agronomy

MDPI

Article

Lignite Substrate and EC Modulates Positive Eustress in Cucumber at Hydroponic Cultivation

Radosław Łaźny [1,*], Małgorzata Mirgos [1], Jarosław L. Przybył [1], Monika Niedzińska [1], Janina Gajc-Wolska [1], Waldemar Kowalczyk [2], Jacek S. Nowak [2], Stanisław Kalisz [3] and Katarzyna Kowalczyk [1]

[1] Department of Vegetable and Medicinal Plants, Institute of Horticultural Sciences, Warsaw University of Life Sciences-SGGW, 166 Nowoursynowska Street, 02-787 Warsaw, Poland; malgorzata_mirgos@sggw.edu.pl (M.M.); jaroslaw_przybyl@sggw.edu.pl (J.L.P.); monika_niedzinska@sggw.edu.pl (M.N.); janina_gajc_wolska@sggw.edu.pl (J.G.-W.); kowalczyk_katarzyna@sggw.edu.pl (K.K.)

[2] The National Institute of Horticultural Research, Konstytucji 3 Maja 1/3 Str., 96-100 Skierniewice, Poland; waldemar.kowalczyk@inhort.pl (W.K.); jacek.nowak@inhort.pl (J.S.N.)

[3] Department of Food Technology and Assessment, Division of Fruit, Vegetable and Cereal Technology, Warsaw University of Life Sciences-SGGW, 166 Nowoursynowska Street, 02-787 Warsaw, Poland; stanislaw_kalisz@sggw.edu.pl

* Correspondence: radoslaw_lazny@sggw.edu.pl

Abstract: Hydroponic cultivation using organic, fully biodegradable substrates that provide the right physical properties for plant growth and development is now the future of soilless production. Despite the high productivity and strict control of production conditions in this method, excessive salinity of the substrate often occurs. However, recent research results indicate that salinity at a high enough threshold can improve yield quality, while prolonged exposure to too high EC, or exceeding the safe EC threshold for a given species, leads to reduced quality and reduced or even no yield. The aim of this study was to determine the effect of biodegradable lignite substrate (L) and eustressor in the form of high EC nutrient solution (7.0 dS·m^{-1}) on morphological and physiological parameters, as well as the quality and yield of cucumber (*Cucumis sativus* L.) in hydroponic cultivation compared to the mineral wool substrate (MW). The MW/high EC combination showed a significant reduction in shoot diameter by nearly 6% compared to the MW/control EC combination. The stomatal conductance (g_s) and the transpiration rate (E) were also significantly reduced in this combination. The present study indicates that the effects of eustressor application vary depending on the growing medium used, and more favorable effects in terms of yield quality were obtained using biodegradable lignite substrate. The high EC of nutrient solution combined with lignite substrate (L/high EC) significantly increased in cucumber fruit the content of β-carotene, lutein, chlorophyll a, chlorophyll b and the sum of chlorophyll a + b by 33.3%, 40%, 28.6%, 26.3% and 26.7%, respectively, as compared to MW/high EC combination.

Keywords: organic substrate; eustress; photosynthetic pigment; photosynthetic efficiency; chlorophyll fluorescence; bioactive compounds

check for updates

Citation: Łaźny, R.; Mirgos, M.; Przybył, J.L.; Niedzińska, M.; Gajc-Wolska, J.; Kowalczyk, W.; Nowak, J.S.; Kalisz, S.; Kowalczyk, K. Lignite Substrate and EC Modulates Positive Eustress in Cucumber at Hydroponic Cultivation. *Agronomy* **2022**, *12*, 608. https://doi.org/10.3390/agronomy12030608

Academic Editor: Antonios Chrysargyris

Received: 10 February 2022
Accepted: 26 February 2022
Published: 28 February 2022

1. Introduction

Cucumber (*Cucumis sativus* L.) is the second most economically important and widely grown species in hydroponic systems after tomato [1,2], but it is one of the vegetables sensitive to high salt concentrations in the medium. According to Chen et al. [2], cucumber plants tolerate electrical conductivity up to a value of 2.5 dS·m^{-1}, and an increase by each unit of electrical conductivity results in a decrease in the yield of more than 10%. In addition to direct effects on plant architecture and yield loss, salinity stress affects plant photosynthetic pigments (chlorophyll a and b) and chlorophyll synthesis [3–5] and leads to disruption of primary and secondary metabolite fluxes [3,6]. A decrease in photosynthetic pigment synthesis under salinity stress has been observed in plants of the genus *Pisum* [7], in the species

Vicia faba (L.) [8], and in the cucumber *Cucumis sativus* (L.) [3], among others. Excessive salinity can result in a decrease in photosynthetic efficiency and excessive production of reactive oxygen species (ROS) [6,9]. Several studies have confirmed that increasing salinity levels cause stomatal closure, deprivation of proteins and cytoplasmic membranes of the photosynthetic apparatus and destruction of chloroplast ultrastructure [4,9–11]. Stomata play an important role in gas exchange between the plant and its environment. They allow CO_2 entry and limit water loss, but are sensitive to environmental stresses [12]. Limited diffusion of CO_2 into the leaf leads to reduced stomatal and internal conductance [12,13]. After entering the leaf, CO_2 diffuses into chloroplasts through intercellular air spaces [14]. Salinity can negatively affect stomatal conductance and CO_2 diffusion, which are important factors in photosynthesis [12,13,15].

The constraints of land scarcity and a growing population have led to a search for alternatives to conventional food production. Soilless cultivation is such an alternative, but even with this cultivation method, salt accumulation in the soil can occur. [16]. In the case of hydroponic cultivation with the solid substrate, where mineral wool is mostly used, an additional problem is that this substrate after the growing season becomes waste that should be disposed [17]. Currently, stone wool is used worldwide for hydroponic cultivation of economically important vegetable species such as tomato, bell pepper and cucumber. This is mainly due to the suitable physical properties of stone wool, which allow for increased yields compared to conventional crops [18,19]. However, producing 1 m^3 of this substrate emits 167 kg of CO_2 into the environment and consumes 275 kWh [17], where the CO_2 emitted during transportation of the substrate to the customer and the disposal of stone wool waste after the production process are not taken into account. These problems have led to a search for alternative organic substrates that will reduce the use of mineral wool in hydroponic production [18,20,21]. For comparison, the CO_2 emitted during the production of $1m^3$ of lignite is about 63 kg of CO_2, which allows to reduce the emitted CO_2 by almost 40%. Calculations based on the life cycle assessment (LCA) methodology [22,23] A fully biodegradable substrate that has comparable physical properties to mineral wool is lignite substrate [20], which can be used as an organic fertilizer in conventional crops after the production process. Using such substrate instead of mineral wool could help reduce the carbon footprint. In addition to the above-mentioned problems, soilless cultivation can not only provide a solution to the problem of lack of arable soil or excessive salinity but also help to improve food quality, such as an increase in bioactive compounds through the use of an elevated EC of nutrient solution combined with an organic substrate [24,25]. Following biological, chemical and physical factors that induce stress, plants switch on defense responses by producing various phytochemicals and bioactive compounds [26]. Available research results clearly indicate that salinity stress can be a tool to improve vegetable quality, including their nutritional value, which is essential for the proper functioning of the human body [25,27]. Many biotic and abiotic factors can be classified as eustressors, depending on their mode of action, composition or origin. An example of such an eustressor can be salinity [25,27,28]. The appropriate level of salinity can affect the color and firmness of cucumber fruit or increase the content of soluble solids [28] or dry matter [29]. Current food trends and processing market requirements are centered around foods with increased content of bioactive compounds [24,30]. Studies have shown that appropriate crop control, together with a stress factor applied at the right growth phase and level, can lead to an increase in bioactive compounds, affect chemical properties and the broader quality of final products [24,30]. There are several research works regarding the use of eustressor in the form of high EC of the nutrient solution (7 $dS \cdot m^{-1}$) in the cultivation of cucumber (*Cucumis sativus* L.) in biodegradable lignite medium. Perhaps the combination of a high EC nutrient solution and an organic lignite substrate will increase bioactive compounds without adversely affecting plant growth and development. The aim of the study was to evaluate the effect of the eustressor, i.e., high EC of the medium on the selected morphological, physico-chemical parameters and the activity of the photosynthetic apparatus in cucumber plants was determined. It was also examined how lignite substrate and eustress affect the yield, selected quality parameters and the content of bioactive compounds in the fruits of cucumber plants growing in lignite substrate.

2. Materials and Methods

2.1. Plant Material, Location and Experimental Conditions

The research was conducted at the Greenhouse Experimental Center of the Warsaw University of Life Sciences, in the cultivation chambers of the Department of Vegetable and Medicinal Plants following two seasons 2020 and 2021.

Microclimate conditions and fertigation were controlled by a climate computer. A greenhouse cucumber cultivar "Mewa" F1 by Rijk Zwaan, with fruits reaching 20–24 cm in length and weighing 200–240 g, was used for the study. The fruit of "Mewa" are characterized by dark, glossy skin with slight ribbing. The substrate for cultivation was made of lignite–carbomat by the CarboHort company, 100 cm × 20 cm × 8 cm (L), and mineral wool Grotop Master by the Grodan company, 100 cm × 20 cm × 7.5 cm (MW). Before cultivation, lignite and mineral wool mats were flooded with pH 5.5 and EC 2.6 dS·m^{-1} nutrient solution, at a rate of 8 dm^3 per mat. After 48 h, two 5 cm long vertical drainage cuts were made in the lignite mat covering plastic film on each of the longer sides of the mat starting at a height of 1 cm from the bottom of the mat. In the mineral wool mat, two horizontal cuts in each of the shorter sides of the mat and two 5 cm vertical cuts in the middle of the longer sides of the mat were made. In the first season, cucumber seedlings were planted on 10 July 2020. The daily solar radiation averaged 1474.9 J/cm^2, growing season temperatures were set to averaged D/N 25/23 °C (Figure 1) and the average humidity and CO_2 concentration were 70% and 800 ppm, respectively. In the second season, plants were planted on 12 July 2021 on mats prepared in the same way as in the first growing season. The daily solar radiation averaged 1407.0 J/cm^2, the D/N temperature was 25/22 °C (Figure 2), and the average humidity and CO_2 concentration were 70% and 800 ppm, respectively.

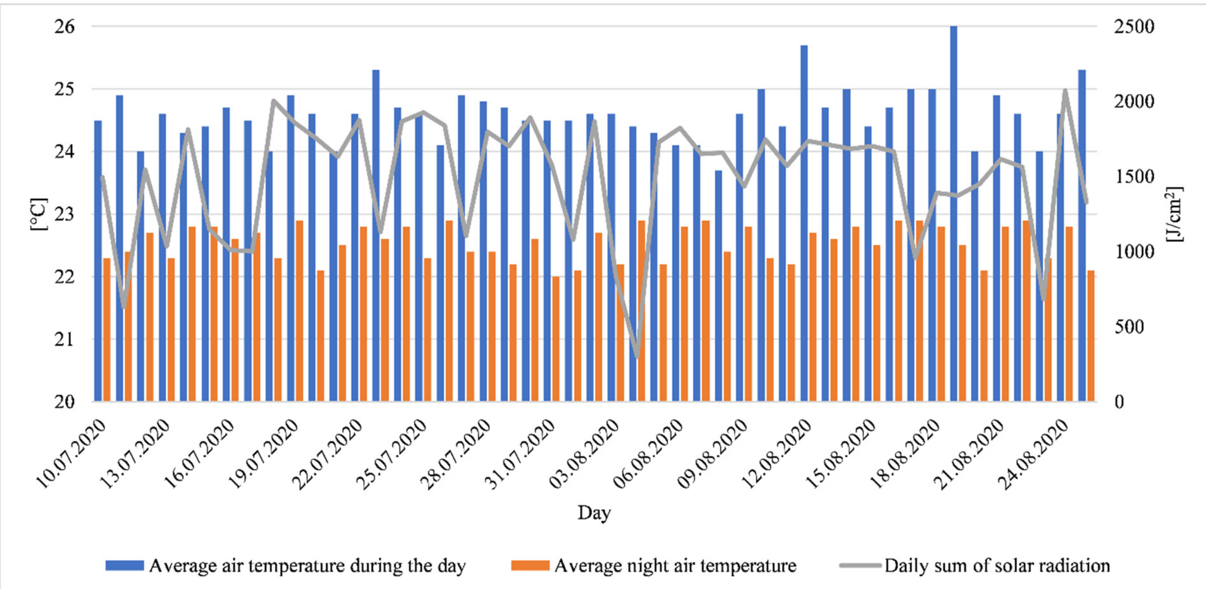


Figure 1. Climate parameters in the cultivation chamber during the experiment—season 2020.

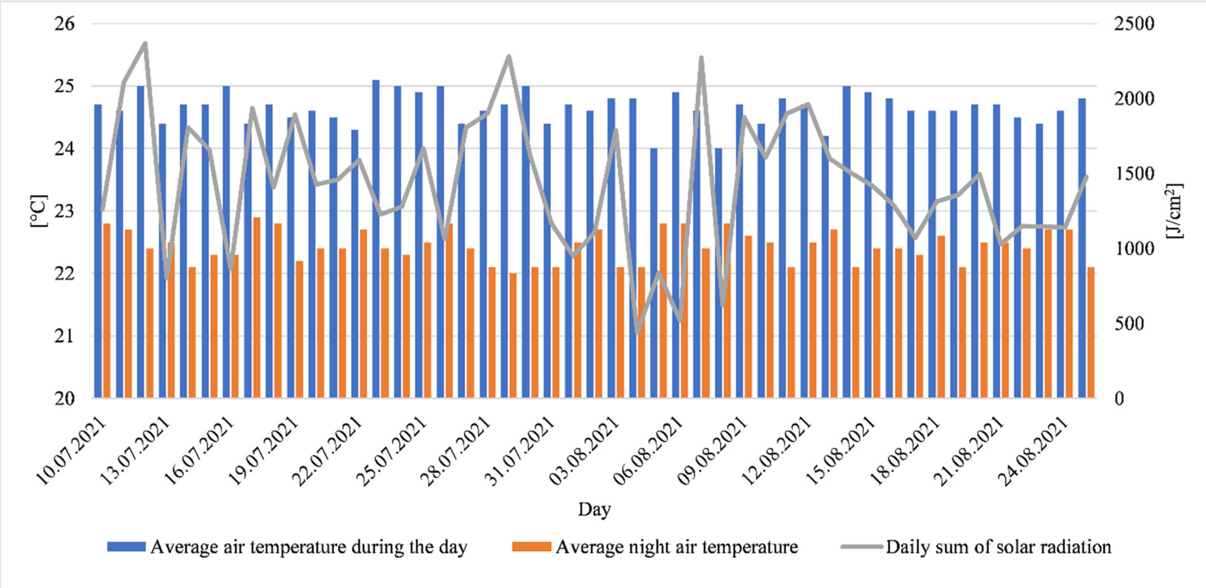


Figure 2. Climate parameters in the cultivation chamber during the experiment—season 2021.

In both seasons the research was carried out in the same way. Just after planting, the plants were fed with a control medium recommended for cucumber growing in mineral wool. Then, 7th day after planting, the experimental conditions were varied by changing the EC of the nutrient solution, for half of the growing plants. An increase in the EC of the nutrient solution was obtained by increasing the concentration of the control nutrient solution to an EC of about 7 dS·m^{-1}. The treatment tested were determined as follows: (1) MW/control EC—mineral wool substrate and control nutrient solution, (2) L/control EC—lignite substrate and control nutrient solution, (3) MW/high EC—mineral wool substrate and concentrated control nutrient solution, (4) L/high EC—lignite substrate and concentrated control nutrient solution. In combination MW/control EC and L/control the EC of the nutrient solution was 3.3 dS·m^{-1}, in combination MW/high EC and L/high the EC of the nutrient solution was 7 dS·m^{-1}. pH of the nutrient solution in all tested combinations was 5.8. The treatment was set up using the randomized block method, in 3 replications, with 9 plants in each. Irrigation was conducted using a computer, and concentrated nutrient solution and acid for pH regulation of the nutrient solution were applied using a Dosatron dispenser (D25RE2 0.2–2%). The concentrated fertilizer solution was divided into two tanks, A and B, where in tank A the following fertilizers were dissolved: calcium nitrate and potassium nitrate, while in tank B—potassium nitrate, magnesium sulphate, monopotassium phosphate and microelements in appropriate proportions. The third tank C contained concentrated HNO_3 acid to regulate the pH of the nutrient solution. Dosatron proportioners took from each of the tanks A and B appropriate, equal parts of concentrated fertilizer solutions to the mixer, where, after adding water, the nutrient solution of the desired EC was obtained. The third proportioner dispensed nitric acid from tank C to bring the nutrient solution to pH 5.8. The nutrient solution was prepared from one- or two-component mineral fertilizers The composition of the nutrient solution in the control was as follows (mg dm^{-3}): N-NO_3 230, N-NH_4 10, P-PO_4 50, K 330, Ca 180, Mg 55, S-SO_4 80, Fe 2.5, Mn 0.80, Zn 0.33, Cu 0.15, and B 0.33. The nutrient solution was dosed through the drip system by computer based on actual solar radiation and substrate water content measurements. Plants were trained on a single fruiting shoot, which was wrapped with a wire-tied twine installed above the cultivation bed at a height of 2.5 m. Twice a week, all lateral shoots and clinging tendrils were removed from the fruiting shoot, as well as the 3 oldest leaves from each plant. In both the first and second year of the study, the first fruit buds up to 4 leaves were removed. Both experiments were terminated at the 35th week of the year.

Fruits and leaves for destructive physico-chemical analyses were taken twice on the 29th and 45th days after planting (DAP). At each date 3 marketable fruits and 3 young fully developed leaves from each combination were taken randomly. Fruit and leaf analyses were performed in 3 repetitions.

2.2. Morphological Measurements

In each combination, 9 representative plants were chosen and measured every 7 days. The increase in length of the cucumber shoot was measured from the point at which the top of the shoot was located 7 days before (place appropriately marked on the string). The diameter was measured at two points on the shoot (with an electronic caliper) in the middle of the internode, between the 4th and 5th and 9th and 10th fully expanded leaves, counting from the shoot top. Leaf length, leaf width, and petiole length, consecutively of the 5th and 10th leaf on the shoot counting from the shoot top, were measured with a ruler. The weight of removed leaves, lateral shoots, and tendrils from each plant was weighed to determine the total green mass-produced.

2.3. Gas Exchange and Chlorophyll Fluorescence

Relative chlorophyll content in leaves by the SPAD (Soul Plant Analysis Systems) test was determined using a Minolta SPAD-502 Plus portable meter. The measurement was performed on the 5th and 10th fully expanded leaf, counting from the shoot apex of the plant. Net photosynthetic rate (P_N), stomatal conductance (g_s) and the transpiration rate (E) were measured using a LI-6400 Photosynthesis System (LI-COR, Inc., Lincoln, NE, USA) equipped with a 6400-40 Leaf Chamber fluorometer and a 6400-01 CO_2 mixer. Measurements were made on 3 randomly selected plants from each combination at 10 am to 12 pm with relatively little change in microclimate. Measurements were made at a reference CO_2 concentration (500 μmol s^{-1}), constant flow rate (400 μmol s^{-1}), relative humidity between 30% and 50%, and photosynthetic photon flux density (PPFD, 1000 mmol m^{-2} s^{-1}). In addition, photosynthetic water use efficiency (WUE) and instantaneous photosynthetic water use efficiency (iWUE) were calculated from the P_N/E and P_N/g_s quotients, respectively. Once the device was stabilized, leaves for the experiments were taken from each plant immediately before measurements were taken so as to limit the effect of leaf ontogeny on net assimilation rate and stomatal conductance. Chlorophyll fluorescence was measured on each of 9 plants in all 4 combinations using the FMS-2 Field Portable Pulse Modulated Chlorophyll Fluorescence Monitoring System (Hansatech Instruments Ltd., King's Lynn, Norfolk, UK), measuring parameters such as (Fs)—steady-state fluorescence yield, (Fm')—light-adapted fluorescence maximum, and (ΦPSII)—maximum quantum efficiency of PS II. Maximum efficiency of PS II photosystem in the dark—(Fv/Fm) was obtained after 30-min adaptation of leaves to the dark. A pocket PEA fluorescence meter (Hansatech Instruments Ltd., King's Lynn, Norfolk, UK) was used to measure direct fluorescence. Chlorophyll fluorescence and gas exchange measurements were made on the 5th and 10th leaves, counting from the shoot apex of the cucumber plant, and conducted in both growing seasons every 7 days and the results were averaged.

2.4. Contents of Dry Matter and Photosynthetic Pigments in Leaves

The dry matter content of the leaves was determined by the weight method at 105 °C, after the preparation of the samples. The (5th and 10th) leaves were taken twice during the experiment, with secateurs. Leaves taken randomly from each combination were cut, and then 5 g samples of plant material were placed in a laboratory dryer. The contents of β-carotene, lutein, and chlorophyll a and b in leaves and fruits were determined by high-performance liquid chromatography HPLC (Shimadzu Scientific Instruments). Cucumber leaves were homogenized with 2 g Na_2SO_4 per 100 g^{-1} f.w. of the sample. The homogenate prepared in this way was weighed on a laboratory scales at 2 g (leaves) and 5 g (fruits) and then grinded in a mortar with cold acetone (−20 °C) and quartz sand. The extracted samples were quantitatively transferred into 50 mL volumetric flasks and made up to 50 mL with cold acetone. Samples were centrifuged in tubes (15,000 rpm), and the resulting supernatant was filtered through a 0.22 µm syringe filter (Supelco IsoDisc™ PTFE 25 mm × 0.22 µm). Extracts were placed in 1 mL containers in a SIL-20AC HT automatic sample feeder (tray temperature 4 °C). An extract of 5 µL was applied to a Kinetex 2.6 µm C18 100 Å 100 mm × 4.6 mm chromatography column from Phenomenex. Compound separation was achieved using isocratic elution with methanol at 40 °C. The wavelength range was for β-carotene, chlorophyll a and b, respectively: 450 nm, 430 nm and 470 nm. From the obtained chlorophyll a and b results, the sum of chlorophyll a and b was calculated. All analyses were performed in triplicate.

2.5. Yield Quantity and Fruit Quality

The fruit was harvested every two days, and the number and weight of fruits were determined considering marketable and unmarketable yield. Based on the results, harvest index (HI) was calculated as the ratio of total yield to the above-ground part of the plant (leaves and shoots) including fruits [31].

The color of the fruit peel was determined on three randomly selected fruits using a MiniScan XE PLUS D/8-S portable color spectrophotometer (CIE Lab-scale—red color proportion—a*, yellow color proportion—b* and brightness—L*). The polar coordinates of chroma (saturation) $C^* = (a^{*2} + b^{*2})^{1/2}$ color intensity (hue angle) $H^* = \tan^{-1}(b^*/a^*)$ and staining index (ratio a*/b*) were also determined from the obtained data [32–34]. A standard white calibration plate was used to calibrate the spectrophotometer.

Fruit firmness was determined using an HPE hardness tester with a shank diameter of 5 mm. The measurement was made at 3 points on the fruit, at an angle of 90° from its plane. The results were given on the HPE hardness scale (0–100 units).

The dry matter and β-carotene, lutein, and chlorophyll a and b content of the fruits were determined by the methods described in Section 2.4. The total soluble solids content (TSS) was determined in freshly squeezed juice from randomly selected 3 fruits, 200 mL in volume, giving the results in % using a digital refractometer (Hanna Instruments HI96801).

The nitrate content of the fruits was determined using a mixed sample of randomly selected fruits with a total weight of 1 kg, which were homogenized. From the mixed sample prepared in this way, 10 g samples of plant material were taken three times by adding 0.5 g of activated carbon and 100 mL of 2% acetic acid ($C_2H_4O_2$) and the samples were then shaken. After 30 min, the samples were filtered through a fluted filter. Nitrate content in mg $N\text{-}NO_3^-$/100 g f.w. of fruit was determined using a Fiastar 5000 Analyzer by reducing nitrate (V) to nitrate (III) by passing the sample solution through a cadmium column. The resulting colored solution was measured spectrophotometrically at 540 nm.

2.6. Statistical Analysis

The results are reported as the mean from a total of two experiments ± standard error (SE) values of nine biological replicates (n = 9). The SE was calculated directly from crude data. Data were evaluated by analysis of variance (ANOVA) and differences between the means were compared by Tukey's test (HSD) at a significance level of $p < 0.05$. Statistical analyses were performed using Statistica 13.3. Prior to analyses, we tested whether the assumptions of an ANOVA, homogeneity of variances were achieved. The homogeneity of variances for all the studied parameters was evaluated by Levene's test.

3. Results

3.1. Morphological Parameters

Although there were no significant differences in weekly shoot length growth between the combinations, at the high EC of the nutrient solution a significant shortening of the total length of shoot was observed in MW/high EC cucumber plants by nearly 2.6% (Table 1), moreover, this combination also recorded a smaller cucumber shoot diameter by nearly 6% compared to MW/control EC. Plants fertilized with the high EC nutrient solution and grown in lignite medium had the smallest width of the tenth leaf, compared to the control

(Table 1). The high EC of the nutrient solution reduced the total leaf and shoot weight of plants growing in lignite by nearly 20% compared to the lower EC of the nutrient solution and mineral wool. There were no significant differences in the SPAD index of cucumber leaves depending on the substrate and EC of the nutrient solution applied (Table 1).

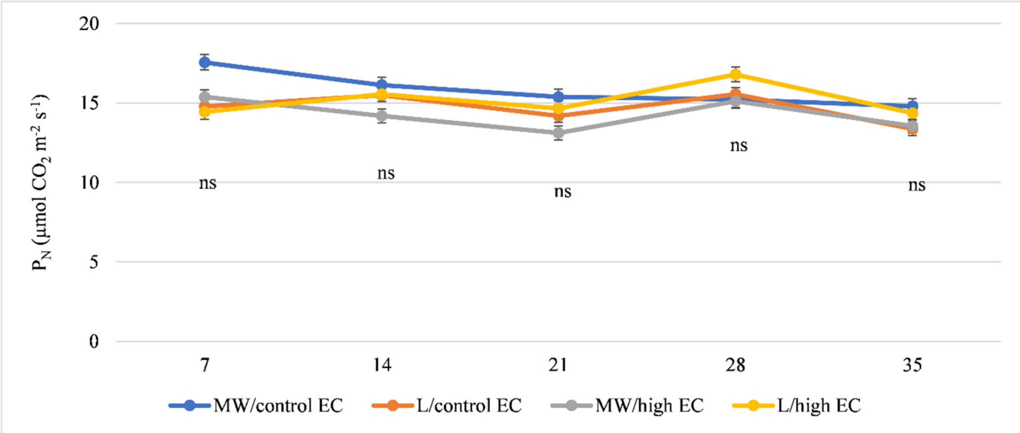
Table 1. Chosen morphological parameters of cucumber plants and chlorophyll content (SPAD) in relation to medium and nutrient solution EC (average from two years).

Parameter			Unit	Combination			
				MW/ Control EC	L/ Control EC	MW/ High EC	L/ High EC
Shoot	Weekly increase in length		cm	57.9 ± 1.9 ns	62.2 ± 1.7 ns	57.6 ± 1.9 ns	60.0 ± 1.7 ns
	Total length			276.8 ± 3.0 ab	286.9 ± 1.4 a	269.7 ± 3.8 b	280.4 ± 4.4 a
	Diameter under 5th leaf		mm	6.6 ± 0.1 a	6.5 ± 0.1 ab	6.2 ± 0.1 b	6.4 ± 0.1 ab
	Diameter under 10th leaf			7.7 ± 0.1 a	8.0 ± 0.1 a	7.3 ± 0.1 b	7.6 ±0.1 ab
Leaf	Number per week		pcs plant^{-1}	4.1 ± 0.1 ns	4.1 ± 0.1 ns	4.0 ± 0.1 ns	4.1 ± 0.1 ns
	5th leaf	Length	cm	20.3 ± 0.4 ns	21.2 ± 0.4 ns	20.3 ± 0.3 ns	20.0 ± 0.4 ns
		Width		23. 8 ± 0.4 ns	24.8 ± 0.5 ns	24.2 ± 0.4 ns	23.7 ± 0.4 ns
		Petiole length		14.0 ± 0.4 ns	14.2 ± 0.4 ns	13.6 ± 0.3 ns	13.6 ± 0.3 ns
		Chlorophyll content	SPAD unit	41.4 ± 0.7 ns	41.2 ± 0.6 ns	42.0 ± 0.7 ns	42.3 ± 0.7 ns
	10th leaf	Length	cm	25.3 ± 0.5 ns	25.6 ± 0.6 ns	24.0 ± 0.5 ns	24.8 ± 0.5 ns
		Width		31.5 ± 0.6 a	31.5 ± 0.6 a	30.7 ± 0.6 ab	29.2 ± 0.6 b
		Petiole length		18.2 ± 0.4 ns	18.0 ± 0.4 ns	17.7 ± 0.3 ns	17.0 ± 0.3 ns
		Chlorophyll content	SPAD unit	44.3 ± 0.4 ns	44.8 ±0.4 ns	44.8 ± 0.7 ns	44.9 ± 0.4 ns
Total leaf and shoot weight			g plant^{-1}	1267.8 ± 28.6 a	1195.7 ± 22.2 a	1164.0 ± 28.5 a	934.9 ± 28.5 b

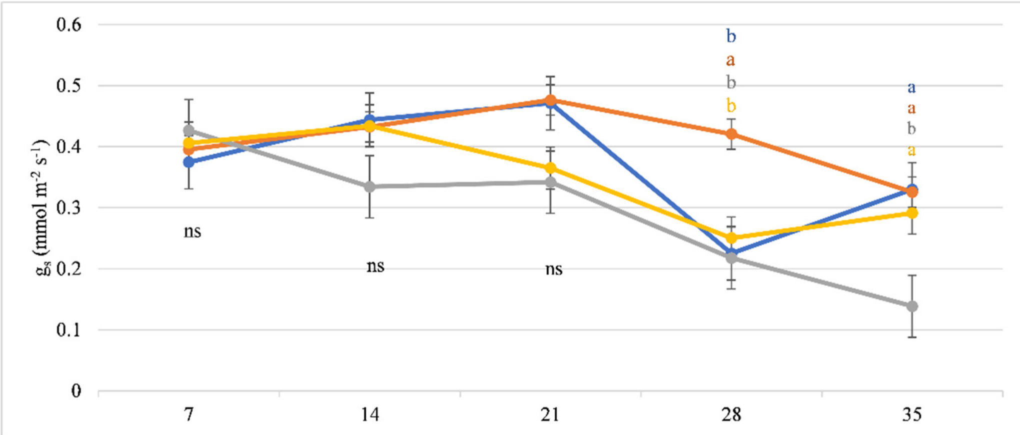
Average values marked with the same letters within the same row are not significantly different within the analyzed parameter at $p < 0.05$. Values with the prefix ± represent standard deviation. Abbreviations: ns, not significant.

3.2. Gas Exchange and Chlorophyll Fluorescence

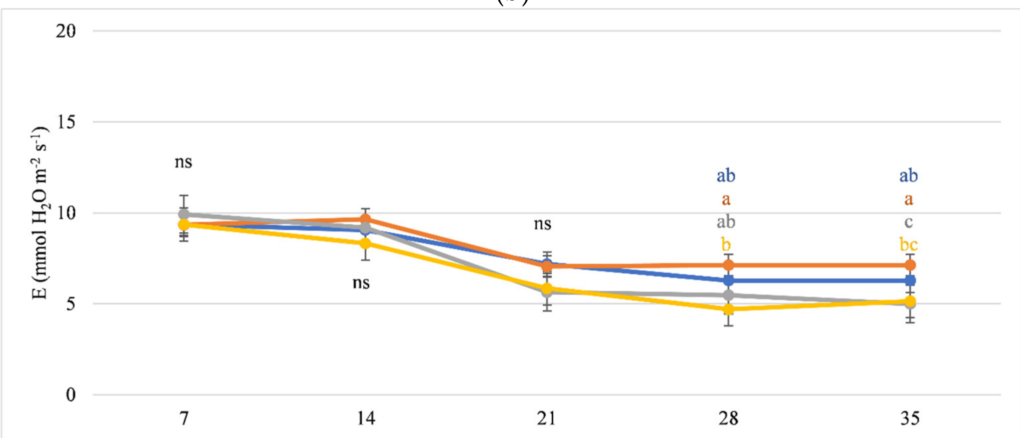
Eustressor in the form of high EC of the nutrient solution did not affect the rate of photosynthesis (P_N) in plants growing in all four combinations (Figure 3a). However, this factor reduced stomatal conductance (g_s) by more than 60% in the case of plants growing in mineral wool, which was not observed in the combination growing in lignite (Figure 3b). In the case of plants growing in the lignite substrate, stomatal conductance (g_s) started to decrease only on the 14th day of the experiment—14 DAP, 7 days after the stress factor was switched on (days after introduction of high EC 7 DAEC. Plants growing in mineral wool substrate showed a significant decrease in g_s immediately after the stress was turned on (Figure 3b). On day 28 DAEC, a temporary significant (by more than 50%) decrease in g_s was observed in plants fertilized with nutrient solution with standard EC growing in mineral wool compared to those grown on lignite (Figure 3b). At the end of the experiment, the high EC of the nutrient solution significantly reduced transpiration rate (*E*) in the mineral wool substrate by more than 30% (Figure 3c). During this period, an increase in photosynthetic water use efficiency (WUE) was also observed in combination with high EC of nutrient solution (MW/high EC and L/high EC) (Figure 3d). In both tested media, the eustressor (high EC) did not affect the instantaneous photosynthetic water use coefficient (WUE), while it was found to decrease significantly in combination L/control EC compared to MW/control EC by more than 8% (Figure 3e).



(**a**)

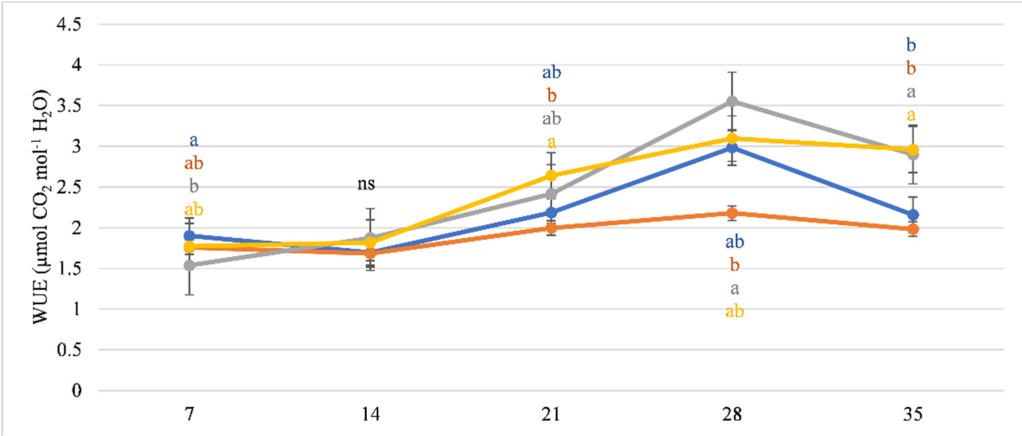


(**b**)

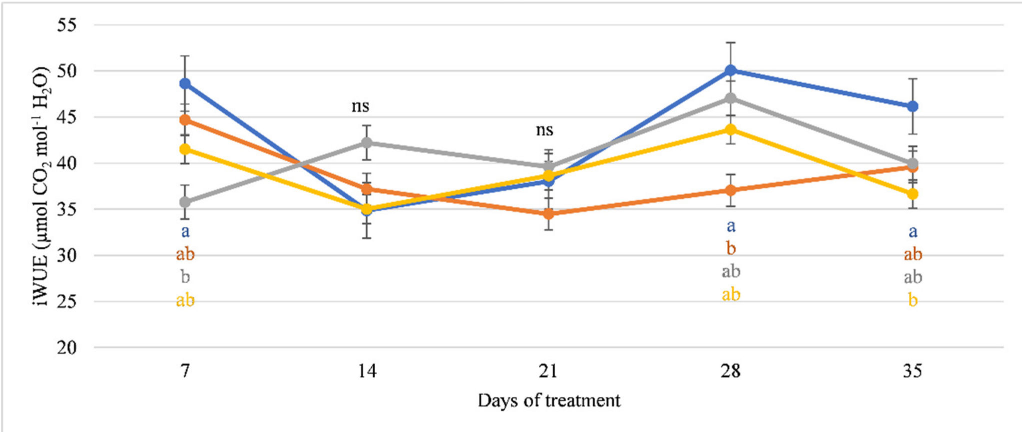


(**c**)

Figure 3. *Cont.*



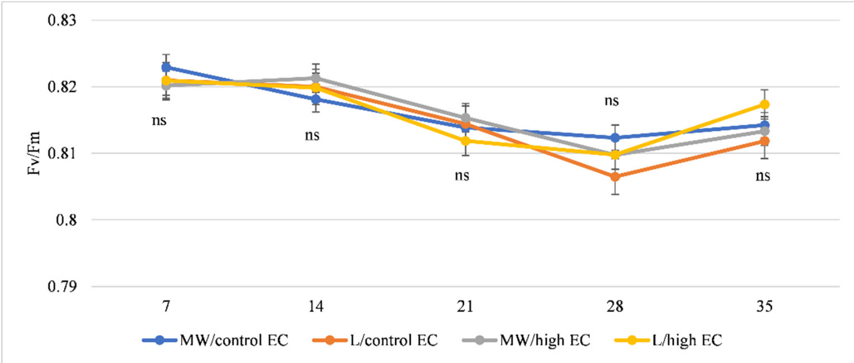
(**d**)



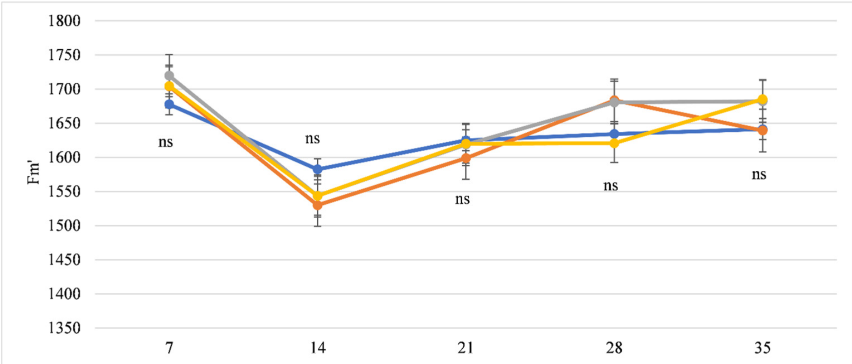
(**e**)

Figure 3. Effect of high EC of nutrient solution on net CO_2 assimilation intensity (P_N) (**a**), stomatal conductance (g_s) (**b**), transpiration intensity (*E*) (**c**), photosynthetic water use efficiency (WUE) (**d**), instantaneous photosynthetic water use efficiency (iWUE) (**e**), of cucumber plants depending on the applied medium on 7, 14, 21, 28, 35 DAEC (average from two years). Vertical bars indicate ± standard deviation. Abbreviations: ns, not significant. Average values marked with the same letters are not significantly different within the analyzed parameter at $p < 0.05$.

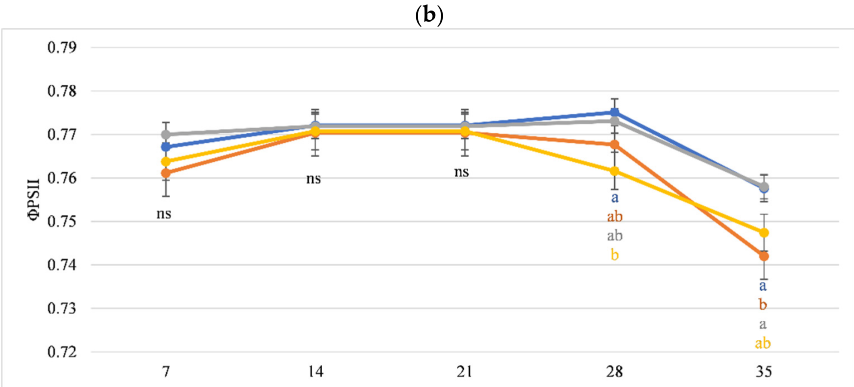
There was no effect of high nutrient solution EC on the maximum photochemical yield of PS II (Fv/Fm), regardless of the combination (Figure 4a). The maximum quantum yield of PS II (ΦPS II) followed a similar pattern, where no differences were obtained until day 21 DAEC of the experiment. At the end of the experiment, there was a significant reduction in ΦPS II in plants fertilized with nutrient solution of standard EC growing in lignite compared to plants growing in mineral wool of standard EC and treated with high EC nutrient solution (Figure 4c). Steady-state fluorescence yield (Fs) varied throughout the experiment. The application of eustressor did not affect this factor at the beginning and at the end of the experiment, while 14 DAEC plants growing in the combination with lignite at standard EC showed a significant increase in Fs, as compared to the other combinations by nearly 10%. On the other hand, on day 21 DAEC, plants treated with high EC of the nutrient solution showed a significant decrease in Fs in the mineral wool substrate by more than 7% compared to the combination with lignite (Figure 4d).



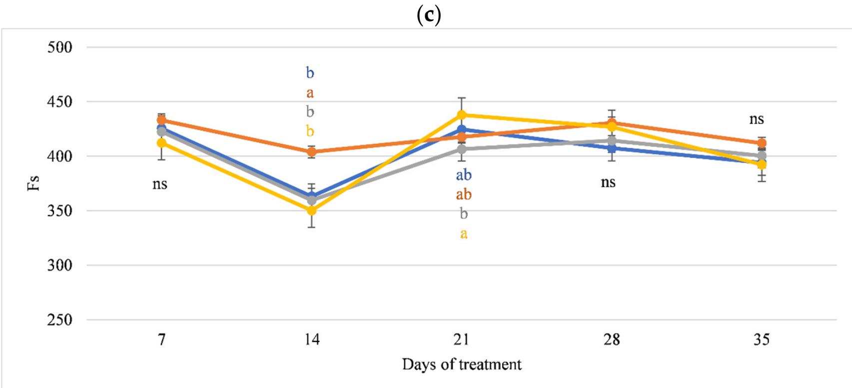
(**a**)



(**b**)



(**c**)



(**d**)

Figure 4. Effect of high nutrient solution EC on maximum photochemical yield of PSII (Fv/Fm) (**a**), maximum chlorophyll a fluorescence in dark-adapted leaves (Fm′) (**b**), the maximum quantum yield of PS II (ΦPSII) (**c**), and stationary fluorescence (Fs) (**d**) of cucumber plants depending on the medium used on 7, 14, 21, 28, and 35 DAEC (average from two years). Vertical bars indicate ± standard deviation. Abbreviations: ns, not significant. Average values marked with the same letters are not significantly different within the analyzed parameter at $p < 0.05$.

3.3. Photosynthetic Pigment Content and Leaf Dry Matter

The highest content of lutein was recorded in plant leaves—combinations L/control EC by more than 28% compared to the MW/control EC—leaf 5. While in combination L/high EC 9% higher content of this compound was found in the tenth leaf compared to leaves from plants of the MW/high EC combination (Table 2). Higher content (by nearly 10%) chlorophyll a content was found in plants grown in combination L/high EC (fifth and tenth leaves) as compared to leaves of plants from combinations MW/high EC. Lignite medium also significantly increased chlorophyll (a + b) and β-carotene content (Table 2).

Table 2. Dry matter content and photosynthetic pigment in leaves of cucumber plants (average from two years).

Number of Leaf	Parameter	Unit	Combination			
			MW/Control EC	L/Control EC	MW/High EC	L/High EC
5th	Dry matter	%	11.4 ± 0.1 a *	11.0 ± 0.1 a	11.5 ± 0.2 a	11.4 ± 0.1 a
	β-carotene	$mg\ 100\ g^{-1}$ FW	16.6 ± 0.1 c	20.5 ± 0.6 b	20.4 ± 0.5 b	22.4 ± 0.3 a
	Lutein		10.6 ± 0.2 c	14.8 ± 0.3 a	13.6 ± 0.4 ab	13.2 ± 0.4 b
	Chlorophyll a		124.4 ± 1.2 c	142.9 ± 2.2 b	139.7 ± 4.0 b	155.0 ± 4.2 a
	Chlorophyll b		39.6 ± 0.4 c	49.8 ± 1.1 a	45.8 ± 1.1 b	46.0 ± 0.7 b
	Total chlorophyll a + b		164.0 ± 1.6 c	204.8 ± 5.3 a	185.5 ± 5.1 b	188.9 ± 2.9 b
10th	Dry matter	%	11.8 ± 0.1 b	12.4 ± 0.2 ab	13.1 ± 0.3 a	13.2 ± 0.3 a
	β-carotene	$mg\ 100\ g^{-1}$ FW	14.9 ± 0.1 ab	16.2 ± 0.5 ab	14.7 ± 0.3 c	16.4 ± 0.4 a
	Lutein		9.7 ± 0.1 ab	10.3 ± 0.1 ab	9.5± 0.4 b	10.4 ± 0.03 a
	Chlorophyll a		114.4 ± 0.9 ab	116.9± 2.7 ab	109.9 ± 4.7 b	122.6 ± 1.4 a
	Chlorophyll b		42.0 ± 0.5 a	38.1 ± 1.0 ab	36.9 ± 1.5 b	40.8 ± 0.9 ab
	Total chlorophyll a + b		156.5 ± 1.0 ab	155.0 ± 3.7 ab	146.8 ± 6.2 b	163.4 ± 2.3 a

* Average values marked with the same letters are not significantly different within the analyzed parameter at $p < 0.05$. Values with the prefix ± represent standard deviation. Abbreviations: ns, not significant.

3.4. Yield, Fruit Quality and Content of Biologically Active Compounds in Cucumber Fruit (Average from Two Years)

High EC reduced yield in the MW/high EC by nearly 27% and in the L/high EC combination by 22% compared to the control (Table 3). The highest number and weight of marketable fruits, with the lowest number of unmarketable fruits, were obtained from plants grown on lignite substrate—L/control EC combination produced 11% more number and nearly 9% more weight of marketable fruits. More than 9.4% fewer unmarketable fruits were obtained from the L/high EC combination compared to MW/high EC, this combination also received obtained more than 5% lower HI index compared to the other combinations. (Table 3). Plants treated with high EC nutrient solution dropped some of their buds, both in the case of mineral wool and lignite substrate but the other one had more than 12.3% fewer dropped buds compared to MW/high EC (Table 3).

Regardless of the EC of the nutrient solution and the type of substrate, no differences were observed for firmness and the L* and a* components of the CIE Lab-scale (Table 4). The high EC of the nutrient solution had an effect on reducing the parameter of the b* (by 15.5%) component of the CIE Lab-scale (L/high EC) compared to L/high EC (Table 4), which indicates a higher proportion of blue. Fruit color indices did not differ significantly after eustressor application, regardless of the applied medium (a*/b*), while cucumber fruits from plants grown in combination MW/control EC and L/control EC were characterized by a significantly lower color index by respectively 5% and 10% (Table 4).

Table 3. Cucumber fruit yield by marketable and unmarketable fruit, number of fruit abortion and harvest index (average from two years).

Harvested Fruit		**Unit**	**Combination**			
			MW/ Control EC	**L/ Control EC**	**MW/ High EC**	**L/ High EC**
Weight of fruit	Total fruit	g plant^{-1}	6503.2 ± 131.1 b	7004.5 ± 102.1 a	4766.0 ± 202.7 d	5471.4 ± 145.3 c
	Marketable fruit		6190.3 ± 113.5 b	6834.2 ± 83.7 a	3486.5 ± 217.8 d	4311.9 ± 150.2 c
	Unmarketable fruit		312.9 ± 71.9 b	170.3 ± 60.7 b	1279.5 ± 108.7 a	1159.5 ± 0.8 a
Number of fruit	Total fruit	pcs plant^{-1}	29.5 ± 0.8 b	32.0 ± 0.6 a	22.9 ± 0.4 d	26.1 ± 0.4 c
	Marketable fruit		27.9 ± 0.5 b	31.2 ± 0.3 a	16.0 ± 0.9 d	19.8 ± 0.7 c
	Unmarketable fruit		1.6 ± 0.3 b	0.8 ± 0.3 c	6.9 ± 0.6 a	6.3 ± 0.5 a
	Aborded fruit		0	0	7.3 ± 0.4 a	6.4 ± 0.3 a
HI index			0.84 ± 0.02 a	0.85 ± 0.02 a	0.80 ± 0.02 b	0.85 ± 0.02 a

Average values marked with the same letters within the same row are not significantly different within the analyzed parameter at $p < 0.05$. Values with the prefix ± represent standard deviation. Abbreviations: ns, not significant.

Table 4. CIE Lab-scale color and firmness of cucumber fruit (average from two years).

		Combination			
Parameter	**Unit**	**MW/ Control EC**	**L/ Control EC**	**MW/ High EC**	**L/ High EC**
Firmness	HPE	63.1 ± 0.8 ns	63.7 ± 0.5 ns	61.8 ± 0.4 ns	63.9 ± 0.6 ns
Colour	a*	−7.2 ± 0.3 ns	−7.0 ± 0.2 ns	−6.7 ± 0.2 ns	−6.6 ± 0.2 ns
	b*	12.7 ± 0.7 ab	12.9 ± 0.5 a	11.2 ± 0.3 ab	10.9 ± 0.3 b
	L*	32.1 ± 1.1 ns	33.4 ± 0.9 ns	31.7 ± 0.3 ns	32.0 ± 0.8 ns
	C*	14.6 ± 0.8 ns	14.7 ± 0.6 ns	13.0 ± 0.4 ns	12.7 ± 0.4 ns
	H*	124.8 ± 2.1 ns	128.0 ± 1.2 ns	122.2 ± 1.6 ns	122.1 ± 1.0 ns
	a*/b*	−0.57 ± 0.02 ab	−0.54 ± 0.01 b	−0.60 ± 0.01 a	−0.60 ± 0.01 a

Average values marked with the same letters within the same row are not significantly different within the analyzed parameter at $p < 0.05$. Values with the prefix ± represent standard deviation. Abbreviations: ns, not significant.

Application of eustressor in the form of high EC increased dry matter of fruits in the MW/high EC combination by nearly 17% and in the L/high EC by 10%. In contrast, the high EC of nutrient solution and type of substrate had no effect on dry matter content (TSS) in cucumber fruits (Table 5). The highest content of bioactive compounds such as β-carotene, lutein, chlorophyll a, b, total of chlorophyll a + b was found in fruits from the L/high EC combination. These values were significantly higher in comparison to fruits from MW/high EC combination by respectively 33.3% (β-carotene), 40% (lutein), 28.6% (chlorophyll a), 26.3% (chlorophyll b) and 26.7% (chlorophyll a + b). Similar relationships were found in fruit from the L/control EC versus MW/control EC combination (Table 5). At the same time, when eustressor was applied to the test media, nitrate accumulation was found to be 50% higher in fruit from the MW/high EC combination compared to fruit from the L/high EC combination, from which it follows that fruit from the L/high EC combination had in nearly 45 mg NO_3 kg^{-1} FW less nitrate (Table 5).

Table 5. Contents of dry matter, TSS and bioactive compounds in cucumber fruits (average from two years).

Parameter	Unit	Combination			
		MW/ Control EC	**L/ Control EC**	**MW/ High EC**	**L/ High EC**
Dry matter	%	3.8 ± 0.1 c	4.0 ± 0.1 bc	4.6 ± 0.2 a	4.4 ± 0.1 ab
TSS	%	3.8 ± 0.1 ns	4.0 ± 0.2 ns	4.3 ± 0.1 ns	4.3 ± 0.2 ns
β-carotene	mg 100 g^{-1} FW	0.2 ± 0.01 b	0.3 ± 0.01 a	0.2 ± 0.01 b	0.3 ± 0.01 a
Lutein	mg 100 g^{-1} FW	0.4 ± 0.01 b	0.5 ± 0.03 a	0.3 ± 0.01 b	0.5 ± 0.01 a
Chlorophyll a	mg 100 g^{-1} FW	3.7 ± 0.1 b	4.6 ± 0.2 a	3.0 ± 0.2 c	4.2 ± 0.09 a
Chlorophyll b	mg 100 g^{-1} FW	1.7 ± 0.07 bc	2.2 ± 0.02 a	1.4 ± 0.07 c	1.9 ± 0.04 ab
Total chlorophyll a + b	mg 100 g^{-1} FW	5.4 ± 0.2 b	6.7 ± 0.3 a	4.4 ± 0.2 c	6.0 ± 0.1 a
Nitrates	mg NO_3 kg^{-1} FW	28.2 ± 1.6 c	15.5 ± 0.6 d	89.9 ± 0.4 a	45.0 ± 1.3 b

Average values marked with the same letters within the same row are not significantly different within the analyzed parameter at $p < 0.05$. Values with the prefix ± represent standard deviation. Abbreviations: ns, not significant.

4. Discussion

4.1. Morphological Characteristics of Cucumber Plants Grown on Organic and Mineral Substrates at High EC

Excessive salinity modifies plant growth and development parameters, negatively affecting the entire plant organism [13]. However, using appropriate salt concentrations and a suitable cultivation strategy, salinity stress can improve the intrinsic quality of vegetables or fruits [25]. Combining controlled salinity stress with organic (biodegradable) substrates that can improve plant growth will achieve the desired effects with environmental benefits. The application of eustressor in the form of high EC at a level of 7.0 dS·m^{-1} of the nutrient solution did not affect the inhibition of shoot growth in the case of combination with lignite, while it significantly reduced the shoot length in plants growing in mineral wool. Despite the introduction of excessive salinity stress, which strongly shortens shoot growth [2], the lignite substrate reduced its negative effects. Salinity stress caused a significant reduction width 10th leaf. in the L/high EC, which probably resulted in a reduction of their area. Reduced leaf area leads to limitations in a light interception and interferes with its proper distribution within the canopy [2,35], which directly reduces plant productivity [36]. High EC simultaneously resulted in a significant reduction of the total leaf and shoot weight gained by the plants, especially in lignite substrate. The results are in agreement with many studies, where it has been proved that plant biomass or leaf area decreases with increasing salt stress intensity [13,37,38].

4.2. Variation in Photosynthetic Efficiency and Chlorophyll Fluorescence of Cucumber Grown on Organic and Mineral Substrates at High EC

The net photosynthetic rate (P_N) followed a similar pattern, where no sensitivity of cucumber plants to the high EC of the nutrient solution was observed (Figure 3a), while at the end of the experiment a strong reduction of stomatal conductance (g_s) in the MW/high EC combination (Figure 3b). A reduction in transpiration rate (E) was also observed in both combinations with eustressor. Perhaps by the end of the experiment, the ion accumulation in the substrate was at a level that led to changes in the parameters discussed. In a study of tomatoes under high salinity conditions, Schwarz and Kuchenbuch [39] found that transpiration rates decreased for the total dry weight as the EC of the nutrient solution increased. Ding et al. [40] reported no change in P_N in leaves of pakchoi plants (*Brassica campestris* L. ssp. *Chinensis*) at a nutrient solution EC of 4.8, while an EC of 9.6 strongly reduced P_N in leaves. For g_s and E, parameters decreased significantly with increasing nutrient solution EC (4.8–9.6). Perhaps the use of an intermediate EC nutrient solution in cucumber cultivation in combination with a lignite substrate would not result in changes in the parameters discussed. Changes in g_s under salt stress can occur rapidly, reducing CO_2 availability, which directly translates into a reduction in P_N [14]. Different results were obtained by treating cucumber plants with NaCl, where P_N and g_s were reduced after only 1 day of the experiment [15], which may indicate that the high EC stress used in the experiment does not have as strong an effect as NaCl. However, changes in P_N, g_s, and E can be caused by both high EC treatment of the nutrient solution as well as nutrient deficiencies and also different nutrients management [40–42].

The iWUE index is a frequently used parameter to assess gas exchange in plants. It has been found to be closely related to the CO_2 concentration [43]. In the environment, CO_2 levels in the plant can be regulated precisely by stress conditions. As indicated by studies conducted on the bean *Phaseolus vulgaris* L. iWUE clearly increases under mild stress conditions [44]. In cucumber stress studies where plants were treated with NaCl, iWUE decreased significantly [45,46], and *Chenopodium quinoa* Willd. plants responded similarly in a pot experiment that simulated salt stress in the groundwater [47]. In the results obtained, WUE and iWUE index did not change significantly in the combinations with high EC compared to the plants with standard EC nutrient solution. This indicates that the iWUE of plants is sensitive to salt stress, but if the salt stress level is moderate, plants tolerate its presence without changes in WUE or iWUE. This may indicate that plants are experiencing mild stress, or that some mechanisms are activated to tolerate this level of stress.

With numerous links to the processes of conversion of absorbed light to a stable chemical form, chlorophyll fluorescence analysis has become the most widely used tool for monitoring the state of the plant [15,48]. The current study showed no significant effect on Fv/Fm and Fm′ in cucumber leaves, regardless of the EC of the nutrient solution and the substrate used. Similar results were obtained in a study on the effect of NaCl on Fv/Fm in cucumber leaves where no effect of salinity on this parameter was recorded [15], but other results show a strong reduction of Fv/Fm and ΦPSII in cucumber and strawberry leaves after the application of NaCl as a stress factor [49,50]. In the results presented here, ΦPSII did not decrease until day 28 DAEC (Figure 4c). Stationary fluorescence (Fs) did not change under the influence of the applied eustressor and nutrient solution for most of the experiment duration, except for the 14th and 28th DAEC, where lignite with standard EC and lignite with high EC obtained a significantly higher Fs index, respectively (Figure 4d). As reported by other authors, in the case of NaCl-induced salt stress, the chlorophyll fluorescence and gas exchange parameters in question are reduced, which is evident even after several hours of stress incorporation [2,9,51].

4.3. Dry Matter and Photosynthetic Pigment Content of Cucumber Leaves Grown on Organic and Mineral Substrates at High EC

The highest content of all discussed compounds was found in the leaves of plants grown in lignite in the fifth leaf of the combination with standard EC and in the tenth leaf of the combination with increased EC. In general, the content of the discussed compounds was higher in the combinations with lignite (Table 2). The presented results are in agreement with the results of chlorophyll a and b content in cucumber and tomato leaves, where the content of the compounds in question increased with increasing salinity [3]. Different results were obtained by studying bean (*Vicia faba* L.) leaves, where with the increase in salinity, the content of carotenes, chlorophyll a and b and total of chlorophyll a + b decreased [8]. Other researchers also confirmed, where the increase in salinity decreases significantly the content of chlorophyll a, b and total (a + b), in *Centaurium erythraea* (L.) *Paspalum vaginatum* (L.) plants [52,53].

4.4. Yield, Quality, and Bioactive Compound Content of Cucumber Fruit Grown on Organic and Mineral Substrates at High EC

Many vegetable species show different responses to the salinity [25]. Cucumber is considered a crop susceptible to high salinity [4]. The conducted studies show that the application of eustressor in the form of high EC of the nutrient solution at the level of 7 $dS \cdot m^{-1}$ strongly reduced the amount and weight of marketable yield in plants growing on mineral wool (Table 3). Dorai et al., 2001 confirmed in their study that high EC of the nutrient solution can lead to lower yield. In their study, Schwarz and Kuchenbuch [39] also obtained a 50% decrease in tomato yield in the combination where nutrient solution with EC 6 dS·m^{-1} was applied compared to plants fertilized with nutrient solution with 1 dS·m^{-1} EC. Similar results were obtained by Albornoz and Lieth [54] who reported that a high concentration of nutrients in the root zone leads to reduced yield. The application of lignite reduced the effect of stress and increased the number and weight of marketable yield compared to mineral wool (Table 3). At the same time, the number of unmarketable fruits was not significantly different between the combinations with high EC (Table 3). The total number and weight of fruits were significantly higher in plants grown in lignite compared to mineral wool (Table 3). The results indicate a significant effect of lignite on stress reduction and yield increase. Sources report that salinity affected both the reduction in the number and average weight of fruits [55]. Analyzing the results obtained, it can be concluded that the plants set a similar number of fruits in the combination of high EC and standard EC, but at the same time, the former dropped the excess fruit set. This translated into a reduced total yield (Table 3), while the unmarketable yield increased in stressed plants. Other researchers have also reported that high EC of nutrient solution leads to a decrease in yield and deterioration of yield quality [56,57]. Available research results prove that high EC reduced the total yield of lettuce grown in hydroponic systems [58,59]. For average fruit weight (total fruit number/total fruit weight quotient, eustressor in the form of high EC of nutrient solution affected its reduction compared to plants fertilized with a nutrient solution of standard EC, which is consistent with other results of stressed plants [60].

Cucumber fruits contain high amounts of water, a characteristic that contributes to the firmness and fresh appearance of the product on the store shelf. Considering the preferences of the final consumer, it is the physical quality and appearance of the product that determines the purchase [25,61]. The vegetable texture is a very complex trait, and the main compounds contributing to the firmness and overall texture are pectins, celluloses and hemicelluloses. In general, firmness is an important sensory trait in vegetable cultivation that is subject to high variability [25,62]. In the present study, the effect of eustressor of high EC of the nutrient solution on the firmness of cucumber fruit was not confirmed, regardless of the medium used. This is in agreement with the results of other researchers, where no effect of salinity stress on fruit firmness of cucumber and bell pepper was proved [28,63]. The high EC of the nutrient solution decreased the color index and the b* component parameter. This is consistent with other results of salinity effects on the L* component of CIE Lab and a*/b* ratio in greenhouse cucumber fruit, where no significant differences were found [64]. In contrast to vegetables, where the usable part is the fruit, in leafy vegetables salinity can have a more significant effect on color [25]. Perhaps salinity induced by a high concentration of minerals in the nutrient solution (high EC) does not affect fruit and/or leaf color as significantly as the application of NaCl. Appropriate fruit skin color also determines the final consumer choice [25]. Studies conducted show that salinity may have no effect on peel color, given the right intensity of the stress factor or when a suitable substrate is used.

The high EC of the nutrient solution led to an increase in fruit dry weight in MW/high EC combination, intermediate values were recorded for fruit from the L/high EC combination. Similar results were obtained by Schwarz and Kuchenbuch [39], where high EC of nutrient solution led to an increase in dry matter in tomato fruit. Dry matter content also increased after treating lettuce plants with high EC of nutrient solution, where the highest content of the trait in question was recorded at a concentration of 4.0 dS·m^{-1} [65]. Similar results were obtained in the cultivation of pakchoi (*Brassica campestris* L. ssp. *Chinensis*) in hydroponic systems, where the dry matter content also increased with increasing EC of the nutrient solution 4.8–9.6 dS·m^{-1} [40]. The presented results do not support the effect of eustressor and substrate type on TSS (Table 5). Rubio et al. [60] also found no effect of NaCl-induced salinity on TSS, while other researchers reported a decrease in TSS in bell pepper fruits after application of sodium sulphate and sodium chloride [63]. On the other hand, Rosadi et al. [57] found the highest concentration of TSS in tomato fruits when the nutrient solution with EC 5 dS·m^{-1}. If the application of a eustressor in the form of a high EC activates signaling pathways leading to the production of a higher content of biologically active compounds in the fruit, this may not lead to a reduction in yield. [25,26]. For the bioactive compounds studied in fruit, the combination of eustressor and lignite substrate significantly increased lutein, β-carotene, chlorophyll a, b and total chlorophyll (a + b) compared to mineral wool (Table 5). Similar results were obtained by studying the effect of reused lignite mats on the content of chosen bioactive compounds in cucumber fruit [20]. Low salinity intensity in romaine lettuce increased lutein and β-carotene [66]. An increase in carotenoids and anthocyanins in lettuce following a combination of higher salinity and CO_2 concentration was also noted by Pérez-López et al. [67]. Unfortunately, increased salinity may also influence the accumulation of more nitrate in the fruit or leaves, which is an undesirable characteristic. This is confirmed by the presented results of this study, where high nitrate content was demonstrated in fruits from plants grown in medium with elevated nutrient EC. However, it can be clearly seen that fruits from plants growing in lignite were characterized by lower nitrate content (Table 5). However, Scuderi et al. [58] report that high EC reduced nitrate content in the leaves. Different results were obtained by Ding et al. [40] where high EC of nutrient solution led to a significant increase in nitrate in pakchoi leaves. The results of nitrate content in cucumber fruits shown in Table 5 are not high, while fruits obtained from plants grown on lignite accumulated less nitrate, which is more desirable for the consumer. The negative effects of nitrates on consumer health make it necessary to control their content in food, focusing at the same time on proper fertilization and agronomic treatments [25,68].

5. Conclusions

A high EC of nutrient solution along with a lignite-based organic substrate can improve the nutritional and functional value of cucumber fruit, and the use of lignite in cultivation can reduce the negative effects of salinity during plant growth. However, the proper intensity of the stress factor and the developmental stage of the plant at which it should be introduced should be determined. Reducing excessive solid waste production and the search for new biodegradable substrates are further challenges for researchers. At the same time, the study of prospective organic substrates for hydroponic vegetable production and strategies for yield and quality control should continue. The results obtained indicate that growing cucumber in a lignite substrate in hydroponic technology using a nutrient solution with an EC of 7 dS·m^{-1} increases cucumber fruit quality, and, compared to cultivation using rockwool, reduces negative environmental impacts.

Author Contributions: Conceptualization, R.Ł., K.K., J.G.-W. and M.M.; methodology, R.Ł., J.L.P., M.N., S.K., W.K., J.S.N. and K.K.; software, J.L.P. and W.K.; validation, J.L.P., M.N., S.K., J.S.N. and W.K.; formal analysis, R.Ł., J.S.N., M.N., M.M. and W.K.; investigation, R.Ł., M.N., M.M., J.S.N. and W.K.; resources, J.G.-W., K.K. and J.S.N., data curation, R.Ł.; writing—original draft preparation, R.Ł. and J.S.N., writing—review and editing, R.Ł., K.K., J.S.N. and M.M.; visualization, R.Ł., supervision, K.K., J.G.-W. and M.M.; project administration, R.Ł., K.K. and J.G.-W.; funding acquisition, R.Ł. and J.G.-W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: I would like to thank the company CarboHort for lending me the cultivation mats and for the support during the experiment.

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

References

1. Kowalczyk, K.; Gajc-Wolska, J.; Bujalski, D.; Mirgos, M.; Niedzińska, M.; Mazur, K.; Niedzińska, P.; Szatkowski, D.; Cichoń, M.; Łęczycka, N. The effect of supplemental assimilation lighting with HPS and LED lamps on the cucumber yielding and fruit quality in autumn crop. *Acta Sci. Pol. Hortorum Cultus* **2018**, *17*, 193–200. [CrossRef]
2. Chen, T.-W.; Gomez Pineda, I.M.; Brand, A.M.; Stützel, H. Determining Ion Toxicity in Cucumber under Salinity Stress. *Agronomy* **2020**, *10*, 677. [CrossRef]
3. Abdel-Farid, I.B.; Marghany, M.R.; Rowezek, M.M.; Sheded, M.G. Effect of Salinity Stress on Growth and Metabolomic Profiling of *Cucumis sativus* and *Solanum lycopersicum*. *Plants* **2020**, *9*, 1626. [CrossRef] [PubMed]
4. Chen, T.-W.; Stützel, H.; Kahlen, K. High light aggravates functional limitations of cucumber canopy photosynthesis under salinity. *Ann. Bot.* **2018**, *121*, 797–807. [CrossRef]
5. Wang, L.Y.; Liu, J.L.; Wang, W.X.; Sun, Y. Exogenous melatonin improves growth and photosynthetic capacity of cucumber under salinity-induced stress. *Photosynthetica* **2016**, *54*, 19–27. [CrossRef]
6. Mohsin, S.; Hasanuzzaman, M.; Bhuyan, M.; Parvin, K.; Fujita, M. Exogenous Tebuconazole and Trifloxystrobin Regulates Reactive Oxygen Species Metabolism Toward Mitigating Salt-Induced Damages in Cucumber Seedling. *Plants* **2019**, *8*, 428. [CrossRef]
7. Miljus-Djukic, J.; Stanisavljevic, N.; Radovic, S.; Jovanovic, Z.; Mikic, A.; Maksimovic, V. Differential response of three contrasting pea ("*Pisum arvense*, *P. sativum*" and *P. 'fulvum'*) species to salt stress: Assessment of variation in antioxidative defence and miRNA expression. *Aust. J. Crop Sci.* **2013**, *7*, 2145–2153.
8. Abdul Qados, A.M.S. Effect of salt stress on plant growth and metabolism of bean plant *Vicia faba* (L.). *J. Saudi Soc. Agric. Sci.* **2011**, *10*, 7–15. [CrossRef]
9. Kamran, M.; Parveen, A.; Ahmar, S.; Malik, Z.; Hussain, S.; Chattha, M.S.; Saleem, M.H.; Adil, M.; Heidari, P.; Chen, J.-T. An Overview of Hazardous Impacts of Soil Salinity in Crops, Tolerance Mechanisms, and Amelioration through Selenium Supplementation. *Int. J. Mol. Sci.* **2019**, *21*, 148. [CrossRef]
10. Gengmao, Z.; Shihui, L.; Xing, S.; Yizhou, W.; Zipan, C. The role of silicon in physiology of the medicinal plant (*Lonicera japonica* L.) under salt stress. *Sci. Rep.* **2015**, *5*, 12696. [CrossRef]
11. Mittal, S.; Kumari, N.; Sharma, V. Differential response of salt stress on *Brassica juncea*: Photosynthetic performance, pigment, proline, D1 and antioxidant enzymes. *Plant Physiol. Biochem.* **2012**, *54*, 17–26. [CrossRef] [PubMed]
12. Zhu, X.; Cao, Q.; Sun, L.; Yang, X.; Yang, W.; Zhang, H. Stomatal Conductance and Morphology of Arbuscular Mycorrhizal Wheat Plants Response to Elevated CO_2 and NaCl Stress. *Front. Plant Sci.* **2018**, *9*, 1363. [CrossRef] [PubMed]
13. Lotfi, R.; Ghassemi-Golezani, K.; Pessarakli, M. Salicylic acid regulates photosynthetic electron transfer and stomatal conductance of mung bean (*Vigna radiata* L.) under salinity stress. *Biocatal. Agric. Biotechnol.* **2020**, *26*, 101635. [CrossRef]
14. Pérez-López, U.; Robredo, A.; Lacuesta, M.; Mena-Petite, A.; Muñoz-Rueda, A. Elevated CO_2 reduces stomatal and metabolic limitations on photosynthesis caused by salinity in Hordeum vulgare. *Photosynth. Res.* **2012**, *111*, 269–283. [CrossRef]
15. Zhang, R.H.; Li, J.; Guo, S.R.; Tezuka, T. Effects of exogenous putrescine on gas-exchange characteristics and chlorophyll fluorescence of NaCl-stressed cucumber seedlings. *Photosynth. Res.* **2009**, *100*, 155–162. [CrossRef] [PubMed]
16. Savvas, D.; Pappa, V.; Kotsiras, A.; Gizas, G. NaCl accumulation in a cucumber crop grown in a completely closed hydroponic system as influenced by NaCl concentration in irrigation water. *Eur. J. Hortic. Sci.* **2005**, *70*, 217–223.
17. Dannehl, D.; Suhl, J.; Ulrichs, C.; Schmidt, U. Evaluation of substitutes for rock wool as growing substrate for hydroponic tomato production. *J. Appl. Bot. Food Qual.* **2015**, *88*, 68–77. [CrossRef]
18. Kennard, N.; Stirling, R.; Prashar, A.; Lopez-Capel, E. Evaluation of Recycled Materials as Hydroponic Growing Media. *Agronomy* **2020**, *10*, 1092. [CrossRef]
19. Kraska, T.; Kleinschmidt, B.; Weinand, J.; Pude, R. Cascading use of Miscanthus as growing substrate in soilless cultivation of vegetables (tomatoes, cucumbers) and subsequent direct combustion. *Sci. Hortic.* **2018**, *235*, 205–213. [CrossRef]
20. Łaźny, R.; Mirgos, M.; Przybył, J.L.; Nowak, J.S.; Kunka, M.; Gajc-Wolska, J.; Kowalczyk, K. Effect of re-used lignite and mineral wool growing mats on plant growth, yield and fruit quality of cucumber and physical parameters of substrates in hydroponic cultivation. *Agronomy* **2021**, *11*, 998. [CrossRef]
21. Gruda, N. Increasing Sustainability of Growing Media Constituents and Stand-Alone Substrates in Soilless Culture Systems. *Agronomy* **2019**, *9*, 298. [CrossRef]
22. Czaplicka-Kolarz, K.; Burchart-Korol, D.; Krawczyk, P. Metodyka analizy ekoefektywności. *J. Ecol. Health* **2010**, *14*, 267–271.
23. Vinci, G.; Rapa, M. Hydroponic cultivation: Life cycle assessment of substrate choice. *Br. Food J.* **2019**, *121*, 1801–1812. [CrossRef]
24. Kyriacou, M.C.; Rouphael, Y. Towards a new definition of quality for fresh fruits and vegetables. *Sci. Hortic.* **2018**, *234*, 463–469. [CrossRef]
25. Rouphael, Y.; Petropoulos, S.A.; Cardarelli, M.; Colla, G. Salinity as eustressor for enhancing quality of vegetables. *Sci. Hortic.* **2018**, *234*, 361–369. [CrossRef]
26. Baenas, N.; García-Viguera, C.; Moreno, D. Elicitation: A Tool for Enriching the Bioactive Composition of Foods. *Molecules* **2014**, *19*, 13541–13563. [CrossRef] [PubMed]
27. Viacava, G.E.; Goyeneche, R.; Goñi, M.G.; Roura, S.I.; Agüero, M.V. Natural elicitors as preharvest treatments to improve postharvest quality of Butterhead lettuce. *Sci. Hortic.* **2018**, *228*, 145–152. [CrossRef]

28. Colla, G.; Rouphael, Y.; Jawad, R.; Kumar, P.; Rea, E.; Cardarelli, M. The effectiveness of grafting to improve NaCl and $CaCl_2$ tolerance in cucumber. *Sci. Hortic.* **2013**, *164*, 380–391. [CrossRef]
29. Giuffrida, F.; Cassaniti, C.; Malvuccio, A.; Leonardi, C. Effects of salt stress imposed during two growth phases on cauliflower production and quality. *J. Sci. Food Agric.* **2017**, *97*, 1552–1560. [CrossRef]
30. Borgognone, D.; Cardarelli, M.; Rea, E.; Lucini, L.; Colla, G. Salinity source-induced changes in yield, mineral composition, phenolic acids and flavonoids in leaves of artichoke and cardoon grown in floating system. *J. Sci. Food Agric.* **2014**, *94*, 1231–1237. [CrossRef]
31. Mayta, M.L.; Arce, R.C.; Zurbriggen, M.D.; Valle, E.M.; Hajirezaei, M.-R.; Zanor, M.I.; Carrillo, N. Expression of a Chloroplast-Targeted Cyanobacterial Flavodoxin in Tomato Plants Increases Harvest Index by Altering Plant Size and Productivity. *Front. Plant Sci.* **2019**, *10*, 1432. [CrossRef] [PubMed]
32. Barbagallo, R.N.; Di Silvestro, I.; Patanè, C. Yield, physicochemical traits, antioxidant pattern, polyphenol oxidase activity and total visual quality of field-grown processing tomato cv. Brigade as affected by water stress in Mediterranean climate. *J. Sci. Food Agric.* **2012**, *93*, 1449–1457. [CrossRef] [PubMed]
33. Kulapichitr, F.; Borompichaichartkul, C.; Fang, M.; Suppavorasatit, I.; Cadwallader, K.R. Effect of post-harvest drying process on chlorogenic acids, antioxidant activities and CIE-Lab color of Thai Arabica green coffee beans. *Food Chem.* **2022**, *366*, 130504. [CrossRef] [PubMed]
34. López Camelo, A.F.; Gómez, P.A. Comparison of color indexes for tomato ripening. *Hortic. Bras.* **2004**, *22*, 534–537. [CrossRef]
35. Rajendran, K.; Tester, M.; Roy, S.J. Quantifying the three main components of salinity tolerance in cereals. *Plant. Cell Environ.* **2009**, *32*, 237–249. [CrossRef]
36. Ashraf, M.; Harris, P.J.C. Photosynthesis under stressful environments: An overview. *Photosynthetica* **2013**, *51*, 163–190. [CrossRef]
37. Ahmadi, F.I.; Karimi, K.; Struik, P.C. Effect of exogenous application of methyl jasmonate on physiological and biochemical characteristics of *Brassica napus* L. cv. Talaye under salinity stress. *S. Afr. J. Bot.* **2018**, *115*, 5–11. [CrossRef]
38. Mallahi, T.; Saharkhiz, M.J.; Javanmardi, J. Salicylic acid changes morpho-physiological attributes of feverfew (*Tanacetum parthenium* L.) under salinity stress. *Acta Ecol. Sin.* **2018**, *38*, 351–355. [CrossRef]
39. Schwarz, D.; Kuchenbuch, R. Water uptake by tomato plants grown in closed hydroponic systems dependent on the EC-level. *Acta Hortic.* **1998**, *458*, 323–328. [CrossRef]
40. Ding, X.; Jiang, Y.; Zhao, H.; Guo, D.; He, L.; Liu, F.; Zhou, Q.; Nandwani, D.; Hui, D.; Yu, J. Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (*Brassica campestris* L. ssp. Chinensis) in a hydroponic system. *PLoS ONE* **2018**, *13*, e0202090. [CrossRef]
41. Van Ieperen, W. Effects of different day and night salinity levels on vegetative growth, yield and quality of tomato. *J. Hortic. Sci.* **1996**, *71*, 99–111. [CrossRef]
42. Gorbe, E.; Calatayud, Á. Optimization of nutrition in soilless systems: A Review. In *Advances in Botanical Research*; Academic Press: New York, NY, USA, 2010; Volume 53, pp. 193–245.
43. Van der Sleen, P.; Groenendijk, P.; Vlam, M.; Anten, N.P.R.; Boom, A.; Bongers, F.; Pons, T.L.; Terburg, G.; Zuidema, P.A. No growth stimulation of tropical trees by 150 years of CO_2 fertilization but water-use efficiency increased. *Nat. Geosci.* **2014**, *8*, 24–28. [CrossRef]
44. Santos, M.G.; Ribeiro, R.V.; Machado, E.C.; Pimentel, C. Photosynthetic parameters and leaf water potential of five common bean genotypes under mild water deficit. *Biol. Plant.* **2009**, *53*, 229–236. [CrossRef]
45. Gong, H.; Chen, K. The regulatory role of silicon on water relations, photosynthetic gas exchange, and carboxylation activities of wheat leaves in field drought conditions. *Acta Physiol. Plant.* **2012**, *34*, 1589–1594. [CrossRef]
46. Wu, Y.; Jin, X.; Liao, W.; Hu, L.; Dawuda, M.M.; Zhao, X.; Tang, Z.; Gong, T.; Yu, J. 5-Aminolevulinic Acid (ALA) Alleviated Salinity Stress in Cucumber Seedlings by Enhancing Chlorophyll Synthesis Pathway. *Front. Plant. Sci.* **2018**, *9*, 635. [CrossRef]
47. Talebnejad, R.; Sepaskhah, A.R. Physiological characteristics, gas exchange, and plant ion relations of quinoa to different saline groundwater depths and water salinity. *Arch. Agron. Soil Sci.* **2016**, *62*, 1347–1367. [CrossRef]
48. Stirbet, A.; Govindjee. On the relation between the Kautsky effect (chlorophyll a fluorescence induction) and Photosystem II: Basics and applications of the OJIP fluorescence transient. *J. Photochem. Photobiol. B Biol.* **2011**, *104*, 236–257. [CrossRef]
49. Christou, A.; Manganaris, G.A.; Papadopoulos, I.; Fotopoulos, V. Hydrogen sulfide induces systemic tolerance to salinity and non-ionic osmotic stress in strawberry plants through modification of reactive species biosynthesis and transcriptional regulation of multiple defence pathways. *J. Exp. Bot.* **2013**, *64*, 1953–1966. [CrossRef]
50. Jiang, J.-L.; Tian, Y.; Li, L.; Yu, M.; Hou, R.-P.; Ren, X.-M. H_2S Alleviates Salinity Stress in Cucumber by Maintaining the Na^+/K^+ Balance and Regulating H_2S Metabolism and Oxidative Stress Response. *Front. Plant. Sci.* **2019**, *10*, 678. [CrossRef]
51. Hussain, S.; Bai, Z.; Huang, J.; Cao, X.; Zhu, L.; Zhu, C.; Khaskheli, M.A.; Zhong, C.; Jin, Q.; Zhang, J. 1-Methylcyclopropene Modulates Physiological, Biochemical, and Antioxidant Responses of Rice to Different Salt Stress Levels. *Front. Plant. Sci.* **2019**, *10*, 124. [CrossRef]
52. Lee, G.; Carrow, R.N.; Duncan, R.R. Photosynthetic responses to salinity stress of halophytic seashore paspalum ecotypes. *Plant. Sci.* **2004**, *166*, 1417–1425. [CrossRef]
53. Siler, B.; Misic, D.; Filipovic, B.; Popovic, Z.; Cvetic, T.; Mijovic, A. Effects of salinity on in vitro growth and photosynthesis of common centaury (*Centaurium erythraea* Rafn.). *Arch. Biol. Sci.* **2007**, *59*, 129–134. [CrossRef]

54. Albornoz, F.; Lieth, J.H. Over fertilization limits lettuce productivity because of osmotic stress. *Chil. J. Agric. Res.* **2015**, *75*, 284–290. [CrossRef]
55. Ouzounidou, G.; Giannakoula, A.; Ilias, I.; Zamanidis, P. Alleviation of drought and salinity stresses on growth, physiology, biochemistry and quality of two *Cucumis sativus* L. cultivars by Si application. *Braz. J. Bot.* **2016**, *39*, 531–539. [CrossRef]
56. Dorai, M.; Papadopoulos, A.; Gosselin, A.; Dorais, M.; Papadopoulos, A.P. Influence of electric conductivity management on greenhouse tomato yield and fruit quality. *Agronomie* **2001**, *21*, 367–383. [CrossRef]
57. Rosadi, R.A.B.; Senge, M.; Suhandy, D.; Tusi, A. The Effect of EC Levels of Nutrient Solution on the Growth, Yield, and Quality of Tomatoes (*Solanum lycopersicum*) under the Hydroponic System. *J. Agric. Eng. Biotechnol.* **2014**, *2*, 7–12. [CrossRef]
58. Scuderi, D.; Restuccia, C.; Chisari, M.; Barbagallo, R.N.; Caggia, C.; Giuffrida, F. Salinity of nutrient solution influences the shelf-life of fresh-cut lettuce grown in floating system. *Postharvest Biol. Technol.* **2011**, *59*, 132–137. [CrossRef]
59. Abou-Hadid, A.F.; Abd-Elmoniem, E.M.; El-Shinawy, M.Z.; Abou-Elsoud, M. Electrical conductivity effect on growth and mineral composition of lettuce plants in hydroponic system. *Acta Hortic.* **1996**, *434*, 59–66. [CrossRef]
60. Rubio, J.S.; García-Sánchez, F.; Rubio, F.; Martínez, V. Yield, blossom-end rot incidence, and fruit quality in pepper plants under moderate salinity are affected by K^+ and Ca^{2+} fertilization. *Sci. Hortic.* **2009**, *119*, 79–87. [CrossRef]
61. Coolong, T.W.; Randle, W.M.; Wicker, L. Structural and chemical differences in the cell wall regions in relation to scale firmness of three onion (*Allium cepa* L.) selections at harvest and during storage. *J. Sci. Food Agric.* **2008**, *88*, 1277–1286. [CrossRef]
62. Kyriacou, M.C.; Rouphael, Y.; Colla, G.; Zrenner, R.; Schwarz, D. Vegetable Grafting: The Implications of a Growing Agronomic Imperative for Vegetable Fruit Quality and Nutritive Value. *Front. Plant. Sci.* **2017**, *8*, 741. [CrossRef]
63. Navarro, J.M.; Garrido, C.; Carvajal, M.; Martinez, V. Yield and fruit quality of pepper plants under sulphate and chloride salinity. *J. Hortic. Sci. Biotechnol.* **2002**, *77*, 52–57. [CrossRef]
64. Colla, G.; Rouphael, Y.; Rea, E.; Cardarelli, M. Grafting cucumber plants enhance tolerance to sodium chloride and sulfate salinization. *Sci. Hortic.* **2012**, *135*, 177–185. [CrossRef]
65. Sublett, W.; Barickman, T.; Sams, C. The Effect of Environment and Nutrients on Hydroponic Lettuce Yield, Quality, and Phytonutrients. *Horticulturae* **2018**, *4*, 48. [CrossRef]
66. Kim, H.-J.; Fonseca, J.M.; Choi, J.-H.; Kubota, C.; Kwon, D.Y. Salt in Irrigation Water Affects the Nutritional and Visual Properties of Romaine Lettuce (*Lactuca sativa* L.). *J. Agric. Food Chem.* **2008**, *56*, 3772–3776. [CrossRef] [PubMed]
67. Pérez-López, U.; Miranda-Apodaca, J.; Lacuesta, M.; Mena-Petite, A.; Muñoz-Rueda, A. Growth and nutritional quality improvement in two differently pigmented lettuce cultivars grown under elevated CO_2 and/or salinity. *Sci. Hortic.* **2015**, *195*, 56–66. [CrossRef]
68. Colla, G.; Kim, H.-J.; Kyriacou, M.C.; Rouphael, Y. Nitrate in fruits and vegetables. *Sci. Hortic.* **2018**, *237*, 221–238. [CrossRef]