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Effect of root zone aeration on the growth and bioactivity of cucumber plants cultured in perlite substrate

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Abstract: This study was aimed at investigating the growth and nutrient uptake of cucumber plants affected by forced aeration of supplying oxygen and stimulating gas exchange rate in root zone in a substrate. Five aeration levels during the growth (0, 0.5, 1.0, 1.5 and 2.0 L/min) were applied. Maximum leaf area and leaf fresh and dry weights were obtained at an aeration level of 0.5 L/min. Excessive aeration in root zone inhibited leaf area expansion, relative leaf growth rate and crop growth rate. An optimum leaf area index of 3.0 to 3.5 was estimated in range of 0 and 0.5 L/min. The highest fruit yield was measured of 1.13 kg/plant at 0.5 L/min, whereas at 2.0 L/min it was 0.62 kg/plant. Potassium concentration in petiole sap was lower at 63 days after transplanting than that at 32 days after transplanting. Ethylene concentrations increased with higher aeration values, however, CO_2 concentration reduced with increased aeration. All bioactive compounds (polyphenols, flavonoids, flavanols, tannins and ascorbic acid) and the levels of antioxidant activities by ferric-reducing/antioxidant power and cupric reducing antioxidant capacity in ethanol extracts of cucumbers differed significantly in the investigated samples and were the highest at aeration level of 0.5 L/min in comparison with other samples ($P < 0.05$). In conclusion, antioxidant status (bioactive compounds and antioxidant activities) improved with the appropriate aeration, which is effective for higher fruit yield and bioactivity. Excessive aeration inhibited root respiration, nutrients, bioactivity, and water uptake, and it resulted in the reduction of plant growth and fruit yield.

Key words: cucumber; growth analysis; perlite; soilless culture; root zone aeration; bioactivity.

Abbreviations: AA, antioxidant activity; CE, catechin equivalents; CGR, crop growth rate; CUPRAC, cupric reducing antioxidant capacity; DAT, days after transplanting; DMACA, *p*-dimethylaminocinnamaldehyde; FRAP, ferric-reducing/antioxidant power; GAE, gallic acid equivalents; LAI, leaf area index; LAR, leaf area ratio; RGR, relative growth rate; RLGR; relative leaf growth rate; SLA, specific leaf area; trolox, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid.

Introduction

Most of perlite cultural systems in Korea had polystyrene foam bed lined with polyethylene film inside in order to prevent water leakage. Polyethylene film lined inside bed often restrains the aeration in root zone. Therefore, growers who are using the cultural systems are facing the problem of poor air exchange in root zone. The availability of oxygen in the root zone is a critical factor in plant growth. Poorly aerated root zone is characterized by low oxygen and high carbon dioxide atmosphere (Glinski & Stepniewski 1985). Consequently, respiration of root and its growth is limited. Moreover, the oxygen limitation results in a reduction of water and nutrients uptake (Janick 1979; Glinski & Stepniewski 1985). High carbon dioxide levels also have a toxic effect on roots (Janick 1979). While the amount of oxygen in root zone decreases below the critical level, the growth of the roots could stop due to the limitation of respiration. The permeability of the roots to water was also reported to reduce at low oxygen levels (Vepraskas 1994). Plant growth in restricted root zone and low buffering capacity, e.g. closed hydroponics system, is deeply associated with supplying condition of the water, nutrient and oxygen. Available oxygen in root zone is mainly determined by layout of the hydroponic system, frequency of water supply and the physical properties of the substrate (Schroeder & Li-

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eth 2004). Oxygen gradient depends on designing flow techniques and flow rates within the hydroponic systems (Verstergaard 1984; Baas et al. 2001; Wever et al. 2001).

To reach certain oxygen concentration by air exchange rate in the root zone is an important environment-control technique for plant growth. However, effects of direct aeration treatment into root zone have rarely been studied and mostly were concentrated on increasing the dissolved oxygen in nutrient solution. In this study, we developed a new soil-less culture system with a direct aeration in root zone for fruit vegetables crop grown in perlite. Cucumber is one of the most consumed and important vegetables, having nutritional and pharmaceutical properties and a rich source of polyphenols (Abu-Reidah et al. 2012; Mukherjee et al. 2013). We decided to investigate the extracts of cucumber after different treatments and to compare its composition with the widely consumed green peppers. To meet this aim, the contents of bioactive compounds (polyphenols, tannins, flavonoids, flavanols, and ascorbic acid) and the level of antioxidant activities (AAs) were determined and compared. Two assays – ferric-reducing/antioxidant power (FRAP) and cupric reducing antioxidant capacity (CUPRAC) – were applied. In order to find out the optimal aeration rate, the nutrient uptake, growth, polyphenols, antioxidant activities and yield responses were studied at different aeration levels in root zone of cucumber plant.

Material and methods

Chemicals

6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (trolox), Tris, tris(hydroxymethyl) aminomethane, Folin-Ciocalteu reagent, $LaCl_3.5H_2O$, $CuCl_2.2H_2O$, 2,9-dimethyl-1,10-phenanthroline (neocuproine), and $FeCl_3.6H_2O$ were purchased from Sigma Chemical Co. (St Louis, MO, USA). All reagents were of analytical grade. Deionised and distilled water was used throughout. 2,4,6-Tripyridyl-*s*-triazine was from Fluka Chemie (Buchs, Switzerland).

Samples

The experiment was conducted in glasshouse at Chonnam National University, Korea. Cucumber (*Cucumis sativus* L. cv. Kyeulsari-chungjang, Heungnong Seed Co., Korea) seeds were sown on August 5, 2010. With two true leaves the young plants were transplanted on August 18 in Wagner pots (3.5 L, 1/5000a) filled with perlite (Parat-2, ø 0.7–3 mm, mean ø 1.7 mm, Samson Ltd., Co., Korea) and they were grown until October 25, 2010. Full strength of Yamasaki-formulated nutrient solution for cucumber (EC 2.4 mS/cm, pH 6.0) was used. Until ten leaves stage, the concentration was adjusted to half strength and thereafter it increased to full strength. Plants were irrigated six times daily on cloudy or rainy days and eleven times on sunny days. The amount of nutrient solution supplied to a plant was 200 mL per irrigation. The bottom of the Wagner pots had a hole for drainage with rubber stopper and a plastic net was placed 5 cm above the bottom to collect the drained solution as shown in Figure 1. Whole perlite was wrapped with cheesecloth. Drained solution was once kept in the 5 cm bottom space and drained twice a day for checking the drainage volume by removing rubber stopper. No roots penetrated into this air space in the Wagner pot. Air compressors and air bubblers in pots were used for forced aeration in the root zone, and aeration level was controlled by a valve and an air flow meter. The rates of aeration were 0, 0.5, 1.0, 1.5 and 2 L/min. Nutrient solution was supplied by a drip irrigation system (4 L/h; Netafim, Israel). Though the diffusion of air and solution in the substrate were not checked, rather even distribution of root system in the substrate seemed to show air and solution diffused smoothly.

The plants were de-topped with 20 true leaves and every lateral shoots were pinched with two leaves. Growth parameters, such as plant height, fresh and dry weights and leaf area from six plants were measured at 3 and 65 days after transplanting (DAT).

Drained solutions were collected twice a day and concentrations of macroelements in the drained solution were determined by ion chromatography (DX-500, Dionex, USA). In order to clarify the changes in the mineral concentrations of petiole sap as affected by root zone aeration, petioles of 10^{th} to 12^{th} leaf from shoot apex were sampled at 32 and 63 DAT. After collection, samples were cut into 1 mm length and 1 g subsamples were taken. Each subsample was macerated with 10 mL of distilled water and immediately filtered. The filtrate was analysed by the above mentioned method.

In order to clarify the condition of root zone gas composition, another experiment was carried out using the aeration levels of 0, 0.3, 0.6, 0.9 and 1.2 L/min. All other conditions and methods of growing were the same as in previous experiment. At 30 DAT (at 10 a.m.), gas samples of 5cc were collected from each Wagner's pot using a syringe, and then ethylene and carbon dioxide were analysed by gas chromatography. Temperature conditions were recorded by a data logger (LI-1000, Li-Cor, USA). The root zone temperatures were collected daily using NiCr-Ni thermocouple (2060-M, Heinz Walz, Germany).

Green peppers (*Capsicum annuum* L.) were purchased at the local market for comparison studies of bioactive compounds. Cucumbers were either peeled or unpeeled. Their edible parts were prepared manually without using steel knives. The prepared vegetables were weighed, chopped and homogenized under liquid nitrogen in a high-speed blender (Hamilton Beach Silex professional model) for 1 min. A weighed portion (50–100 g) was then lyophilized for 48 h (Virtis model 10-324), and the dry weight was determined. The samples were ground to pass through a 0.5 mm sieve and stored at –20 °C until the bioactive substances were analysed.

Determination of bioactive compounds

The contents of polyphenols, tannins, flavonoids, flavanols, and ascorbic acid in extracts of the studied vegetables were determined as described previously (Gorinstein et al. 2010).

The lyophilized samples of cucumbers and peppers (1 g) were extracted with 100 mL of ethanol at room temperature in darkness for 24 h. The polyphenols were determined by Folin-Ciocalteu method with measurement at 750 nm with spectrophotometer (Hewlett-Packard, model 8452A, Rockvile, USA). The results were expressed as mg of gallic acid equivalents (GAE)/g dry weight (Singleton et al. 1999). The extracts of condensed tannins (procyanidins) with 4% methanol vanillin solution were measured at 500 nm. Flavonoids, extracted with 5% $NaNO_2$, 10% $AlCl_3 \cdot H_2O$, and 1 M NaOH, were measured at 510 nm. The total flavanols were estimated using the

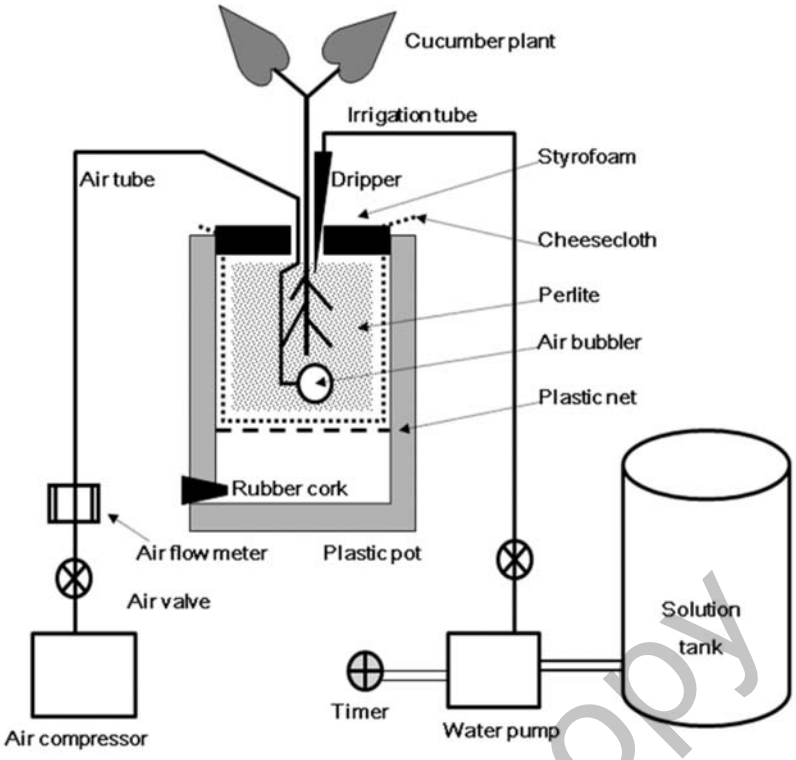

Fig. 1. Schematic diagram of the experimental system for forced aeration treatment.

p-dimethylaminocinnamaldehyde (DMACA) method, and then the absorbance at 640 nm was measured (Arnous et al. 2001; Park et al. 2011). (+)-Catechin served as a standard for tannins, flavonoids and flavanols, and the results were expressed as catechin equivalents (CE). Total ascorbic acid was determined by CUPRAC assay in water extract (100 mg of lyophilized sample and 5 mL of water). The absorbance of the formed bis (Nc)-copper (I) chelate was measured at 450 nm (Ozyurek et al. 2007).

Determination of antioxidant activity

The AA was determined by two assays: (i) FRAP assay measures the ability of the antioxidants in the investigated samples to reduce ferric-tripiridyltriazine to a ferrous form (Fe^2). FRAP reagent (2.5 mL of a 10 mM ferric-tripiridyltriazine solution in 40 mM HCl plus 2.5 mL of 20 mM $FeCl_3.H_2O$ and 25 mL of 0.3 M acetate buffer, pH 3.6) of 900 µL was mixed with 90 µL of distilled water and 30 µL of samples as the appropriate reagent blank. The absorbance was measured at 595 nm (Benzie & Strain 1996). (ii) CUPRAC assay is based on utilizing the copper (II)-neocuproine [Cu (II)-Nc] reagent as the chromogenic oxidizing agent. The absorbance at 450 nm was recorded against a reagent blank (Apak et al. 2004).

Statistical analysis

Comparison of growth parameters of plant and the values of observation at different treatment was done by Statistical Analysis System (SAS Institute Inc., Ver. 6.0).

Results and discussion

Some of the growth parameters of cucumber plant significantly affected by root-zone aeration (Table 1). Stem diameter, leaf area, petiole and leaf dry weight was quadratically changed with peak values under 0.5 L/min of aeration. The aeration above 1.0 L/min tended to inhibit the plant growth. This inhibition was high in the growth of root and leaf. Roots at 0 L/min aeration might seek for oxygen into pore space and consequently the roots grew extensively. Air temperature ranged from 19.0 ℃ to 32.4 ℃ at 16 DAT, and root zone temperature ranged from 16.6 ℃ to 29.4 ℃. Thus, the maximum temperature difference between air and root zone was about 3.0 ℃ and this difference increased with aeration levels.

Relative growth rate (RGR) and crop growth rate (CGR) showed linear relationship with aeration level (Table 2). RLGR was decreased with excess aeration and hence low leaf area was measured at highly aerated condition (Tables 1,2), whereas leaf area ratio (LAR) and specific leaf area (SLA) were not significantly affected. The rate of leaf area expansion decreased and hence leaf area decreased with forced aeration in root zone. Consequently, low leaf area index (LAI) directly influenced the light interception per unit area. This difference significantly affects the crop growth rate (Table 2). Any effect on net assimilation rate (NAR) between aeration levels and any difference in dry mass production per unit leaf area were estimated. The different crop growth rate could be explained by the result of light interception. Consequently, CGR increased with LAI (Fig 2). Our data can be compared with Matsui et al. (1994), where the influence of aeration level on the value of NAR and LAR was not observed. Matsui et al. (1994) reported that growth analysis of onion treated by abscisic acid showed the highest CGR and RGR at the time when LAI reached the maximum. The relationship between LAI and NAR, and between LAI

Table 1. Growth characteristics of cucumber plant as affected by the root-zone aeration 65 DAT.[a]

Aeration (L/min)	Plant height (cm)	Stem diameter (mm)	Number of leaves	Leaf area (cm^2)
0	303ab	7.43a	37.0a	2803b
0.5	305ab	7.79a	37.7a	4857a
1.0	295a	7.65a	38.7a	2622b
1.5	275bc	7.59a	34.3ab	2352bc
2.0	248c	6.31b	31.7b	1996c
LSD	66.5	0.54	–	1057
F-probabilities				
Aeration	0.780	<0.001	–	0.001
Linear	0.262	0.001	–	0.003
Quadratic	0.915	<0.001	–	0.045

Aeration (L/min)	Dry weight (g per plant)				
	Petiol	Leaf	Stem	Root	Total
0	2.52b	11.08b	15.65a	6.00a	35.25ab
0.5	3.35a	16.00a	14.21ab	5.48ab	39.04a
1.0	1.96c	9.70b	12.93ab	4.91bc	29.50bc
1.5	1.34d	6.82c	11.48bc	3.73cd	23.37c
2.0	1.09d	6.28c	9.31c	2.70d	19.38c
LSD	0.44	2.15	4.16	1.96	7.30
F-probabilities					
Aeration	<0.001	<0.001	0.049	0.022	<0.001
Linear	<0.001	<0.001	0.004	0.002	<0.001
Quadratic	0.024	0.015	0.730	0.497	0.187

[a]LSD, least significant difference ($P = 0.05$) for comparing means between aeration levels. Different letter within a column means difference by LSD ($P = 0.05$).

Table 2. Growth analysis of cucumber plants as affected by root-zone aeration in perlite culture on 65 days after transplanting.[a]

Aeration (L/min)	T/R ratio	RGR (g/g.wk)	NAR (g/dm^2.wk)	LAR (dm^2/g)	SLA (dm^2/g)	LAI (dm^2/m^2)	CGR (g/m^2.wk)	RLGR (dm^2/wk)
0	4.88	0.584	5.90	0.099	0.206	2.64	15.59	0.465
0.5	6.14	0.596	4.25	0.140	0.251	4.07	17.31	0.526
1.0	5.01	0.565	5.18	0.109	0.227	2.52	13.04	0.458
1.5	5.26	0.539	4.47	0.121	0.288	2.31	10.30	0.445
2.0	6.17	0.518	4.19	0.123	0.271	2.03	8.53	0.427
LSD	2.26	0.039	1.38	0.035	0.095	0.79	3.250	0.061
F-probabilities								
Aeration	0.357	0.006	0.110	0.170	0.299	0.001	<0.001	0.035
Linear	0.292	<0.001	0.048	0.519	0.112	0.003	<0.001	0.021
Quadratic	0.469	0.208	0.512	0.356	0.623	0.051	0.188	0.153

[a]T/R ratio, top/root ratio; RGR, relative growth rate; NAR, net assimilation rate; LAR, leaf area ratio; SLA, specific leaf area; LAI, leaf area index; CGR, crop growth rate; RLGR, relative leaf growth rate. Growth analysis is performed using the data of 3 DAT and 65 DAT. LSD, least significant difference ($P = 0.05$) for comparing means between aeration levels.

and CGR exhibited quadratic regression. This difference seems to be caused by the growing environment, cultivar and ecotypes in both experiments.

Accumulated fresh fruit weight and the number of fruits per plant were the highest at the 0.5 L/min until 65 DAT (Fig. 3a), and then they decreased with increasing of aeration levels. With the higher levels of aeration at 1.5 and 2.0 L/min, yield and number of fruits was low in spite of the higher rate of female flowers (data not shown). Root-zone stress might stimulate reproductive growth of cucumber with increase in the rate of female flowers. The oxygen concentration in nutrient film technique nutrient solution easily decreased in cucumber than in tomato (Gislerød & Adams 1983; Ho & Adams 1995). Our results are in line with Gislerød & Kempton (1983), who reported strong damage in cucumber plant at low oxygen concentration (below 3 mg/L). The diurnal temperature change also strongly affected the oxygen concentration in root zone. Eventhough oxygen level was not measured during the experiment, the level

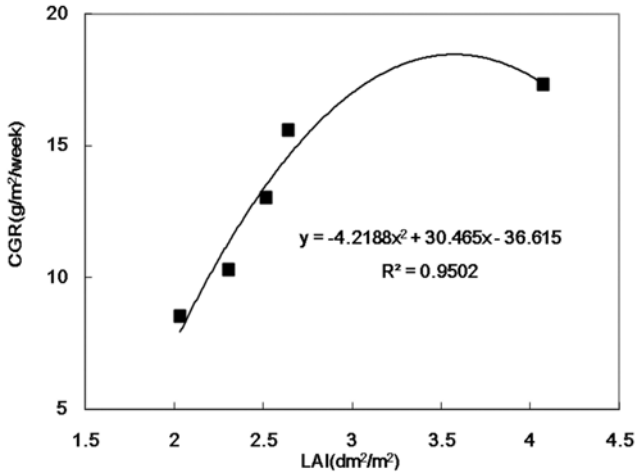

Fig. 2. Relationships between leaf area index (LAI) and crop growth rate (CGR) of cucumber plants as affected by root zoon aeration treatment.

might be around 20% in all aeration treatments due to continuous forced aeration into root zone. Excessive forced aeration could damage the root system by drying or by unknown physiological stress. Consequently, this stress resulted in reducing water and nutrient absorption and finally in the reduction of fruit yield. The rate of forced aeration was a critical point of cultural management in perlite substrate for yield of cucumber.

Petiole saps were analysed at 32 and 63 DAT in order to compare the internal concentrations of macroelements (Table 3). Concentrations of nitrate at 63 DAT were significantly lower than those at 32 DAT in all treatments. Nitrate and phosphorus concentrations were at the peaks under 0.5 or 1.0 L/min treatments at 32 DAT, but this tendency almost disappeared at 63 DAT. Potassium concentrations decreased with increasing of aeration level. Calcium concentrations of aerated plants at 32 DAT were lower than the non-aerated plants, but the values slightly increased at 63 DAT. Magnesium concentrations at 32 DAT in all treatments were not significantly different, while at 63 DAT peaked up in 0.5 L/min of aeration treatment.

Plant sap analysis has been considered to be one of appropriate methods to characterize nutrient status and to provide information for adjusting fertilization programs (Jones 1985; Hochmuth 1994). In this study, petiole samples were taken because the mineral concentrations in petiole tissue sensitively reflect the availability of mineral elements in many vegetable crops (Coltman 1987; Hochmuth 1994). Shimizu et al. (1991) reported that nitrogen concentration of cucumber leaf using classical leaf tissue analysis was the highest, following by potassium, calcium, magnesium and phosphate in the order of their concentrations. The same order was obtained in our experiment (Table 3). This fact could be explained that sap analysis is an appropriate method for checking the mineral nutrient condition of cucumber plants. The excessive forced aeration markedly reduced potassium concentrations at the both times of 32 and 63 DAT, but other elements were slightly affected.

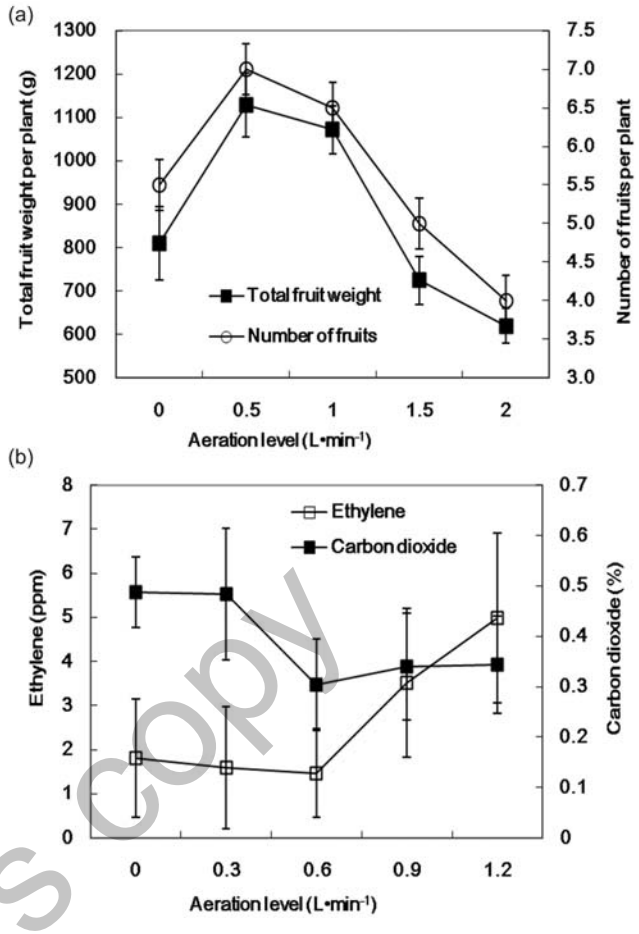

Fig. 3. Effects of root zone aeration on: (a) the total fruit weight and number of fruits of cucumber; and (b) ethylene and carbon dioxide contents in root-zone at 30 DAT. Vertical bars indicate the standard deviation of the mean.

The conditions of carbon dioxide and ethylene concentrations in root zone were different (Fig. 3b). Ethylene concentration was unchanged from 0 to 0.6 L/min aeration, then with increasing of aeration sharply increased. Excessive forced aeration retarded root growth and ethylene would be produced as a consequence. Carbon dioxide was higher in 0 and 0.3 L/min aeration than in the treatments above 0.6 L/min aeration. The effects of gaseous phase by forced aeration cannot be overestimated, but these condition changes may affect the stress in the root system.

Poor soil aeration inhibits water and nutrient absorption of plants and thus inhibits their growth (Russell 1977). The inhibition has been partly attributed to suppression of root respiration caused by low oxygen concentration (Glinski & Stepniewski 1985) and a high carbon dioxide concentration (Kitaya et al. 1992) in the soil. Soffer et al. (1991) reported that the growth of *Chrysanthemum* and *Ficus* was reduced as dissolved oxygen in solution decreased, however, plants were able to adapt to low oxygen concentration. But, once oxygen supply is limited, carbon dioxide and ethylene will increase in the root zone. Accumulation of root respiration products can inhibit plant growth. Concentrations over 0.1 μL/L of ethylene can be harmful for plants

Table 3. Effects of aeration levels on mineral contents in petiole sap of 10^{th} to 12^{th} leaf at 32 DAT and 63 DAT.

Sampling date	Aeration	Macrolement contents (mg/gFW)				
		NO_3-N	P	K	Ca	Mg
32 DAT	0.0	11.94	0.59	6.57	3.03	0.59
	0.5	12.65	0.93	7.88	1.87	0.58
	1.0	14.38	0.62	7.28	1.74	0.57
	1.5	11.10	0.50	6.60	1.83	0.59
	2.0	10.00	0.52	5.66	1.05	0.63
63 DAT	0.0	5.01	0.39	7.42	2.58	0.69
	0.5	5.63	0.49	7.08	2.60	0.80
	1.0	6.31	0.49	5.92	2.50	0.68
	1.5	6.33	0.56	5.30	2.45	0.65
	2.0	6.20	0.54	3.66	1.98	0.58
F-probabilities						
Sampling date (A)		0.035	0.019	0.656	0.266	0.200
Aeration (B)		0.983	0.006	0.019	0.266	0.583
A X B		0.979	0.006	0.385	0.463	0.183

Table 4. Bioactive compounds and antioxidant activities in ethanol extracts of cucumber samples treated with different aeration and comparison with green pepper.[a]

	Pol (mg GAE)	FRAP (μM TE)	CUPRAC (μM TE)	Flavan (mg CE)	Flavon (mg CE)	Tannin (mg CE)	VitC (mg Asc)
GP	8.96	9.00	18.99	0.06	0.05	0.37	1.87
Pulp1	2.89	7.77	9.45	9.97	0.62	0.02	1.05
Unpeeled1	3.22	9.83	11.5	13.30	0.75	0.13	1.14
Pulp2	2.47	6.64	8.08	8.47	0.53	0.02	0.89
Unpeeled2	2.78	8.47	9.91	11.47	0.65	0.11	0.97
LSD	0.893	1.659	2.457	1.922	0.1347	0.1029	0.4215
F-probabilities	<0.001	0.015	<0.001	<0.001	<0.001	<0.001	0.003

[a]Abbreviations: Pol, polyphenols; GAE, gallic acid equivalent; FRAP, ferric-reducing/antioxidant power; TE, trolox, 6-hydroxy-2,5,7,8-tatramethylchroman-2-carboxylic acid; CUPRAC, cupric reducing antioxidant capacity; Flavan, flavanols; Flavon, flavonoids; CE, catechin equivalent; VitC, vitamin C; Pulp1, ethanol extract of pulp at aeration level 0.5 L/min; Pulp2, ethanol extract of pulp after aeration level 2.0·L/min; Unpeeled1, ethanol extract of whole cucumber at aeration level 0.5 L/min; Unpeeled2, ethanol extract of whole cucumber at aeration level 2.0 L/min; GP, green pepper.

(Abbeles 1982). In this experiment, ethylene concentration increased and carbon dioxide slightly changed with the increasing of aeration. The oxygen concentration of root zone was equal to ambient condition by aeration. The increase in ethylene concentration over 0.9 L/min seemed to be a cause for root stress. Though appropriate root zone aeration is effective for higher yield, excessive level of forced aeration caused restriction in root respiration and in nutrient and water uptakes. This resulted in the reduction of plant growth and fruit yield.

The results of the determination of the contents of the bioactive compounds in all studied samples are summarized in Table 4. As can be seen, the significant highest contents ($P < 0.05$) of polyphenols, flavonoids, flavanols, tannins, and ascorbic acid, were in ethanol extracts of Pulp1 and Unpeeled1 cucumbers at aeration level of 0.5 L/min in comparison with all other samples; the lowest was at 2.0 L/min (Pulp2 and Unpeeled2; Table 4). As can be seen (Table 4) the AA values by FRAP and CUPRAC assays (μMTE/g) for Pulp1 and Unpeeled1 ethanol extracts were the highest in comparison with other samples. As calculated, a very good correlation was found between the AA and the contents of total polyphenols (R^2 from 0.96 to 0.83). The correlation between the AA and ascorbic acid was lower than with polyphenols (R^2 from 0.84 to 0.50). Our results can be compared with Melo et al. (2006), who reported the polyphenol contents in cucumber. Total phenolic contents, flavonols and proanthocyanidins were found to be 9.05 ± 0.83, 2.06 ± 0.09 and 55.66 ± 1.52 mg/100 g fresh weight, respectively, in cucumber extract. Kaur & Kapoor (2002) showed that total phenolic content was found to be 48.0 ± 0.9 mg /100 g fresh weight. The whole extract of cucumber contained higher concentrations of ascorbic acid and were similar to the results of 1.49 ± 0.85 mg/100 g fresh weight (Melo et al., 2006). As it is presented in Table 4, unpeeled cucumbers showed higher amount of all bioactive compounds. Our results are in full agreement with Sotiroudis et al. (2010), who estimated the phenolic content of three cucumber tissues, peel, pulp and juice, and found that the pulp had the highest amount of phenolics (more than two fold the amount present in peel and juice), while the juice had the lowest amount. Our results can be compared with some reports about the AAs of cucumber extract against various assays (Kaur & Kapoor 2002;

Pellegrini et al. 2003; Stratil et al. 2006). The FRAP values presented in Pellegrini et al. (2003) were similar to our results. The comparison of the AAs and bioactive compounds of cucumber and green pepper were in limits as presented by Stratil et al. (2006).

In conclusion, bioactive compounds and AAs improved with aeration. Appropriate root zone aeration is effective for higher fruit yield and bioactivity of the fruit in perlite culture, but excessive aeration inhibited root respiration, nutrients, bioactivity, and water uptake, and it resulted in the reduction of plant growth and fruit yield.

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