effects was determined by measuring and evaluating plant growth, biomass production and photosynthetic performance of basil. Main results showed that plant height (25.69 ± 2.87 cm/plant), length of internodes (2.47 ± 0.17 cm/plant) and leaves number (10.89 ± 1.02 leaves/plant), fresh and dry weight of shoots (9.17 ± 0.49 g and 1.03 ± 0.05 g, respectively) and roots (5.22 ± 0.14 g and 0.37 ± 0.03 g, respectively) were significantly higher in aquaponically grown plants in comparison to hydroponics. However, no significant differences were noted between aquaponics and hydroponics regarding the shoot and root dry matter contents. In addition, the content of chlorophyll a (44.59 ± 3.42 $\mu g \cdot mg^{-1}$ FW) and the efficiency of the photosystem II (Fv/Fm) (0.83 ± 0.01) were significantly higher in basil grown in aquaponics when compared to the hydroponic system. Overall, these findings indicate that aquaponics seems to be more suitable for growing basil plants than the hydroponic system.

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1. Introduction

Over the past decades, the increased demand for medicinal and aromatic plants has prompted a surge in interest in their cultivation and use. These plants are valued for their countless beneficial properties and nutraceutical effects. Besides, its by-products mainly colorants, dyes, essential oils, phytoconstituents and bioactive compounds are broadly applied in many cosmetic and pharmaceutical industries (Vartak et al., 2022). Basil (*Ocimum basilicum* L.), a member of *Lamiaceae* family is an herbaceous plant that originated from India but is presently cultivated worldwide as an aromatic plant for its flavor and various therapeutic benefits (Foliard, 2014). This culinary herb is used mainly as a spice (dried or fresh) in salads, sauces, baked goods, and meat products (Filip, 2017; Milenković et al., 2019). It is also considered as a medicinal plant since it has been used for a long time in traditional folk medicine. Indeed, basil possesses health properties and thus, was used in the treatment of minor illnesses (headaches, insomnia, sunstroke, fever, colds, coughs, abdominal pains, diarrhea, constipation, kidney malfunctions and rheumatism) as well as in the treatment of respiratory diseases such as asthma and even in insects' stings and scorpion bites. On the other hand, basil possesses stomachic, vermifuge, tonic as well as diuretic properties (Filip, 2017; Padalia et al., 2016). It is noteworthy to mention that the essential oil extracted from the leaves of *O. basilicum* is notable for its richness in phenolic compounds, mainly methyl chavicol (75%) and linalool (20%). In addition to these compounds, this oil contains terpenoids, alkaloids, flavonoids, and tannins (Al-Snafi, 2021; Foliard, 2014). Furthermore, the ingestion of this medicinal and aromatic plant's leaves has many benefits since it is rich in macrominerals such as potassium and magnesium as well as vitamins and β-carotene (Filip, 2017).

Generally, basil is cultivated in accordance with conventional agriculture (Kaur et al., 2024). However, this latter is nowadays affected by climate change and desertification (Food and Agriculture Organization of the United Nations [FAO], 2016; Verdoliva et al., 2021) which is mainly the result of the erosion of the soil and the decline of its fertility as well as the devaluation of a stable ecosystem (Food and Agriculture Organization of the United Nations [FAO] & Intergovernmental Technical Panel on Soils [ITPS], 2015; Goddek et al., 2019).

Consequently, the adoption of agricultural practices that ensure improved productivity and more efficient natural resource management is a strategy that can be employed to overcome the aforementioned limiting factors. This approach is particularly relevant in the context of water management (Goddek et al., 2019; Putra & Yuliandro, 2015). In this context, soilless cultures such as hydroponics and aquaponics meet these expectations (Goddek et al., 2019; Treftz & Omaye, 2016). Indeed, hydroponics is a cultivation practice where crops are cultivated using a nutrient solution, composed of fertilizers mixed in water that is delivered to the plants *via* the roots (Treftz & Omaye, 2016). As for aquaponics, this agricultural practice combines hydroponics and aquaculture where plants receive water, rich in nutrients, originating from the fish tank (Eck et al., 2019b; Goddek et al., 2019). For both cultivation practices (Knaus et al., 2020; Tzortzakis et al., 2020), plants are either cultivated on substrates such as rockwool, sand, cocopeat (Patil et al., 2020), expanded clay (Forchino et al., 2017) as well as gravel (Knaus et al., 2018, 2020, 2022) or without sterile mediums such as Deep Water Culture also called floating raft (Bulgari et al., 2016; Forchino et al., 2017; Puccinelli et al., 2021; Roosta & Hamidpour, 2011; Roosta & Mohsenian, 2012; Yang & Kim, 2020) and Nutrient Film Technique (Knaus et al., 2020; Saha et al., 2016; Suhl et al., 2016). Indeed, both these soilless cultivation systems inscribe in the urban agriculture practices since they can be considered as sustainable and adaptable to the urban regions (Pollard et al., 2017; Rufí-Salís et al., 2020). Conversely, it is interesting to note that different basil cultivars could be successfully grown in soilless systems such as hydroponics (Bulgari et al., 2016; Kolega et al., 2020; Laribi et al., 2023; Mourantian et al., 2023; Walters & Currey, 2018, 2019) and aquaponics (Ferrarezi & Bailey, 2019; Knaus et al., 2020; Mourantian et al., 2023; Saha et al., 2016).

It is important to acknowledge the substantial body of research (including Chen et al., 2020; Greenfeld et al., 2022; Pomoni et al., 2023) conducted on the environmental impact of soilless cultivation systems. A significant focus of these studies has been dedicated to the evaluation of these systems' influence on both power consumption, water-intake and land use with the objective of assisting farmers in enhancing their production's environmental performance. However, a crucial aspect that merits attention is the evaluation of the specific effects of these soilless systems on the cultivated species. Despite the substantial data on the hydroponic and aquaponic cultivation of basil, there is a dearth of information about their effects on basil cultivated in Tunisia. To the best of our knowledge, only hydroponically grown purple basil has been investigated in Tunisia (Laribi et al., 2023). Therefore, this comparative study is the first report on the effects of the soilless cultivation system (aquaponics/ hydroponics) on basil's (*O. basilicum* L. cv. *Genovese*) growth, production of dry matter and photosynthetic performance when grown in Tunisia.

2. Material and methods

2.1 Presentation of the experimental soilless cultivation systems

The present experiment was conducted under a glasshouse at the National Agronomic Institute of Tunisia (Latitude 36°51' N; Longitude 10°11' E; Altitude 10 m) and has lasted 6 weeks (September and November 2020). During this period, the mean relative humidity varied from 21 ± 3 % to 65 ± 5 % and the average daily temperature fluctuated from 16.03 ± 3 °C to 35.92 ± 5.18 °C, agriculture fan was used to mitigate the variability of temperatures.

2.1.1 Hydroponic system

The hydroponic system contained 4 tubes with a distance of 0.40 m between each tube. These tubes were placed at a height of 1.25 m. Each channel is 5 m long and has a diameter of 0.10 m and contains 30 holes, with each one having a diameter equal to 6 cm. Previously uprooted basil (this process was done carefully to avoid damaging the root system that was afterwards washed using tap water) were inserted into grid pots within these holes.

This hydroponic system includes a 100 L barrel for the nutrient solution and a water pump with a flow rate of 7.5 $m^3 \cdot h^{-1}$. All the plants were fed with a Hoagland and Arnon (1950) nutrient solution containing: 16.5 mM NO_3^-; 0.82 mM NH_4^+; 1 mM $H_2PO_4^-$; 6 mM K^+; 10 mM Ca^{2+}; 4 mM Mg^{2+}; 3.7 mM SO_4^{2-}. This solution has been slightly modified by adding 2 mg.L^{-1} of Fe^{2+} and increasing the amount of NO_3^-, NH_4^+ and SO_4^{2-} (from 15; 0 and 4 to 16.5; 0.82 and 3.7 respectively). The circulating solution has a potential of hydrogen (pH) equal to 5.5 and an electrical conductivity (EC) of 1.2 dS/m was circulated in an enclosed system, ensuring continuous aeration. It was changed weekly during the period of the experiment in order to replace nutrient contents that might have been reduced.

2.1.2 Aquaponic system

The aquaponic system is composed of a 1,000 L fish rearing tank, a mechanical filter and biofilter tanks of 80 L each. The biofilter was made of bio balls that were colonized by nitrifying bacteria which formed the biofilm.

Prior to the initiation of the experiment, it was imperative to set up the biofilter for a duration of one month (the cycling process). This critical first step allows the establishment of bacteria and the attainment of optimal rates of ammonia oxidation to nitrates. The process of aeration in fish tank as well as the functioning of the biofilter were facilitated by eight aquarium air pumps. It should be noted that the fish were added to the fish rearing tank a day after the end of the cycling process.

Nile tilapia (*Oreochromis niloticus*) was employed during this experiment. For this purpose, 205 fingerlings with a mean initial length of 9.8 ± 1.8 cm and a mean initial weight of 24.3 ± 13.1 g were placed in the fish rearing tank. They were fed with a commercial feed (50% protein, 16% fat, 8% ash and 1.2% phosphorus) three times per day (08:00, 12:00 and 17:00) at a rate of 4% of the fish body weight.

Water from the fish rearing tank flows unidirectionally into the mechanical filter, wherein solid fish waste is separated. Afterwards, water is pumped into the second filter (biofilter) where the nitrification process is carried out by nitrifying bacteria. The water is ultimately channeled into the designated plant bed area. It permeates and subsequently exits the plant growth tubes and finally returns to the fish tank. The movement of water through the system is facilitated by an electric pump. The tanks are interconnected by a network of pipes and valves regulating the direction and rate of water flow.

The physical and chemical parameters of the fish rearing tank's water were measured to assess its quality once a week. Water's temperature (°C) and pH were determined with an aquarium thermometer and a pH meter (Lutron WA-2017SD Multi Water Quality Meter, Bangkok, Taiwan), respectively. Chemical water parameters: ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) were measured using test kits (Combiset Test Plus NH_4^+/NH_3, JBL, Germany).

2.2 Plant material and experimental design

The experimented plant material was Basil (*O. basilicum* L. cv. *Genovese*) which seeds were obtained from the Italian seed supplier "Emanuele Larosa Sementi". These last were sown in July 2020 in cell plug-trays filled with peat and then placed under greenhouse conditions. Basil plants of 8 cm height were transplanted into the experimented systems after 2 months with a density equal to 22.7 plants.m^{-2}.

The experimental design of this trial was the factorial randomized complete block with three repetitions and the soilless cultivation system (hydroponics and aquaponics) is considered as the only variation factor. It is noteworthy to mention that the randomization was done by randomly assigning basil plants to either hydroponic or aquaponic systems.

2.3 Plant growth measurements

Measurements of plant height, leaf number and length, length of internodes and roots were recorded on eighteen plants two weeks after transplantation into the plant growth tubes of the aquaponic and hydroponic systems.

Subsequent to harvest, fifteen plants were randomly selected from each cultivation system for the purpose of biomass determination: the entire plant was uprooted and eventually partitioned into roots and shoots (stems and leaves). The samples were immediately weighted in order to determine their fresh weight (FW). Afterwards, plants were wrapped in clean paper bags, labelled and then oven-dried (75 °C for 48 h) and reweighted to estimate their dry weight (DW). Finally, the dry matter contents (DMC) of roots and shoots were computed by applying the following equation:

$$DMC\ (\%) = \frac{\mathrm{DW}}{\mathrm{FW}} \times 100$$

2.4 Photosynthetic pigments content measurements

The photosynthetic pigments namely chlorophyll a, chlorophyll b and total chlorophyll as well as carotenoids, were determined according to Torrecillas et al. (1984) method. In brief, samples (five leaf discs each; ø = 22 mm) were taken from healthy leaves and were extracted with acetone

80% v/v. The total extraction took place in darkness at 4 °C for 72 hours and the full extraction of chlorophyll was achieved when the sample was discolored.

The absorption of the extracts was measured at 460 nm, 645 nm, and 663 nm by an Optizen 3220 UV-Visible spectrophotometer (Mecasys Co., Ltd, Korea). The estimation of photosynthetic pigment levels was done according to Arnon (1949) and MacKinney (1941) equations before their expression in µg·mg^{-1}.FW.

2.5 Chlorophyll fluorescence measurements

Chlorophyll fluorescence recordings were done using a Multi-Mode Chlorophyll Fluorometer (OS5p, Opti-Sciences, Hudson, USA) on vigorous leaves that had been dark-adapted for twenty minutes. The fluorescence parameters namely Fo (initial fluorescence), Fm (maximal fluorescence) and Fv (variable fluorescence) were measured and then the efficiency of photosystem II (PS II) primary photochemistry, given as Fv/Fm, was assessed (Baker & Rosenqvist, 2004). This measurement was conducted in triplicate.

2.6 Statistical analysis

An examination of the data set was conducted to determine statistically significant differences using the one-way analysis of variance (ANOVA) and expressed as mean ± standard deviation. For comparisons of the means, the Duncan's multiple range tests ($P < 0.05$) was employed. All the analyses were performed using the statistical package SAS 9.0 version (SAS Institute, 2002).

3. Results

3.1 Effects of the aquaponic and hydroponic systems on plant growth of basil

The effects of the aquaponic and hydroponic systems on plant growth of basil is reported in Table 1. It has been shown that plants grown under aquaponic conditions have significantly the higher plant height (25.69 cm) and the longer internodes (2.47 cm) when compared to those cultivated in the hydroponic system (14.36 cm and 2.12 cm, respectively). Moreover, aquaponically grown plants presented more leaves (10.89) with the significant higher length (6.23 cm) as well as the longer roots (16.2 cm) in comparison to those cultivated in the hydroponic system (Table 1).

Table 1. Effect of the cultivation system (aquaponics and hydroponics) on some growth parameters of Genovese basil (Ocimum basilicum L. cv. Genovese) plants

Cultivation system	Plant height (cm·plant^{-1})	Number of leaves·plant^{-1}	Internodes length (cm·plant^{-1})	Leaf length (cm·plant^{-1})	Root length (cm·plant^{-1})
Aquaponics	25.69 ± 2.87^{a}*	10.89 ± 1.02^{a}	2.47 ± 0.17^{a}	6.23 ± 0.45^{a}	16.2 ± 1.94^{a}
Hydroponics	14.36 ± 1.54^{b}	10.61 ± 1.24^{a}	2.12 ± 0.15^{b}	4.43 ± 0.35^{b}	15.95 ± 1.44^{a}

*Values followed by different superscripts (a-b) in the same column are significantly different at probability level P < 0.05 (Duncan test).

3.2 Effects of the aquaponic and hydroponic systems on biomass production of basil

The biomass of basil cultivated in aquaponics and hydroponics is detailed in Table 2. As presented in this table, fresh and dry shoot weights of basil plants cultivated in the aquaponic system were significantly higher (9.17 g and 1.03 g, respectively) when compared to those grown under hydroponic conditions (1.57 g and 0.17 g, respectively). Additionally, the fresh and dry weights of roots increased significantly under aquaponic conditions (5.22 g and 0.37 g, respectively) while in hydroponically grown plants, these parameters were only 2.98 g and 0.2 g, respectively (Table 2).

A slight enhancement (11.25%) of the dry matter content of basil shoots was noticed in plants grown under aquaponic conditions in comparison to those cultivated in the hydroponic system (10.59%). However, the difference was not significant between the two cultivation systems (aquaponics and hydroponics) as shown in Table 2. A high percentage of dry matter content (7.07%) was noted in roots of aquaponically grown plants in comparison to those cultivated under hydroponic conditions (6.73%). Nevertheless, the differences were not significant (Table 2). However, the shoot and root dry matter contents (11.25% and 7.07%, respectively) were improved but not significantly in aquaponically grown basil when compared to those cultivated in hydroponics (10.59% and 6.73%, respectively) (Table 2).

Table 2. Effect of the cultivation system (aquaponics and hydroponics) on biomass production of Genovese basil (Ocimum basilicum L. cv. Genovese) plants

Parts of the plant	Biomass production	Cultivation system	
		Aquaponics	Hydroponics
Shoots	Fresh weight (g)	9.17 ± 0.49[a]*	1.57 ± 0.09[b]
	Dry weight (g)	1.03 ± 0.05[a]	0.17 ± 0.01[b]
	Dry matter content (%)	11.25 ± 0.86[a]	10.59 ± 0.78[a]
Roots	Fresh weight (g)	5.22 ± 0.14[a]	2.98 ± 0.37[b]
	Dry weight (g)	0.37 ± 0.03[a]	0.20 ± 0.03[b]
	Dry matter content (%)	7.07 ± 0.63[a]	6.73 ± 1.33[a]

*Values followed by different superscripts (a-b) in the same line are significantly different at probability level P < 0.05 (Duncan test).

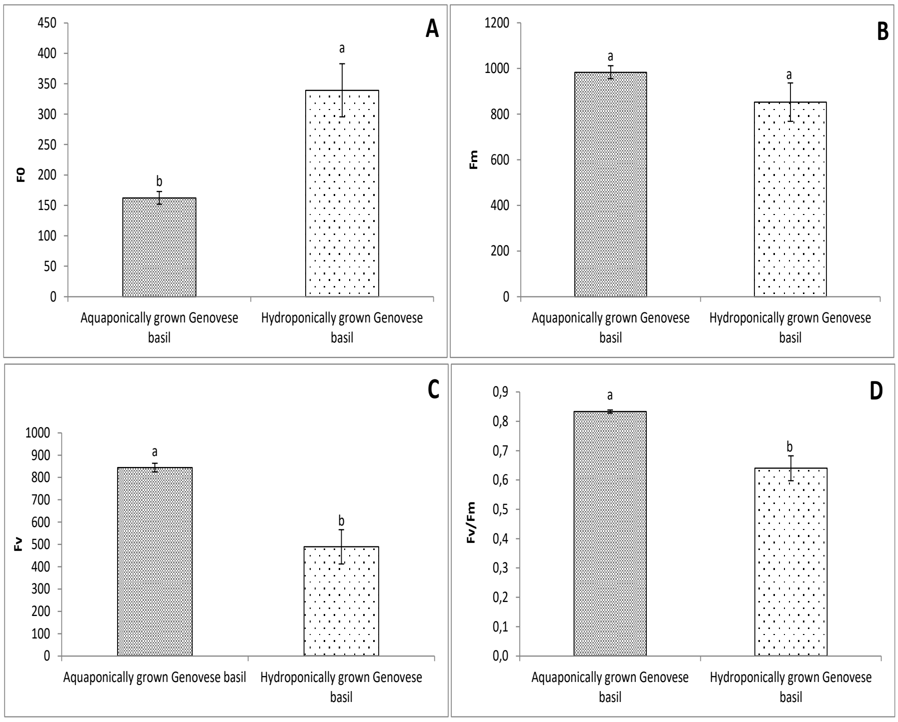

Figure 1. Effects of the cultivation system (aquaponics and hydroponics) on the chlorophyll fluorescence parameters. (A) Initial fluorescence F0; (B) Maximum fluorescence Fm; (C) Variable fluorescence Fv and (D) Fv/Fm = maximal quantum yield of the photosystem II of Genovese basil (Ocimum basilicum cv. Genovese) plants. Values followed by different superscripts (a-b) are significantly different at probability level P < 0.05 (Duncan test)

3.3 Effects of the aquaponic and hydroponic systems on photosynthetic performance of basil

The impacts of the variation of the experimented systems on photosynthetic status of basil plants are presented in Figure 1. Results demonstrated that Fm (Figure 1B), Fv (Figure 1C) and Fv/Fm (Figure 1D) levels were improved significantly in plants cultivated in aquaponics when compared to those obtained in plants grown under hydroponic conditions. However, F0 was enhanced but not significantly in aquaponically grown plants' leaves in comparison to the hydroponic system (Figure 1A).

The effects of the aquaponic and hydroponic systems on photosynthetic pigment contents are presented within Table 3. Chlorophyll a (44.59 $\mu g \cdot mg^{-1}$ FW), chlorophyll b (64.89 $\mu g \cdot mg^{-1}$ FW) and total chlorophyll (124.27 $\mu g \cdot mg^{-1}$ FW) as well as carotenoids (13.45 $\mu g \cdot mg^{-1}$ FW) were enhanced in aquaponically grown basil in comparison to plants grown under hydroponic conditions (28.2 $\mu g \cdot mg^{-1}$ FW, 56.41 $\mu g \cdot mg^{-1}$ FW, 110.18 $\mu g \cdot mg^{-1}$ FW and 9.40 $\mu g \cdot mg^{-1}$ FW, respectively). It is noteworthy that except for chlorophyll a, the differences were not significant.

Table 3. Effect of the cultivation system (aquaponics and hydroponics) on photosynthetic pigments content of Genovese basil (Ocimum basilicum L. cv. Genovese)

Cultivation system	Chlorophyll a ($\mu g \cdot mg^{-1}$ FW)	Chlorophyll b ($\mu g \cdot mg^{-1}$ FW)	Total chlorophyll ($\mu g \cdot mg^{-1}$ FW)	Carotenoids ($\mu g \cdot mg^{-1}$ FW)
Aquaponics	44.59 ± 3.42^{a}*	64.89 ± 4.33^{a}	124.27 ± 8.86^{a}	13.45 ± 2.32^{a}
Hydroponics	28.28 ± 6.51^{b}	56.41 ± 4.9^{a}	110.18 ± 8.24^{a}	9.40 ± 0.93^{a}

*Values followed by different superscripts (a-b) in the same column are significantly different at probability level $P < 0.05$ (Duncan test)

4. Discussion

4.1 Plant growth and biomass production

This current study's results proved that basil grown under aquaponic conditions presented significantly the highest plant height and the longer internodes in comparison to plants cultivated in the hydroponic system (Table 1). Thus, our findings are in accordance with those previously recorded by Saha et al. (2016) who noted that plant height of aquaponically-grown basil was twice higher (≈ 30 cm) than that observed in plant cultivated under hydroponic conditions (≈ 15 cm) after three weeks of cultivation. It is noteworthy to mention that in our case, the height value of aquaponically-grown plants is much lower than that obtained by Knaus et al. (2020) who found that basil plant height reached 96.7 cm after 41 days of aquaponic culture.

Moreover, aquaponically grown plants presented more leaves with significantly higher length as well as longer roots in comparison to those cultivated in the hydroponic system; It is noteworthy to mention that the differences were not significant for the newly developed leaves number and for the length of roots (Table 1). These results are in accordance with those recorded in aquaponically grown spinach plants which showed longer roots when compared to those cultivated in hydroponics (Atique et al., 2022). In contrast to our results, Yang and Kim (2020) noted that basil plants grown under hydroponic conditions developed significantly more leaves with a higher length in comparison to those cultivated in aquaponics.

Accordingly, results obtained herein regarding the enhancement of growth of aquaponically grown basil plants could be explained by the availability of nitrogen in aquaponic water as previously suggested by Saha et al. (2016). Indeed, nitrogen is among the most important elements for the growth and development of crops. Schmautz et al. (2021) has reported that nitrogen (N) is initially introduced into an aquaponic system through proteins that exist in the fish feed as organic nitrogen. Later on, they are assimilated and subsequently converted by the aquatic organisms into ammonia (NH_3) which is predominantly released into the water through passive gill diffusion.

The residual organic N present in the fish's excreta, uneaten food, and decaying biomass undergoes mineralization to NH4⁺. A portion of the inorganic N undergoes further transformation to NO_2^- and NO_3^- via nitrification or is assimilated into biomass by microbes and plants. The aforementioned authors concluded that nitrogen concentrations differed considerably among the system's compartments. Moreover, Schmautz et al. (2017) discovered that each compartment had distinct microbial communities. Furthermore, it has been proved that the system's design as well as the water source used highly influenced the bacterial communities (Bartelme et al., 2019). Besides, Sanchez et al. (2019) found that certain bacterial strains derived from the aquaponic systems exhibited plant growth-promoting properties namely siderophores production and phosphorus solubilization. Among the identified genera: Microbacterium, Bacillus, Pseudomonas, etc. Additionally, Monsees et al. (2017) proved that aerobic conditions, caused by a simple aeration, resulted in the mobilization of phosphorus (P) and potassium (K^+) with a concomitant loss of NO_3^-—N. Thus, improving these nutrients' supply to the plants in the system. In the same context, it has been demonstrated that plants grown in nitrogen-abundant conditions are characterized by a higher growth rate (Pilbeam, 2010). Eventually, nutrient elements needed for vegetative growth derive from both the fish feed and the water provided into the aquaponic system. Indeed, only 20-30% of nitrogen supplied to fish (in the form of fish feed) is consumed and hence, 70-80% of this element can be found freely in the water (Eck et al., 2019a; Roosta & Hamidpour, 2011). However, it has been reported that elevated levels of macronutrients, such as nitrogen (300 ppm), potassium (350 ppm) and calcium (350 ppm) have the potential to exert deleterious effects on plant growth of lettuce cultivated under hydroponic conditions (Sapkota et al., 2019).

Regarding the biomass production, our results proved that fresh and dry weights of shoots and roots of aquaponically grown *O. basilicum* were significantly enhanced in comparison to hydroponically grown plants (Table 2). Therefore, the increase observed in fresh weight of basil plants could be attributed to the higher nitrogen levels in aquaponics when compared to hydroponics (Saha et al., 2016). On the contrary, Yang and Kim (2020) found that fresh and dry shoots weights of basil plants grown under hydroponic conditions were improved significantly when plants were cultivated in aquaponics. Conversely, these same authors noted a significant increase of the weights of fresh and dry roots in aquaponically grown basil plants when compared to those cultivated in hydroponics, which is in accordance with our finding. On the other hand, Vandam et al. (2017) reported that there were no statistically significant differences between aquaponically and hydroponically grown (pH = 5) spinach (*Spinacia oleracea*).

In the context of root development, Schwartz et al. (2019) observed that lettuce's (*Lactuca sativa* cv. Flandria) total root surface area remained unaffected to the variation in the cultivation systems employed for this species, namely the standard hydroponic system and an aquaponic system (supplemented with iron). This finding indicates that the roots of plants cultivated through aquaponics tend to be more fine-structured compared to those raised under hydroponic conditions.

On the other hand, Atique et al., 2022 reported that the shoot to root ratio weight of spinach plants was not affected significantly by the aquaponic and hydroponic systems although the shoot and root dry matter content increased in hydroponically grown plants when compared to aquaponics, which is not in accordance with our findings.

4.2 Plant photosynthetic performance

Chlorophyll fluorescence has become a widely used technique for studying different stresses' impact on the photosynthetic process. Since its introduction, the Fv/Fm ratio has been employed extensively as a sensitive indicator of plant photosynthetic performance (Guidi et al., 2019). Even though numerous experiments have been assessing the impacts of the hydroponic system on the photosynthetic performance of many crops including basil, lettuce, rocket etc. (Bulgari et al., 2016; Laribi et al., 2023; Nkcukankcuka et al., 2021; Puccinelli et al., 2021; Walters & Currey, 2018), only very scarce investigations studied the impacts of the aquaponic conditions on the chlorophyll fluorescence and the photosynthetic pigment contents of some horticultural crops such as tomato and pepper (Roosta & Mohsenian, 2012).

In the present study and except the initial fluorescence (F0) which was enhanced but not significantly in leaves of aquaponically-grown basil plants. Indeed, a significant increase of Fm, Fv and Fv/Fm levels was observed in plants cultivated in aquaponics when compared to those obtained in hydroponically grown basil (Figure 1). In fact, the most optimal value of the maximal quantum yield of PS II photochemistry for the majority of species of plants is in the range of 0.83.

Previously, it has been reported that the Fv/Fm in tomato plants was not significantly affected by the soilless agricultural systems (aquaponics and hydroponics) although this parameter was slightly higher in hydroponically grown plants (Roosta & Hamidpour, 2011).

Conversely, the highest Fv/Fm were noted in aquaponically grown pepper's leaves (*Capsicum annum* L.) treated with $FeSO_4$ by foliar application in comparison to the control (Roosta & Mohsenian, 2012). Likewise, Moderalli et al., (2023) found that Fv/Fm value was slightly higher in aquaponically grown basil when compared to plants grown in hydroponics; nevertheless, no significant differences between these studied cultivation systems were observed. The aforementioned authors attributed the decline in Fv/Fm in hydroponically grown basil to photoinhibition, which is consistent with a decrease in the yield of PSII and an increase in the yield of non-regulated quenching suggesting that the photosystems are experiencing a considerable level of stress. These findings are consistent with the explanations provided by Guidi et al., (2019) who presented photoinhibition as a phenomenon in which a decline in Fv/Fm signifies a diminution in photosystem II (PSII) efficiency, resulting in a decrease of the photosynthetic activity mainly due to light-induced decreases in CO_2. This phenomenon becomes inevitable when light intensity surpasses the photosynthetic rate. Various stresses, including mineral deficiency, drought, heat, heavy metal toxicity, and air pollution, can determine the point at which the light absorbed by chlorophyll pigments becomes excessive for the requirements of photosynthetic machinery. In our case, the photoinhibition was probably caused, in hydroponically grown basil plants, by mineral deficiency: the level of mineral elements being higher in aquaponics further supporting the hypothesis that we proposed earlier in the "Plant growth and biomass production" section.

Additionally, this current experiment's findings showed an increase of chlorophyll a, b, total and carotenoids contents in leaves of aquaponically grown basil in comparison to hydroponically grown plants. This enhancement observed in the photosynthetic pigments contents was not significant except for chlorophyll a (Table 3). Concomitant with our results, chlorophyll a and b were enhanced in aquaponically grown plants of tomato as previously stated by Roosta and Hamidpour (2011). These authors attributed the greener color and the higher chlorophyll levels observed in tomato leaves to higher but non-toxic level of ammonium absorption by plants when cultivated in aquaponics. On the contrary, it has been reported that the total chlorophyll content was significantly higher in hydroponically grown strawberry plants when compared to those cultivated in aquaponics (Afsharipoor & Roosta, 2010). Indeed, a significant positive relationship has been demonstrated between the nitrogen content of the nutrient solution and the chlorophyll content in lettuce cultivars grown in a floating hydroponic system (Sapkota et al., 2019).

5. Conclusion

Overall, results of the present investigation regarding the comparison between the two soilless cultivation systems namely aquaponics and hydroponics and their effects on Genovese basil plant growth, biomass production and photosynthetic status showed some significant differences. Indeed, aquaponically grown plants were more performant concerning vegetative growth, fresh and dry weight of shoots and roots as well as the maximal quantum yield of the photosystem II (Fv/Fm) when compared to plants cultivated in the hydroponic system. Consequently, aquaponics is the most suitable soilless cultivation system for growing Genovese basil plants. The present study explores the potential for innovative agricultural practices in Tunisia, a nation grappling with water scarcity and drought. The findings of this study hold particular relevance for Tunisian farmers, who stand to benefit from the adaptation of these innovative methods to their agricultural context. It is interesting to study in the future the vegetative growth, crop yield, and quality of Genovese basil plants aquaponically and hydroponically grown, by applying biostimulants such as those derived from algae, plant growth-promoting rhizobacteria as well as arbuscular mycorrhizal fungi. Nevertheless, given that aquaponic systems are complex and dynamic, further studies on the processes related to the interactions plants-fishes should be carried out to prevent limitations thus optimizing this soilless system.

Authors' declaration and contribution

The authors report there are no competing interests to declare. Each author made equal contributions.

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