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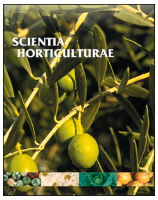

Research Paper

Moderate saline waters are effective to enhance a landrace of unripe melon cultivated in a “water culture system” with high input efficiency

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ABSTRACT

The aim of agricultural activity is to produce more, consuming less, focusing on a more efficient use of production inputs and on a reduction of biodiversity loss. Irrigation water salinization is one of the most severe causes of yield reduction in modern agriculture. Basing on this, the aim of the experimental trial was to study if nutrient film technique (NFT) system, with a complete nutrient solution (NS) recirculation, may be an effective system to counteract the negative effects of raising NaCl concentrations in the NS on crops. A landrace of unripe melon (Cucumis melo L.) called ‘Scopatizzo’ was grown in a spring-summer cycle, in the greenhouse, in an NFT system with a closed management of NS and three levels of NaCl (0, 2.5 and 5 mM). ‘Scopatizzo’ plants absorbed an average of 145 L of NS per plant, with daily uptake increasing from 0.5-0.8 L·plant-1 to over 2 L·plant-1, linearly related to total light integral (TLI). Higher NaCl levels raised NS electrical conductivity, with significant differences over time. Water use efficiency (WUE) and average production were 27.6 L·kg-1 and 5.31 kg·plant-1 respectively and fruits with NaCl had higher titratable acidity but lower glucose. NaCl enhanced gas exchange, increasing photosynthetic rate, stomatal conductance, and transpiration, while altering electron transport properties. NFT as a cultivation system has proven to allow the use of moderately saline water without compromising the yield and fruit quality of ‘Scopatizzo’ which represents a valid alternative to the cultivation of cucumber. Further study will be necessary in order to verify up to which concentration of NaCl no significant stress symptoms are identified on the production and growth of the plant.

1. Introduction

As part of the Farm to Fork strategy, one of the central pillars of the European Green Deal, the European Commission aims to see a reduction in nutrient losses of at least 50% by 2030, while ensuring no deterioration in soil fertility (European Commission, 2022), thus expecting a reduction in fertilizer use of at least 20% (European Commission, 2022). Furthermore, Humanity’s Ecological Footprint has increased by about 173% over the last 60 years and now exceeds the planet’s biocapacity (the capacity of an ecosystem to generate an on-going supply of renewable resources and to absorb its spillover wastes) by 56%: this means that human activity is currently 1.56 times more than what the Earth can regenerate (Fussy and Papenbrock, 2022). Currently, global agriculture feeds over 7 billion people, but is also a major cause of multiple types of environmental degradation. Agricultural activities emit 25–33% of greenhouse gases (Tubiello et al., 2014), occupy 40% of Earth’s land surface (Clark and Tilman, 2017), account for >70% of freshwater withdrawals (Clark and Tilman, 2017), drive deforestation and habitat fragmentation, with a resultant loss in biodiversity, apart from eutrophying and acidifying natural aquatic and terrestrial ecosystems with agrochemicals (Clark and Tilman, 2017). The new paradigm of agriculture must be to produce more, consuming less, focusing on a more efficient use of production inputs, including water (Stanghellini, 2014).

Brackish water and salt accumulation in soils of arid and semi-arid regions of the world is a major problem of irrigated agriculture and soil salinization is one of the most severe causes of yield reduction in modern agriculture (Signore et al., 2008). In fact, in the last years several researchers conducted studies to alleviate the salt effects on production of vegetables in Mediterranean Area (D’Imperio et al., 2018; Di Gioia et al., 2013; Huang et al., 2009; Neocleous and Savvas, 2016; Serio et al., 2004; Signore et al., 2008; Voutsinos-Frantzis et al., 2023)

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and several winter and summer vegetable varieties, that were abundant some decades ago, were now absent or rare both in qualitative and quantitative terms due to salinity accumulation in soil (Rahman et al., 2011). Therefore, the increase in salt concentration in irrigation water is leading to a loss of agro-biodiversity and therefore it is necessary to adopt cultivation techniques/technologies that limit the unwanted effects of salinity on plant cultivation (Rahman et al., 2011).

It has been shown that producing vegetables in a greenhouse does not increase the environmental impact compared to cultivation in the field, but may even allow it to be reduced (Muñoz et al., 2008). Soilless culture systems are increasingly adopted as a major technological component in the modern greenhouse industry (Massa et al., 2020).

The soilless systems may be either open or closed; in open systems the drainage solution is discharged while in closed systems the drainage solution is collected and reused (Massa et al., 2010). Despite the NS management is more difficult in closed than open soilless systems, there is a shift toward the first ones, due to their environmental benefits and the substantial reduction in fertilizer and water use, without compromising yield performance (Putra and Yuliando, 2015). The soilless systems include both water culture systems, with merely NS as root environment, and cultivation on porous growing media, which create a matrix that can retain both air and water at suitable ratios for plant growth (Savvas and Gruda, 2018). Among the water culture systems, the nutrient film technique (NFT) has been reported to have many advantages as follows: i) watering is greatly simplified, since it is no longer necessary to make day-to-day assessments of water requirements and the tedious task of cleaning blocked irrigation nozzles is eliminated; ii) uniformity of nutrient supply is ensured; iii) root temperature may be raised whenever required; iv) the rapid turn-round of crops is readily achieved; v) pollution of environment is minimized by reducing water and nutrient loss and using minimal substrate (Tüzel et al., 2019). In fact, NFT has been used as soilless system to study the: i) NaCl accumulation in relation to water uptake (Neocleous and Savvas, 2016); ii) influence of growing season on fruit yield and quality of melon (Pardossi et al., 2000); iii) impact of manganese and zinc applications on bean growth, yield, photosynthesis, and nutrient uptake (Neocleous et al., 2020); iv) smart NS management of tomato crop according to plant needs (Signore et al., 2016); v) hydroponic production of pepper with brackish water (Bione et al., 2021).

Soilless cultivation has increasingly moved towards closed systems due to their advantages in water and fertilizer use efficiency and the environmental constraints related to groundwater pollution. Nevertheless, the gradual accumulation of salinity poses a significant challenge in managing closed-cycle hydroponic systems when low-quality water is used for irrigation. Salt ions like sodium (Na^+) and chloride (Cl^-) are often present in excessive amounts in low-quality irrigation water, consequently, recycling NS made with such water gradually subjects plants to salt stress (Neocleous et al., 2017).

It is well known that the melon crop (*Cucumis melo* L.) is less sensitive than many other vegetable crops to salinity (Neocleous and Savvas, 2016). Previous studies demostrated that: i) the cultivation of melon cultivar ‘Cory’ or cultivars with similar responses to salinity, in systems with continual reuse of the NS is possible without yield and quality losses when the NaCl concentration in the irrigation water does not exceed a concentration of 2.5 mM (Neocleous et al., 2017); ii) with concentrations of NaCl higher than 2 mM in the irrigation water, a partial discharge of drainage water seems inevitable in order to prevent a build-up of Na^+ and Cl^- in the root zone at harmful levels, leading to a decrease of fruit yield in cucumber (Savvas et al., 2005b); iii) the continuous recycling of the nutrient solution with a NaCl concentration by 5 mM reduced the cumulative water consumption by melon plants by about 11% (Neocleus and Savvas, 2016).

It is interesting to highlight that Apulia region (Southern Italy) is an important secondary center of diversity for *C. melo* L. (Somma et al., 2021). Several landraces of this species are still grown there including the so-called unripe melons, such as ‘Barattiere’, ‘Carosello’, ‘Scopatizzo’. To this end, several studies have been carried out to valorize the production of these landraces (Palmitessa et al., 2022, 2021).

‘Scopatizzo’, belonging to the *Cucumis melo* L., is a local variety grown in Apulia region (Southern Italy), which is consumed as unripe melon as an alternative of cucumber due to its better-quality profile (Palmitessa et al., 2022). This local variety is characterized by its relatively small-sized fruits, which have a light and sparse fuzziness. At the commercial harvest, the ‘Scopatizzo’ fruits do not have well-formed seeds. In fact, in addition to the flesh (mesocarp), the central part (placenta) of the fruit can be eaten like other genotypes of Apulian unripe melons (Palmitessa et al., 2021).

To our best knowledge, the literature lacks information regarding the use of saline water to produce ‘Scopatizzo’ fruits using a water culture system. The purpose of this study was to investigate the effects of varying NaCl concentrations in NS on the growth, yield, and physiological responses of an unripe melon (*Cucumis melo* L.) landrace, called ’Scopatizzo’. By examining how different salt levels impact water uptake, electrical conductivity, fruit production, and photosynthesis, the research aimed to understand the optimal conditions for cultivating this crop in a nutrient film technique (NFT) system.

The importance of this study lies in its potential to enhance agricultural practices for unripe melon cultivation in hydroponic systems. By identifying how NaCl levels affect plant health and productivity, the findings could be useful to growers on managing salinity to optimize water use efficiency and crop yield. Additionally, the study contributes to existing literature by providing detailed insights into the physiological mechanisms underlying plant responses to salinity, such as changes in gas exchange performance and photosynthetic efficiency.

This research adds to the body of knowledge on salt stress in plants, offering practical applications for improving unripe melon production in controlled environments. It also lays the groundwork for further studies on salinity management and its broader implications for sustainable agriculture and food security.

2. Materials and methods

The experimental trial was carried out at the experimental farm “La Noria” of the National Research Council, Institute of Sciences of Food Production (Mola di Bari, Italy; 41.062156° N, 17.066914° E) in an unheated polymethacrylate greenhouse with a maximum height of 4.5 m.

2.1. *Plant materials and growing conditions*

Apulian landrace of unripe melon (*C. melo* L.), called ‘Scopatizzo’, was grown from May to mid-July 2023. The seedlings were purchased from a local plant nursery and placed, at the phenological stage of two true leaves, in rockwool cubes (Grodan Delta, 75 × 75 × 65 mm). At the phenological stage of four true leaves, the cubes were transferred to the NFT cultivation modules, and the experimental trial started. Seven days after cubes transfer (DAT) the main stem of the plants was tied to a string and raised vertically. Instead, in order to allow uniform flowering and fruiting, based on the work carried out by Somma et al. (Somma et al., 2021), the primary and secondary shoots were pruned after the second node.

2.2. *Cultivation system, nutrient solution management and experimental treatments/design*

The cultivation system used was the NFT with a closed NS management. Twenty plants per bench were arranged in eleven aluminum benches (600 × 20 cm length and width, respectively) distanced by 30 cm and an inter-row distance of 100 cm (plant density 2.5 plants·m^{-2}). The benches were covered with a black (inner) and white (outer) film to avoid the direct contact between roots and aluminum benches, and the sun radiation to reach the roots and the NS, provoking its evaporation. Each bench was irrigated independently and represented the elementary unit of the experiment trial. In order to allow the NS to flow evenly, each bench had a slope of 2% and a 90 L tank was placed at the base of the bench in which the NS consumed by the plants was re-integrated and the drainage NS was recovered and recirculated. To facilitate absorption of water and nutrients by the plants, and to avoid roots anoxia phenomena, the NS was distributed at a flow rate of 0.9 $m^3 \cdot h^{-1}$. To promote the oxygenation of the NS (Suhl et al., 2019) the fertigation schedule included the NS supply for 50 minutes per hour from 7 a.m. to 7 p.m., and subsequently 20-minute fertigation were scheduled at 8 p.m., 9 p.m., 11 p.m., 3 a.m., 5 a.m. and 6 a.m., as there was no solar radiation. Instead, the climate control unit inside the greenhouse allowed the recording of the following climate parameters: temperature, relative humidity, daily light integral (DLI), CO_2 and the total light integral (TLI) was calculated as sum of DLIs. The first and the last benches were not considered for data collection in order to exclude border effects, while the remaining nine benches were used for the application of three experimental treatments with three repetitions. The experimental design used was the randomized block and the treatments applied were three concentrations of sodium chloride (NaCl) in the NS, namely 0 (control), 2.5 and 5 mM, as it was previously tested by Neocleus & Savvas in an experiment concucted with melon (Neocleous and Savvas, 2016). Three stock of NS were prepared in 7000 L tanks before the start of the experimental activity (one for each NaCl treatment) with this macro-nutrient concentrations ($mg \cdot L^{-1}$): 144 $N\text{-}NO_3$, 8 $N\text{-}NH_4$, 236 K, 40 P, 24 Mg, 139 Ca, 68 S. Micronutrient composition was calculated according to Hoagland and Arnon (Hoagland and Arnon, 1950). The stock NSs were used for the replenishment of the 90 L tanks placed at the base of each bench (Fig. S1). Subsequently, every two days the consumed NS in every bench was replenished, its volume recorded, and the pH and electrical conductibility (EC) values were measured before and after the replenishment with the new NS. The EC of the stock NS for the treatments 0, 2.5 and 5 mM was respectively espressed as $dS \cdot m^{-1}$: 1.53, 1.95 and 2.34.When the pH values of the NS after the replenishment were outside the range 5.0 - 6.5, the pH values were adjusted adding sulfuric acid 0.5 M or potassium hydroxide 0.5 M. The NS consumption was used to calculate the water use efficiency (WUE) by dividing the NS consumption (L) by the fruits production (kg).

2.3. *Climatic conditions*

The average greenhouse temperature showed a tendency to increase from the time of transplanting to the end of the growing cycle (Fig. 1a). Since the day the cubes were transferred in the NFT system until 33 DAT the average day/night temperature was 26.3/18.08°C, while from 34 DAT to end of the cycle the average day/night temperature was 31.5/22.9°C (Fig. 1a). The average day/night relative humidity (RH) into the greenhouse was 48.8/70.6% (Fig. 1b), while the average CO_2 day/night concentration during the cultivation was 401-419 $mg \cdot L^{-1}$ of air (Fig. 1c) and the average DLI was on average 36.5 $mol \cdot m^{-2} \cdot day^{-1}$ from 1 to 33 DAT and on average 44.5 from 34 DAT to the end of the crop cycle (Fig. 1d).

2.4. *Fruit and growth analysis*

The harvest of the fruits started 28 DAT, when the weight was approximately 180 - 220 $g \cdot fruit^{-1}$ (Fig. S2) and it was performed every two-three days, depending on the actual size of the fruits. The fruits harvested from the first and last plants in the bench were not considered for the purposes of the research, as these plants were considered to be “edge plants”. During each harvest operation, the number of harvested fruits was recorded, as well as the total fruit fresh weight (FW). On 24, 40 and 71 DAT, destructive measurements were carried out on sample plants for the determination of the following characters: stem length, leaves number, leaf area (LA), fresh (FW) and dry weight (DW) of leaves, stem and roots. DW was determined by placing the samples in a forced-draft oven at 65°C until constant weight.

2.5. *Fruit quality analysis*

Samples of fruits harvested on 51 DAT were analyzed to detect some qualitative aspects. The whole fruits were cut in small pieces and homogenized using an electric grinder, and the resulting products were

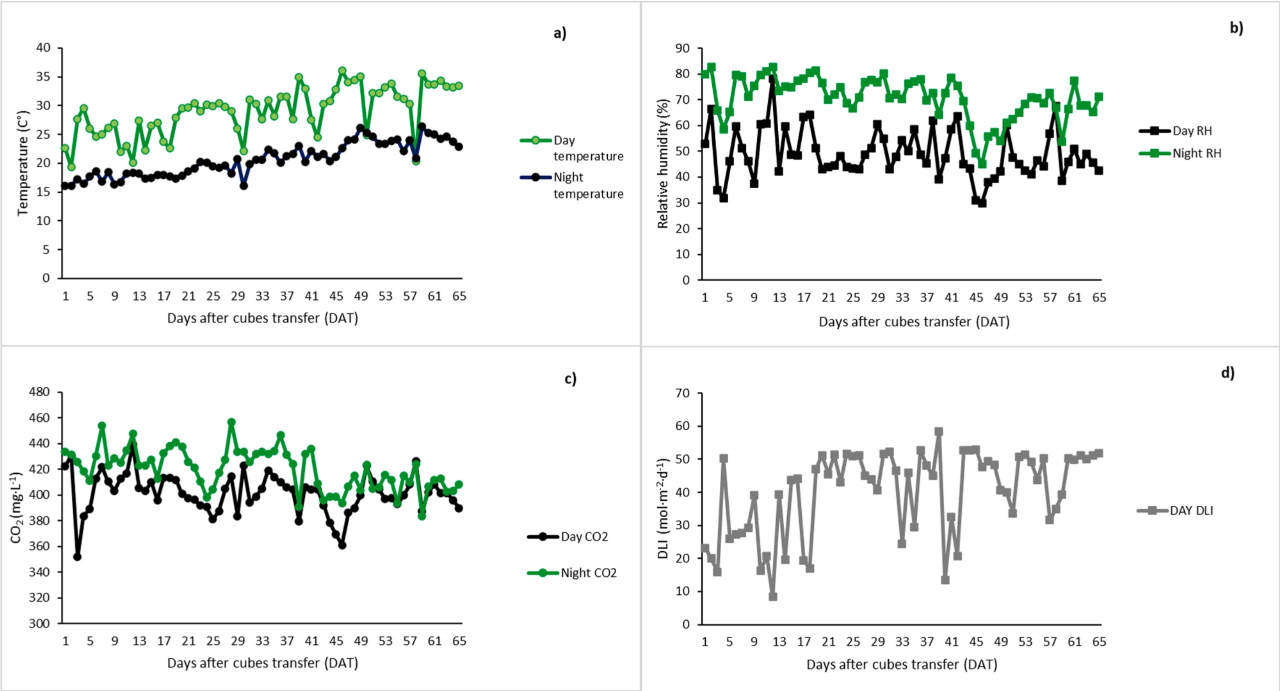

Fig. 1. Average day/night temperature (a), average day/night relative humidity (RH; b); average day/night CO_2 in the greenhouse environment (c); daily light integral (d) during the crop cycle.

used for the analysis of pH, total soluble solids and titratable acidity. pH was determined using a digital pH meter (Edge HI2002, Hanna Instruments, Villafranca Padovana, Italy). Total soluble solids content (°Brix) was determined using an Abbe's refractometer (Carl Zeiss, Oberkochen, Germany). The values of titratable acidity were obtained according to the method described by (Manchali et al., 2021). Specifically, 2 g of homogenized sample was mixed with 25 mL of double-distilled water and subsequently titrated using 0.1 N NaOH and phenolphthalein as indicator. The results were expressed as grams of citric acid per 100 g of product.

For the determinations of total phenolic compounds, glucose, fructose, chlorophylls and carotenoids the homogenized fruits were lyophilized (Lyovapor L-200; BÜCHI Labortechnik AG, Flawil, Switzerland).

The total phenolic compounds content was assessed following the method described by (Renna et al., 2020) with slight modifications. To obtain the phenolic extract, 1 g of lyophilized sample were mixed with 6 mL of an 80:20 (v:v) methanol-water solution and stirred for 10 minutes. Then, the mixture was sonicated in an ultrasonic bath (CEIA international, Viciomaggio, Italy) for 20 minutes and further stirred for an additional 20 minutes. The sample was then centrifuged (Thermo Fisher Scientific SL16R, Waltham, MA, USA) at 10,000 × g for 10 minutes at 4°C. The supernatant was collected, and the pellet was re-extracted twice following the same procedure. 20 μL of extract were mixed with 980 μL of deionized water and 100 μL of Folin-Ciocâlteu reagent (Merck KGaA, Darmstadt, Germany), and after 3 minutes, 800 μL of 7.5 % Na2CO3 were added. Then, the samples were incubated at room temperature for 60 min. The absorbance was taken at a wavelength of 720 nm using a Cary 60 UV–Vis spectrophotometer (Agilent Technologies, Santa Clara, CA, USA). The results were expressed as mg of gallic acid equivalents per gram of fresh weight (FW).

Glucose and fructose contents (mg·g^{-1} on FW) were determined following the procedures described by (Squeo et al., 2022) using the high-performance liquid chromatography equipped with a Refractive Index Detector (1260 Infinity, Agilent Technologies, Santa Clara, USA).

Chlorophylls (mg·kg^{-1} on FW) were spectrophotometrically determined following the analytical procedures described by (Paradiso et al., 2018). Total carotenoids content (mg·kg^{-1} 1 of β-carotene on FW) was assessed using the method reported in (Summo et al., 2019).

All the determinations for the assessment of the fruit quality were carried out in triplicate for each block.

2.6. *Gas exchange systems and rapid light-response curves (RLCs)*

Net photosynthetic rate (*A*, μmol CO_2·m^{-2}·s^{-1}), stomatal conductance (*gs*, mol H_2O·m^{-2}·s^{-1}), and transpiration rate (*E*, mol H_2O·m^{-2}·s^{-1}) were measured on 57 DAT (full vegetative development stage), with the LI-6400 photosynthesis system (LI-COR, Lincoln, NE, USA), using a transparent cuvette (enclosed leaf area: 6 cm^2). Leaflets were enclosed in the cuvette at 400 ± 0.7 μbar CO_2, 800 ± 2.8 μmol photons·m^{-2}·s^{-1}, 20.0 ± 0.5°C cuvette temperature, 70 ± 1% RH and a flow rate of 500 μmol·s^{-1}. Once the parameters in the cuvette had reached stability, *gs* and *E* were logged 10 times at 30 s intervals; these values were later averaged over the nine biological replicates to improve accuracy.

Rapid light curves were performed with the PAM-2500 (Walz GmbH, Effeltrich, Germany) with gradually increasing irradiance in seven steps. For each step, the irradiance was 40, 140, 270, 500, 870, 1400 and 2000 μmol·m^{-2}·s^{-1}, and the fluorescence signal was recorded. Data were recorded using the software by PamWin V3.12g. The two important parameters used for characterizing photosynthesis activity were the maximum quantum yield for whole chain electron transport, at low light intensities (*Alpha*), the maximum electron transport capacity, at light saturation (*ETRmax*) and the light saturation coefficient (*Ik*).

2.7. *Statistical analysis*

All data were performed using the GLM (General Linear Model) and REG (Regression) procedures of SAS software (SAS Software, Cary, NC, USA); the experimental treatment (NaCl content of the NS) was considered as fixed for this purpose. According to research objectives, analysis of variance with two orthogonal contrasts (Steel and Torrie, 1988) was performed on all data: 1) 0 vs 2.5 and 5 mM; 2) 2.5 vs 5 mM. The regression study concerned the relationship between the average NS consumption and average cumulative fruit yield with the total light integral (TLI).

3. Results

3.1. *Plants development during the crop cycle*

Leaves number was not influenced by NaCl content in the NS with an average number of 59.8, 161.6 and 231.9 at 24, 40 and 71 DAT, respectively (Table 1). Instead, the average stem length was 73.2 cm at 24 DAT and 186.9 cm at 40 DAT, while at 71 DAT the plants grown with 5 mM of NaCl in the NS had a stem 27.1% longer than the plants grown with 2.5 mM of NaCl in the NS (Table 1). As leaves number, the leaf area (LA) was not influenced by NaCl concentration in the NS and it was 6,078, 18,162 and 24,157 cm^2 at 24, 40 and 71 DAT, respectively (Table 1).

The biomass production and its dry matter content was not influenced by NaCl concentration in the NS, and leaves, stem and roots fresh weight (FW) increased during the crop cycle (Table 2). More in details, the average leaves FW was 223, 1,052 and 1,437 g·plant^{-1}, respectively, at 24, 40, and 71 DAT (Table 2), while the average leaves dry weight (DW) content was 11.06, 8.17 and 10.94 g·100 g^{-1} of FW at 24, 40 and 71 DAT, respectively (Table 2). Furthermore, the stem FW increased during the crop cycle and it was, on average, 292, 989 and 1,563 g·plant^{-1}, respectively, at 24, 40 and 71 DAT (Table 2); while the average stem DW was 5.03, 5.51 and 6.47 g·100g^{-1} FW at 24, 40 and 71 DAT, respectively (Table 2). Finally, on average, roots FW was 141, 454 and 986 g·plant^{-1} at 24, 40 and 71 DAT, respectively, while roots DW was 4.87, 3.48 and 3.96 g·100 g^{-1} FW at 24, 40 and 71 DAT, respectively (Table 2).

3.2. *NS consumption and EC and pH variation during the crop cycle*

The NaCl concentration in the NS did not influence plant water uptake and at the end of the crop cycle, on average, the plants adsorbed 145 L of NS·plant^{-1} (Fig. 2). While in the early stage of plants

Table 1
Effects of three NaCl concentrations in the NS, on leaves number, stem length and leaf area (LA) of a plant of 'Scopatizzo' (*Cucumis melo* L.) analyzed at 24, 40 and 71 days after cubes transfer (DAT).

		Leaves n.·plant^{-1}	Stem lenght cm	LA cm^2·plant^{-1}
NaCl (mM)	**DAT**			
0	24	62.3	66.2	5,975
2.5		57.1	74.2	6,161
5		59.9	79.1	6,100
0	40	160.9	178.7	17,262
2.5		171.7	190.7	19,791
5		152.1	191.2	17,434
0	71	207.6	412.3	24,760
2.5		246.7	380.5	24,784
5		242.2	483.3	22,929
Significance[1]				
0 *vs* NaCl (2.5 and 5 mM)	24	ns	ns	ns
2.5 mM *vs* 5 mM		ns	ns	ns
0 *vs* NaCl (2.5 and 5 mM)	40	ns	ns	ns
2.5 mM *vs* 5 mM		ns	ns	ns
0 *vs* NaCl (2.5 and 5 mM)	71	ns	ns	ns
2.5 mM *vs* 5 mM		ns	*	ns

[1] Significance: *, for $p \leq 0.05$; ns, not significant. Note: The values are means of six samples (n = 6)

Table 2
Effects of three NaCl concentration in the NS on leaves, stem and roots fresh weight (FW) and dry weight (DW) of a plant of 'Scopatizzo' analyzed at 24, 40 and 71 days after cubes transfer (DAT).

		Leaves FW g·plant^{-1}	Leaves DW g·100 g^{-1} FW	Stem FW g·plant^{-1}	Stem DW g·100 g^{-1} FW	Roots FW g·plant^{-1}	Roots DW g·100 g^{-1} FW
NaCl (mM)	**DAT**						
0	24	216	11.32	280	5.22	134	5.16
2.5		226	11.14	294	4.96	128	5.02
5		226	10.73	301	4.91	161	4.42
0	40	1,053	8.12	862	5.78	438	3.45
2.5		1,060	8.11	1,039	5.40	473	3.61
5		1,044	8.28	1,068	5.35	451	3.37
0	71	1,543	10.69	1,576	6.67	792	4.00
2.5		1,373	11.51	1,496	6.64	1,217	4.06
5		1,395	10.62	1,616	6.11	949	3.84
Significance[1]							
0 *vs* NaCl (2.5 and 5 mM)	24	ns	ns	ns	ns	ns	ns
2.5 mM *vs* 5 mM		ns	ns	ns	ns	ns	ns
0 *vs* NaCl (2.5 and 5 mM)	40	ns	ns	ns	ns	ns	ns
2.5 mM *vs* 5 mM		ns	ns	ns	ns	ns	ns
0 *vs* NaCl (2.5 and 5 mM)	71	ns	ns	ns	ns	ns	ns
2.5 mM *vs* 5 mM		ns	ns	ns	ns	ns	ns

[1] Significance: ns, not significant. Note: The values are means of six samples (n = 6).

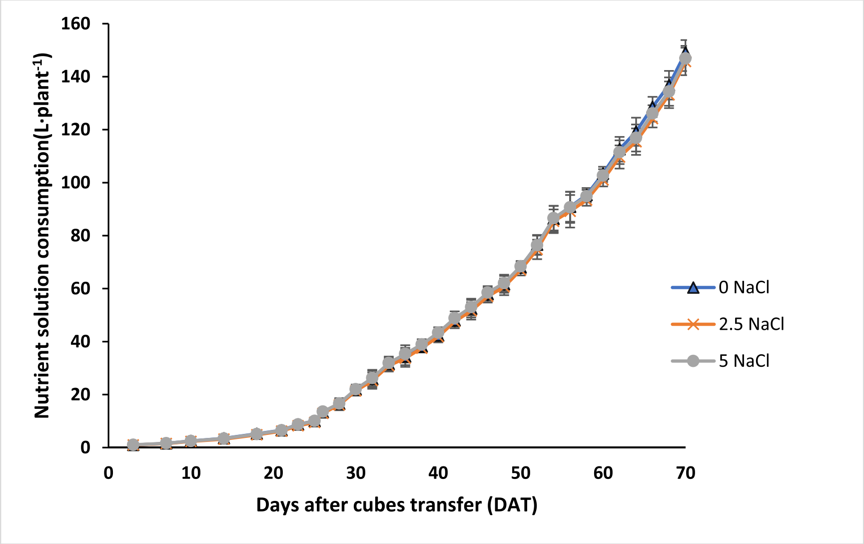

Fig. 2. Cumulative nutrient solution (NS) consumption of the plants of 'Scopatizzo' (*Cucumis melo* L.) fertigated with three levels of NaCl (0, 2.5 and 5 mM) in the NS. ± vertical bars represent the standard error of mean values (n = 3).

development the daily NS uptake of the plants was on average 0.5 – 0.8 L·plant^{-1} (Fig. 2), in the phase of full vegetative developments the daily NS uptake exceeded 2 L·plant^{-1} (Fig. 2). The average NS cumulative uptake was not only influenced by plants growth but, as was shown on Fig. 3, it was lineary related to the sum of the daily photosyntetic active radiation (total light integral:TLI) measured into the greenhouse at plant level. Regarding the EC of the NS, the NS with the highest NaCl concentration shown always the highest EC (Fig. 4). Furthermore, the differences of EC between the treatments increased during the crop cycle, and at 69 DAT the EC of the NS with 5 mM of NaCl reached the value of 7.17 dS·m^{-1}, the NS with 2.5 mM of NaCl reached the EC value of 4.93 dS·m^{-1} and the NS without the addition of NaCl had an EC value of 4.16 dS·m^{-1} (Fig. 4). It is fundamental to underline that during the cultivation cycle the NS was replenished every two-three days, but never completely discharged and renewed, and the average water use efficiency (WUE) was 27.6 L of NS·kg^{-1} (Table 3).

3.3. Fruits production and quality traits

For all the three treatments, the harvest began at 28 DAT, with an average yield, at the end of the cycle, of 5.31 kg·plant^{-1} (Table 3). As it was shown on Fig. S3, only during the last four harvests the plants fertigated with NS with 5 mM of NaCl showed a slight fruits production decrease compared with the other two treatments, but this was not sufficient to be considered statistically different the total yields. The average number of fruits harvested was 26.2 fruits·plant^{-1}, with an average fruits weight of 203 g. Finally, cumulative fruits yield showed a parabolic relation with the TLI described by the equation reported on Fig. 5.

Considering the qualitive traits of fruits, the average fruits dry weight (DW) was 4.95 g·100 g^{-1} of FW, the average pH value of the fruits was 5.94, and the average TSS was 3.16 °Brix (Table 4). The fruits harvested from the plants fertigated with the addition of NaCl in the NS had 28.8% more titratable acidity content compared with the plants grown without the addition of NaCl in the NS (Table 4). Instead, the average total phenolic content was 0.182 mg of gallic acid · g^{-1} of FW (Table 5), while the glucose content was 6.4% higher for the plants grown without the addition of NaCl in the NS compared with those growth with the addition of NaCl in the NS and the average fructose content in the fruits was 10.13 mg·g^{-1} of FW (Table 5). Furthermore, the

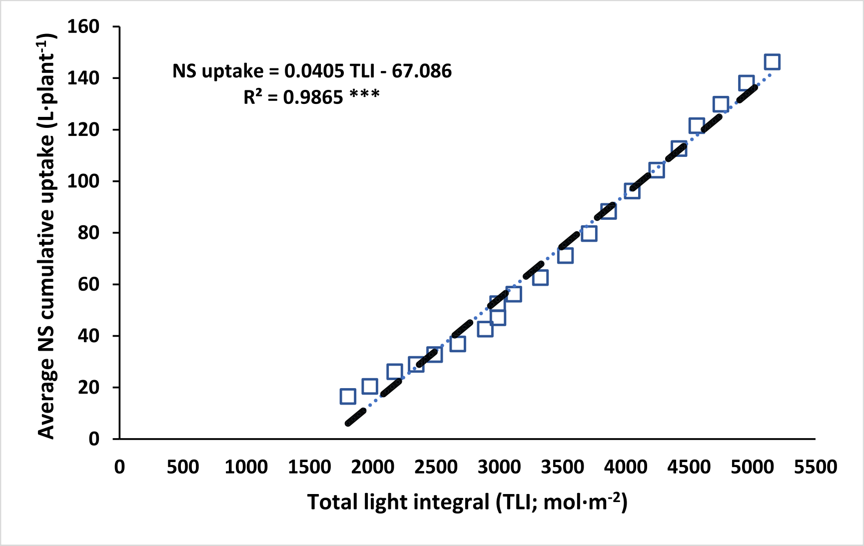

Fig. 3. Relationship between the average cumulative NS uptake (n = 3) of the plants of 'Scopatizzo' (*Cucumis melo* L.) and the cumulative natural photosynthetic acitve radiation supplied to the plants (TLI). Symbols depict mean measured values for NS cumulative uptake at the correspondig TLI. Significance: *** for $p \leq 0.001$

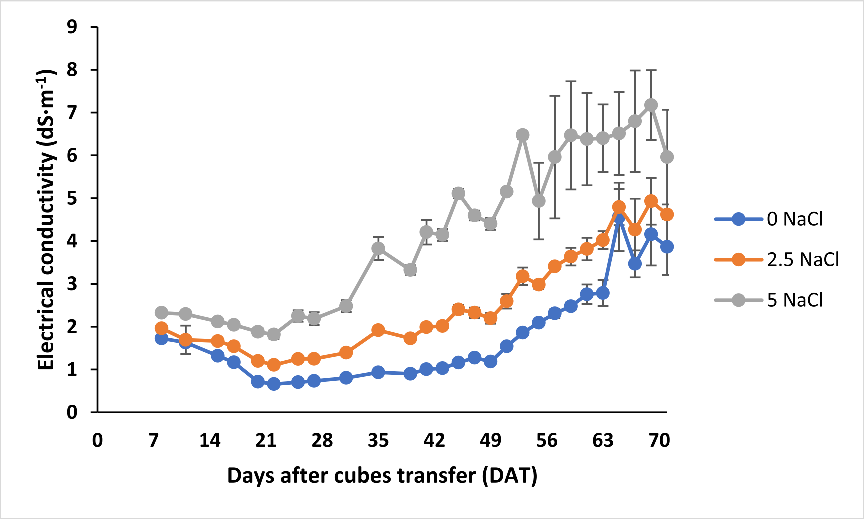

Fig. 4. Variation of electrical conducibility (EC) of the NS with three levels of NaCl (0, 2.5 and 5 mM) ricirculated in the NFT system during the cultivation of 'Scopatizzo' (*Cucumis melo* L.). ± vertical bars represent the standard error of mean values (n = 3).

Table 3
Effects of three NaCl concentration in the NS on fruits yield, fruits number, fruits fresh weight (FW) and water use efficiency (WUE) of the plants of 'Scopatizzo' (*Cucumis melo* L.) grown with NFT system.

	Yield $\text{kg}\cdot\text{plant}^{-1}$	Fruits n.	Fruits fresh weight (FW) $\text{g}\cdot\text{fruit}^{-1}$	Water use efficiency (WUE) $\text{L}\cdot\text{kg}^{-1}$
NaCl (mM)				
0	5.45	27.2	201	27.3
2.5	5.37	26.4	203	27.0
5	5.13	25.1	204	28.6
Significance[1]				
0 *vs* NaCl (2.5 and 5 mM)	ns	ns	ns	ns
2.5 mM *vs* 5 mM	ns	ns	ns	ns

[1] Significance: ns, not significant. Note: The values of yield, fruits and fruits fresh weight are means of nine samples (n = 9) while the values of WUE are the means of three samples (n = 3).

total chlorophyll content in the fruits was 26.7% higher in plants of the treatment 2.5 mM with respect of those of 5 mM treatment (Table 5). Finally, the total carotenoids content was 55.7 mg of β-carotene·kg^{-1} of FW, irrespective of the NaCl concentration in the NS (Table 5).

3.4. Gas exchange systems and photosynthesis performances

Generally, the addition of NaCl in the NS increased the gas performace system of the plants of 'Scopatizzo' (Table 6). On detail, the net photosynthetic rate (*A*) was 13.9% more for the plants fertigated with the addition of NaCl in the NS compared to the plants fertigated without the addition of NaCl in the NS (Table 6), while the stomatal conductance (*gs*) and the transpiration rate (*E*) were, respectively, 52.9 and 77.5% more for the plants of 'Scopatizzo' fertigated with the addition of NaCl in the NS compared with those fertigated without the addition of NaCl in the NS.

From the analysis of the rapid light response curves it was observed that the maximum quantum yield for whole chain electron transport at low light intensity (*Alpha*) was 12.2% lower in plants fertigated with the

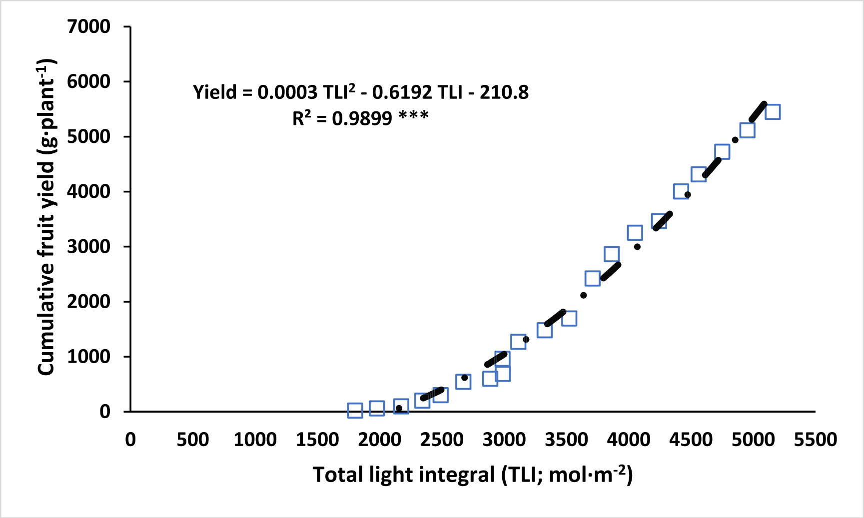

Fig. 5. Relationship between the average cumulative fruits yield of the plants of 'Scopatizzo' and the cumulative natural photosynthetic active radiation supplied to the plants (TLI). Symbols depict mean measured values for cumulative fruit yield at the correspondig TLI Significance: *** for $p \leq 0.001$

Table 4
Effects of three NaCl concentration in the NS (0, 2.5 and 5 mM) on fruits dry weight (DW), pH, total soluble sugars (TSS) and titratable acidity for the plants of 'Scopatizzo' (*Cucumis melo* L.) grown with NFT system.

	Dry weight (DW) $g \cdot 100\ g^{-1}$ of FW	pH	Total soluble solids (TSS) °Brix	Titratable acidity $g \cdot 100\ g^{-1}$ of citric acid
NaCl (mM)				
0	4.93	5.93	3.14	0.085
2.5	5.02	5.89	3.17	0.110
5	4.90	5.99	3.17	0.109
Significance[1]				
0 *vs* NaCl (2.5 and 5 mM)	ns	ns	ns	*
2.5 mM *vs* 5 mM	ns	ns	ns	ns

[1] Significance: *, for $p \leq 0.05$; ns, not significant. Note: The values are means of nine samples ($n = 9$).

Table 5
Effects of three NaCl concentration in the NS on fruits content of total phenolic compounds, glucose, fructose, total chlorophyll and carotenoids for the plants of 'Scopatizzo' (*Cucumis melo* L.) grown with NFT system.

	Total phenolic compounds mg of gallic acid $\cdot\ g^{-1}$ of FW	Glucose $mg \cdot g^{-1}$ of FW	Fructose $mg \cdot g^{-1}$ of FW	Chlorophyll $mg \cdot g^{-1}$ of FW	Total Carotenoids mg of β-carotene $\cdot\ kg^{-1}$ of FW
NaCl (mM)					
0	0.188	10.28	10.35	0.111	55.63
2.5	0.183	9.47	9.64	0.133	56.47
5	0.174	9.88	10.41	0.105	55.08
Significance[1]					
0 *vs* NaCl (2.5 and 5 mM)	ns	*	ns	ns	ns
2.5 mM *vs* 5 mM	ns	ns	ns	*	ns

[1] Significance: *, for $p \leq 0.05$; ns, not significant. Note: The values are means of nine samples ($n = 9$).

Table 6
Effects of three NaCl concentration in the NS (0, 2.5 and 5 mM) on photosynthesis net rate (*A*), stomatal conductance (*gs*) and transpiration rate (*E*) of the plants of 'Scopatizzo' grown with NFT system.

NaCl (mM)	*A* µmol $CO_2.m^{-2}.s^{-1}$	*gs* mmol $H_2O.m^{-2}.s^{-1}$	*E* mmol $H_2O.m^{-2}.s^{-1}$
0	41.10	0.103	6.38
2.5	46.21	0.140	10.12
5	47.40	0.175	12.53
Significance[1]			
0 *vs* NaCl (2.5 and 5 mM)	**	**	**
2.5 mM *vs* 5 mM	ns	ns	ns

[1] Significance: **, *, respectively, for $p \leq 0.01$ and $p \leq 0.05$; ns, not significant. Note: The values are means of six samples ($n = 6$).

Table 7
Effects of three NaCl concentration in the NS (0, 2.5 and 5 mM), on the maximum quantum yield for whole chain electron transport, at low light intensities (*Alpha*), the maximum electron transport capacity, at light saturation (*ETRmax*), and the light saturation coefficient (*Ik*) of the plants of 'Scopatizzo' grown with NFT system.

NaCl (mM)	Alpha µmol $electrons \cdot m^{-2} \cdot s^{-1}$	ETRmax µmol $electrons \cdot m^{-2} \cdot s^{-1}$	Ik µmol $photons \cdot m^{-2} \cdot s^{-1}$
0	1.31	229	529
2.5	1.14	384	1,014
5	1.28	214	507
Significance[1]			
0 *vs* NaCl (2.5 and 5 mM)	ns	ns	ns
2.5 mM *vs* 5 mM	**	**	**

[1] Significance: **, *, respectively, for $p \leq 0.01$ and $p \leq 0.05$; ns, not significant. Note: The values are means of six samples ($n = 6$).

addition of 2.5 mM of NaCl in the NS compared to those fertigated with the addition of 5 mM of NaCl in the NS (Table 7). Instead, the efficiency of electron transport chain at saturation light intesity (*ETRmax*) was by 79.4% more for the plants fertigated with 2.5 mM of NaCl in the NS compared to those fertigated with 5 mM of NaCl and the photosynthetic photon flux density (PPFD) to obtain the saturation of the electron transport chain (*Ik*) was two times higher for the plants growth with the treatment 2.5 mM than for those obtained with treatment 5 mM (Table 7).

4. Discussion

In both open field and soilless cultivation systems, the presence of NaCl in irrigation water leads to a reduction in crop productivity (Tedeschi et al., 2011) and the discharge of the drained NS, to an increase in the environmental impacts of agricultural activity (Savvas et al., 2005a). Several studies reported the effect mechanisms of salt stress on melon. For example, Munns and Tester (2008) reported that salt stress affects melon plants by disrupting water uptake, ion balance, and metabolic processes, leading to reduced growth and yield (Munns and Tester, 2008). High NaCl concentrations in the NS increase the osmotic pressure, making it difficult for plants to absorb water, which in turn reduces turgor pressure and cell expansion (Parida and Das, 2005). Salt stress also causes ion toxicity, particularly from sodium ($Na+$) and chloride ($Cl-$) ions, which interfere with nutrient uptake and transport, causing nutrient imbalances and deficiencies (Zhu, 2001).

At the physiological level, salt stress reduces photosynthetic efficiency by affecting gas exchange parameters. Increased salt levels lead to higher stomatal conductance and transpiration rates, which can exacerbate water loss and further stress the plant (Chartzoulakis and Klapaki, 2000). Additionally, salt stress affects the electron transport chain in photosynthesis, reducing the quantum yield and overall photosynthetic performance (Chaves et al., 2009). In our research, we used the NFT with NS recirculation (closed system), in order to avoid the discharge of NS, with a consequent increase in WUE and, furthermore, to reduce the environmental impact of the agriculture activity, and to enhance the qualitative profile of an local variety of unripe melon (called 'Scopatizzo'), which fruits are consumed as alternative to cucumber (*Cucumis sativus* L.) (Palmitessa et al., 2021; Somma et al., 2021). Grewall et al. (Grewal, 2010) reported that, an increase of NaCl concentration from 0.5 to 2 mg·kg^{-1} of soil, the water uptake and the WUE of barley, canola, wheat, and chickpeas progressively decreased. Also considering the cultivation of tomato in greenhouse with soilless system, increasing the salt content of the NS the fruits yield and the WUE decrease (Qaryouti et al., 2007). Basing on these evidences, the first remarkable results of our research activity were that the whole plants biomass and architecture of 'Scopatizzo' were not negatively affected by the NaCl content in the NS (Table 1 and 2). Furthermore, differently to what has been described by the previous studies cited (Grewal, 2010) (Qaryouti et al., 2007), the NS uptake (Fig. 2), the fruits yield and WUE (Table 3) of the plants of 'Scopatizzo' were not negatively influenced by the NaCl content of the NS. Considering the root environment of the NFT cultivation system, the main characterisics are that: i) NS is continuosly available, ii) NS is continuously flowing, avoiding the accumulation of the indesiderable ions on roots surface, iii) only part of the roots are submerged in the NS (Hurd, 1978). Our hypothesis, about the results obtained during the research activity, is that thanks to the charachteristics of NFT system and through a smart management systems of the NS (fertigation shedule, EC and pH managemet), as Tzortzakis (Tzortzakis, 2009) already observed for lettuce, NFT systems may alleviate salt stress syntoms, allowing the success of cultivation of 'Scopatizzo'. During our research trial, the NS circulated in the NFT system was never discharged, allowing to increase the WUE of the cultivation system at the average value by 27.6 L·kg^{-1} (Table 3). These results are particularly interesting to underline the sustainability and the environmental impact of the proposed cultivation system. In fact, it was premised that the 'Scopatizzo' landrace has been proposed as alternative of the cultivation and consumption of cucumbers. According to recent studies, that investigated the cultivation of cucumber in a soilless system with growing media, the average yield of the cucumber (hybrid F1), considering the commercial crop cycle, was around 2.4 – 5.6 kg·plant^{-1} (Ashraf et al., 2020; Çakir et al., 2017; Singh et al., 2019), comparable with the yield of the 'Scopatizzo' obtained during our study (Table 3). The variability of the yield of cucumber plants found in the cited studies depends of different factors: genotype, climatic conditions, growth system, etc. Similarly, the WUE found for the aforementioned studies (Ashraf et al., 2020; Çakir et al., 2017; Singh et al., 2019) varied from 15 to 45 L·kg^{-1}, that is the same range of the WUE value reported in our study (27.6 L·kg^{-1}: Table 3). Furthermore, the salinity levels of NS did not negatively influence the overall quality of 'Scopatizzo' fruits (Table 4 and Table 5). Since 'Scopatizzo' looks very much like a melon, but it greatly resembles a cucumber (Renna et al., 2020), it might be interesting to compare the quality traits between this local variety and cucumber. Based on the average data reported by the National Nutrient Database of the United States Department of Agriculture, the dry matter content of cucumber fruit was 4.80 g·100 g^{-1} of FW (USDA, 2019), comparable with the average DW of 'Scopatizzo' (4.95 g·100 g^{-1} of FW; Table 4). Instead, considering the glucose + fructose content of cucumber it was 1.63 g·100 g^{-1} of FW (USDA, 2019), while it was, on average, 2.06 g·100 g^{-1} of FW for the fruits of 'Scopatizzo'(Table 5). In fact, the glucose content of the fruits was negatively influenced by the addition of NaCl in the NS, but glucose + fructose content of the fruits did not shown significant differences between the treatments (data not shown). This result was further confirmed by the TSS analysis (Table 4), that was not influenced by the NaCl content of the NS. Regarding, titratable aciditity, it increased in fruits obtained adding NaCl in the NS compared with the fruits of the plants fertigated without the addition of NaCl in the NS (Table 4), in agreement with the results obtained for tomato (Agius et al., 2022) and cucumber (Huang et al., 2009). The analysis of the total chlorophyll content of the fruits (Table 5) showed a decrease passing from 2.5 to 5 mM of NaCl in the NS, an aspect that could be considered a slight sign of salt stress, as previously reported in the literature, that is to say that increasing the salt concentration in the NS beyond certain levels (depends of growth condition and genotypes) the chlorophyll content of cucumbers decreases (Tiwari et al., 2010). In general, the nutracetical profile of the fruits of 'Scopatizzo' observed during our study was similar with those observed for another Apulian landrace of unripe melon called 'Carosello' (Palmitessa et al., 2022) and adding NaCl in the NS untill reach the concentration of 5 mM did not modify the fruits quality traits.

Furthermore, the increase in salt concentration in the NS did not negatively influence the gas exchange system (Table 6) and photosynthetic activity (Table 7) of 'Scopatizzo'. In a study conducted on cucumber, it has been observed that the increase of NaCl content of the NS led to a reduction of net photosyntetic rate and stomatal conductance (Wang et al., 2017). In our study it was observed that the plants fertigated with NS added with NaCl shown the photosynthesis performances comparable with those fertigated without the addition of NaCl in the NS and this could be explained according to Wang et al. (Wang et al., 2019), who demonstrated that photosynthetic activity can be promoted by low NaCl contents (under plant stress limit) in the NS and inhibited at higher salinity levels. RLCs are a powerful tool used to assess photosynthetic activity, in terms of photophysiological parameters. These parameters provide detailed information on the saturation characteristics of the electron transport system and describe light adaptation state and capacity to tolerate short-term changes in light condition of a plant (Ralph and Gademann, 2005).

In fact, from the analysis of the photosythesys obtained by RLCs during this study (Table 7) emerged that the best efficiency of electron transport chain at saturation light intesity (*ETRmax*) and highest PPFD to obtain the saturation of the electron transport chain (*Ik*) were found for the plants grown with intermedie NaCl content of the NS (2.5 mM – Table 7).

5. Conclusion

This research activity demonstrates that the cultivation of 'Scopatizzo' in a spring-summer cycle, with NFT closed system and moderate level of NaCl in the NS, allowed to obtain a similar yield of that obtained in cucumber, without compromising the nutraceutical content of fruits and with a WUE similar to that obtained by the cultivation of grafted cucumber hybrids in the modern greenhouses. For these reasons, the results of this study may be exploited for promoting the cultivation of ‘Scopatizzo’, as alternative to cucumber, also since the seeds of ‘Scopatizzo’ are cheaper than those of the hybrids of cucumber and may be reproduced freely by the growers.

The NS circulating in the NFT system was never completely renewed, but only replenished at regular intervals, depending on the uptake of the crop, determining a reduction of agriculture footprint and an increase of fertilizer and water efficiency. Further research activities have been undertaken to optimize the NS management in soilless systems and to study further margins for the enhancement of unripe melon landraces through the use of cultivation systems with high agronomic inputs use efficiency.

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CRediT authorship contribution statement

Onofrio Davide Palmitessa: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Massimiliano Renna:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **Davide De Angelis:** Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Angelo Signore:** Writing – review & editing, Visualization, Methodology, Data curation. **Francesco Serio:** Writing – review & editing, Visualization, Validation, Methodology, Conceptualization. **Carmine Summo:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Pietro Santamaria:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scienta.2024.113599.

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