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RESEARCH ARTICLE

Shoot nutrient contents and vegetative melon plants growth at different pH levels of the nutrient solution

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ABSTRACT

Melon plants development are determined by nutrient availability in the nutrient solution which is markedly influenced by the solution pH. The objective of this work was to evaluate the effects of hydroponic nutrient solution pH on growth and mineral content of melon plants. The plants were growth in nutrient solution at five pH levels (4, 5, 6, 7 and 8) in a completely randomized design with three replicates. At 40 days after transplanting were evaluated shoot and roots fresh and dry weight as well as the root volume. Leaf nutrients contents was also determined. It was concluded that it is essential to keep the nutrient solution pH at 6.0 in order to obtain plants with high leaf number, fresh and dry root mass, root volume and iron and zinc contents in the leaves.

Keywords: *Cucumis melo* L.; Hydroponic cultivation; Greenhouse; Hydrogen potential; Dry matter.

INTRODUCTION

The melon (*Cucumis melo* L.) is a vegetable belonging to the family of Cucurbitaceae with great acceptance by the national and international consumer market. Brazil is the third largest melon exporter, with Europe being the main destination of national production (Mulderij, 2018), and quality-demanding consumers (Nunes et al., 2005).

In 2016, worldwide melon harvest area was 1.2 M ha with 36 M t production (FAOSTAT, 2018). Melon plants development and production can be influenced by several factors mainly by adequate nutrients supply which is markedly influenced by the pH, not only in soil conditions, but mainly in nutrient solution due to its lower buffering capacity (Gorbe and Calatayud, 2010). Several factors influencing plant grows in a hydroponic system including light, water temperature, genotype, nutrient solution composition, and pH.

Maintaining the pH of the nutrient solution in an adequate value is crucial for the proper crop development because it is directly related to the nutrient availability to the plants (Spinu et al., 1998). As a general rule, at pH between 5.5 and 6.5, nutrients are in available forms and ensures normal development of most crops (Islam et al., 1980; Sardare and Admane, 2013). Bugbees (2013) recommends the value of 5.8. The author mentioned when the pH is higher, nutrients such as Mn, Cu, Zn, and Fe have a reduced availability and the availability of Mg, Ca, K, and P is slightly decreased.

Early marketable cucumber fruit yield was higher at pH 5.0 compared to pH 8.0 but total yield was unaffected by pH treatment, in recirculating aquaponics (Tyson et al., 2008). For Kane et al. (2006), maintained the pH at 6.5 increased onion biomass significantly in relation to pH of 5.8, indicating that small variations in the pH of the nutrient solution directly impacted crop yield. Limited information is available for melon. Gomes et al. (2011) observed no differences in leaf number and melon plant height submitted to pH levels in nutrient solution varying from 4.0 to 8.0.

Therefore, it is verified that the effect of nutrient solution pH on the plants depending on the specie and the characteristic measured. The objective of this study was to determine the effects of different nutrient solution pH

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levels on the shoot nutrient contents and growth of melon plants.

MATERIALS AND METHODS

The experiment was conducted in a 3-phase hydroponic system in a greenhouse of the Department of Crop Science of the Federal University of Vicosa (UFV), from April to June 2018. The experimental design was completely randomized, with three replications. The treatments were constituted by five pH levels of the nutrient solution (4.0, 5.0, 6.0, 7.0, and 8.0). Each experimental plot consisted of a vessel containing one plant. The nutrient solution was that recommended by Benoit (1987) cited by Castellane and Araujo (1994) and Enshi cited by Hori (1966). The nutrient solution contained, in mM L^{-1}, 14.08 NO_3, 1.35 NH_4, 1.35 H_2PO_4, 6.02 K, 4.03 Ca, 2.03 Mg, 2.03 S, 0.020 B, 0.05 Cu, 0.022 Fe, 0.0114 Mn, 0.0007 Mo and 0.0004 Zn. The micronutrient iron was supplied as a chelate as ethylenediaminetetraacetic acid (EDTA).

Cantaloupe melon cultivar Pampa F1 (TPC-05814) seeds were sown on April 11 in a tray containing washed sand. The acclimation of the seedlings was carried out by 21 days after sowing, when they presented 2 definitive leaves. The nutrient solution for acclimatization was the same recommended for definitive cultivation, with 50% strength. At 30 days after sowing, the seedlings were transferred to pots filled with 8 L of nutrient solution. The vessels were covered with styrofoam lids coated with foil where the plants were fixed. The oxygenation of the nutritive solutions was done by air compressor, using a porous capsule in each vessel.

Nutrient solution monitoring was performed daily through the electrical conductivity (EC) and pH readings according to Furlani et al. (1999). The daily pH correction was done according to the treatments, allowing variations up to ± 0.05 using 1 mol L^{-1} HCl or 1 mol L^{-1} NaOH. Whenever the EC reached a value equal or inferior to 1.5 dS m^{-1}, the nutrient solution was reestablished. Deionized water was replaced whenever necessary.

At 8, 15, 22, 29 and 40 days after transplanting (DAT), plants were evaluated for height, leaf number and SPAD (Soil Plant Analysis Development) index. The height (cm) of plants was measured from the base to the apex of the last leaf; leaf number was determined by direct counting of the fully expanded leaves. For the SPAD evaluation, reading was performed on three leaves of the middle third located on the main stem of the melon plant by Minolta Chlorophyll meter SPAD-502.

At 40 DAT plant were harvested and divided into shoot and root which were weighted and the root volume evaluated. Shoot and root were conditioned in paper bags and dried at 65 ° C until reaching constant weight. After drying, shoot and root dry weight were obtained. Subsequently, foliar chemical analysis was performed.

For leaf chemical analysis, the samples were passed in a Wiley type mill equipped with a 20-mesh sieve. Total nitrogen (N-total) was determined by the Kjeldahl method described by Bremner (1965). Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) were determined after nitric-perchloric acid digestion. P was quantified calorimetrically in a spectrophotometer following the methodology proposed by Braga and Defelipo (1974). The K was determined in flame photometer and the Ca, Mg, Fe, Mn, Zn and Cu by atomic absorption spectrophotometry.

Analysis of variance (F test $P \leq 0,05$) was conducted using the ExpDes.pt package (Ferreira et al., 2018) in software R and means were separated by Duncan's Multiple Range Test at the 5% level.

RESULTS AND DISCUSSION

Melon plant height (shoot length) as affected by different nutrient solution pH, evaluated at 8, 15, 22, 29 and 40 days after transplanting, are in Table 1. At any time, no pH effect was observed on plant height which increased with time from 5.72 to 176.62 cm as an average of nutrient solution pH treatments. Under nutrient solution, cucumber shoot length was similar in pH 5.0, 6.0, and 7.0 but reduced at

Table 1: Melon plant height and leaf number as affected by nutrient solution pH at 8, 15, 22, 29 and 40 days after transplanting [(1)]

pH	Plant height (cm)					Number of leaves				
	8[ns]	15[ns]	22[ns]	29[ns]	40[ns]	8[ns]	15[ns]	22[ns]	29[ns]	40[ns]
4.0	5.4	11.9	35.3	89.0	160.5	8.0	13.8	22.8	34.0[b]	42.3[d]
5.0	5.8	13.6	42.0	98.8	174.8	9.0	12.8	22.5	35.8[b]	50.3[cd]
6.0	6.6	17.1	51.3	115.3	195.0	9.0	14.3	29.0	49.0[a]	74.0[a]
7.0	5.0	12.5	42.5	106.5	179.0	8.0	14.3	24.5	42.3[ab]	62.8[ab]
8.0	5.8	14.5	44.3	102.0	173.8	8.0	15.5	24.0	40.5[ab]	56.5[bc]
CV (%)	26.2	29.2	24.7	13.1	10.4	20.9	15.5	15.6	15.8	13.4

[(1)]Different letters indicate significant differences between means within columns at the 5% probability level according to Duncan test. [ns]stands for no significant difference at 0.05 level.

pH 8.0 (Tyson et al., 2008). Plant height obtained in the present study was higher than reported by Gomes et al. (2011) and similar to values found for melon grown in soil, under greenhouse conditions (Lima et al., 2009).

Melon plant leaf number as affected by different nutrient solution pH evaluated at 8, 15, 22, 29 and 40 days after transplanting are in Table 1. Only at 29 and 40 DAT the pH of the nutrient solution significantly affected leaf number (LN). Lower pH (4.0 and 5.0) and higher pH (8.0) led to lower LN than pH 6.0, which were 49 and 74 leaves plant^{-1}. Gomes et al. (2011) did not find significant influence of the nutrient solution pH on melon leaf number.

At 40 DAT, pH treatments significantly influenced shoot and root fresh and dry weight as well root volume (Table 2). The highest values were obtained at pH 6.0, although there was no significant difference for treatments at pH 7 and 8 in shoot dry weight and root volume (Table 2). The highest SDW was 37.6 g plant^{-1} at pH 6.0. Comparing the values of the dry weight of the roots, there was a growth between the pH ranges 4 to 6, but a decrease in the ranges 7 and 8. At pH 6, there is a low availability of H^+ in the solution, which allows higher efficiency of the ionic pump bound to the ATPases of the plasma membrane and thus favors the absorption of essential ions for the growth and accumulation of dry matter (Marschner, 2012).

The pH of the nutrient solution significantly affected the root volume. The plants that grew up at pH 6 presented higher individual mean between the treatments and better visual appearance of roots, with a clear coloration and higher volume (Fig. 1). Treatments with higher acidity resulted in lower mean root volume. A reduction in the pH of the nutrient solution increases the competition of the H^+ ion, especially the K^+, for the sites of the membrane carriers (Marschner, 2012), which reduces the absorption of essential elements and, therefore, reduces the development of the roots**.** Plants grown under extreme pH ranges have lower root development due to reduced hydraulic conductivity (Kamaluddin et al. 2004). Long et al. (2017) showed that citrus plants showed reduced root growth at low pH, as a consequence of H^+ accumulation toxicity, causing root damage and reducing water absorption, which can induce water stress, causing a reduction in biomass accumulation. (Table 2). Qi et al. (1994) showed that the increase in bicarbonate concentration, as a consequence of pH increase, led to lower root growth by inhibition of respiration. Damage effects of pH 4 and 8 levels on the visual aspect of the roots were observed. At these extreme levels, there were reduced growth, darker coloration and lower root distribution (Fig. 1).

The treatments did not differ in terms of green leaf color, measured by the SPAD index (Table 2). The

Fig 1. Melon root growth at different pH levels of the nutrient solution, at 40 DAT.

Table 2: Melon shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW),root dry weight (MSR), root volume (RV) and SPAD index as affected by nutrient solution pH, at 40 days after plant emergence(1)

pH	SFW	SDW	RFW	RDW	RV	SPAD
	g plant^{-1}				cm^3	
4.0	260.73^c	19.92^b	114.38^c	2.56^{bc}	115.0^b	32.88^a
5.0	320.33^c	22.76^b	124.00^c	2.42^c	100.0^b	33.45^a
6.0	545.05^a	37.85^a	218.87^a	4.90^a	190.0^a	36.44^a
7.0	466.05^b	33.87^a	124.68^c	2.77^{bc}	121.7^b	33.85^a
8.0	465.67^b	34.50^a	156.17^b	3.28^b	153.3^{ab}	32.93^a
CV (%)	9.26	13.48	8.01	13.15	22.34	9.34

(1)Different letters indicate significant differences between means within columns at the 5% probability level according to Duncan test.

SPAD is an effective instrument for the leaf greenness measurement being closely related to the chlorophyll content. SPAD could satisfactorily estimates N status of several species including melon (Azia and Stuart, 2001; Colla et al., 2010).

Concentrations of macronutrients N, P and K in the shoot were not significantly affected by the applied treatments (Table 3) and reached means values of 44.2, 8.0 and 43.4 g kg^{-1}, respectively. However, significant pH effects were observed for Ca and Mg concentrations (Table 3). Ca concentration was higher, 11.2 and 10.2 g kg^{-1}, at pH 7.0 and 6.0, respectively. Mg concentration was higher, 13.7 and 12.4 g kg^{-1}, at pH 8.0 and 7.0, respectively. Mills and Jones (1996) suggest for Ca and Mg the normal values of 23 – 30 and 3 – 8 g kg^{-1}, respectively. Similar values of 25 – 50; 3 – 7 and 25 – 40 for N, P and K, respectively and 25 – 50 and 5 – 12 g kg^{-1} for Ca and Mg are cited as normal, respectively (Trani & Raij, 1997). It is verified that shoot N, P, K and Mg concentrations were at adequate levels. More acidic or basic the nutrient solution lowers the Ca concentrations. This was true for Mg only under more acidic pH treatments (Table 3). Independently of pH treatments, the Ca concentration was below the lower limit of the sufficiency range (Table 3) but no visual Ca deficiency symptoms was observed in the shoot.

Table 3: Macro and micronutrient concentration in the shoot dry matter of melon as affected by nutrient solution pH, at 40 days after plant emergence [(1)]

pH	N[ns]	P[ns]	K[ns]	Ca	Mg	Cu[ns]	Fe[ns]	Zn	Mn
	g kg^{-1}[ns]					mg kg^{-1}			
4.0	45.6	7.9	43.8	6.6^{c}	7.9^{c}	7	122	38^{a}	220^{a}
5.0	46.8	9.3	45.0	8.4^{bc}	9.3^{c}	8	138	34^{a}	193^{a}
6.0	40.9	7.8	39.4	9.4^{ab}	10.2^{bc}	10	185	24^{b}	140^{b}
7.0	46.5	8.2	48.6	11.2^{a}	12.4^{ab}	9	147	20^{b}	122^{b}
8.0	41.2	6.6	40.2	8.2^{bc}	13.7^{a}	9	117	16^{b}	105^{b}
CV (%)	6.6	15.62	16.17	12.72	12.64	16.43	29.34	18.66	14.85
SR	25-50	3-7	25-40	25-50	5-12	5-30	100-500	27-100	20-300

[(1)]Different letters indicate significant differences between means within columns at the 5% probability level according to Duncan test. [ns]stands for no significant difference at 0.05 level. SR stands for sufficiency range of the nutrient

Table 4: Macro and micronutrient accumulation in the shoot dry matter of melon as affected by nutrient solution pH, at 40 days after plant emergence [(1)]

pH	N	P	K	Ca	Mg	Cu	Fe	Zn	Mn
	g plant^{-1}					mg plant^{-1}			
4.0	0.91^{b}	0.16^{c}	0.87^{c}	0.13^{d}	0.16^{c}	0.14^{c}	2.42^{b}	0.76^{b}	4.38^{a}
5.0	1.06^{b}	0.21^{c}	1.04^{bc}	0.19^{c}	0.21^{c}	0.17^{c}	3.05^{b}	0.76^{b}	4.36^{a}
6.0	1.55^{a}	0.30^{a}	1.48^{a}	0.36^{a}	0.38^{b}	0.37^{a}	7.03^{a}	0.90^{a}	5.30^{a}
7.0	1.58^{a}	0.28^{ab}	1.64^{a}	0.38^{a}	0.42^{ab}	0.32^{b}	5.04^{ab}	0.68^{b}	4.13^{a}
8.0	1.39^{a}	0.22^{bc}	1.35^{ab}	0.27^{b}	0.46^{a}	0.31^{b}	3.97^{b}	0.54^{b}	3.48^{a}
CV (%)	9.92	14.60	16.03	9.95	10.95	9.35	32.24	9.69	15.72

[(1)]Different letters indicate significant differences between means within columns at the 5% probability level according to Duncan test.

The lower concentration of Ca at pH 4 may be caused by the loss of this nutrient from the roots, due to the longer exposure time. Arnon et al. (1941) reported a significant reduction of Ca, Mg, NO_3^- and K levels in barley (*Hordeum vulgare*) when it was exposed to pH 3. According to them, the lower absorption of Ca may be linked to the reduction of plasma membrane permeability, ion absorption and retention, and to the role of Ca pectates formation as a structural component of the cell wall.

Concentrations of micronutrients Cu and Fe in the shoot were not significantly affected by treatments (Table 3) and reached means values of 8.6 and 142 mg kg^{-1}, respectively. Shoot Zn and Mn concentrations were lowered as the solution pH increased (Table 3). For melon, Mills and Jones (1996) sugest the sufficient ranges of 7-30; 50-300; 20-200; and 50-250 mg kg^{-1} for Cu, Fe, Zn, and Mn, respectively. According to Munson (1998), suficient range concentration of Cu, Fe, Zn, and Mn are 5 – 30; 100 – 500; 27 – 100 and 20 – 300 mg kg^{-1}, respectively. In this study, the plants did not show visual symptoms of micronutrients deficiency.

The reduction of Zn and Mn contents result from the effect of carbonate formation (HCO_3^-) in the nutrient solution. The high concentration of HCO_3^- inhibits the uptake of Zn by roots (Dogar and Van Hai, 1980) and translocation to shoot (Forno et al., 1975). Similar results were observed in the cultivation of lettuce (Roosta, 2011), lupine (Bertoni et al., 1992), rice (Yang et al., 1993), and olive trees (De la Guardia and Alcantara, 2002) in regard to the concentration of Mn.

Accumulation of macronutrients (N, P, K, Ca, Mg) and micronutrients (Cu, Fe, Zn, and Mn) in the melon shoot was significantly affected by pH treatments (Table 4). The macronutrients N, P, K, and Ca accumulated more at pH 7.0. Mg accumulated more at pH 8.0 but the micronutrients Cu, Fe, Zn, and Mn besides P accumulated more at pH 6.0.

In summary, the variables plant height, leaf number, shoot and root dry weight, root volume, leaf greenness and shoot concentration of Cu and Fe were higher at pH 6.0 than in others pH treatments.

CONCLUSIONS

Based on our findings, pH 6 provided better conditions for plant growth. In this pH range, the shoot presented higher levels of macro and micronutrients, which resulted in higher growth conditions.

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Author's contributions

Jose Maria, Bruno, Gustavo, Rafaela, and Paulo Fontes conceived and planned the experiment. Jose Maria, Bruno, Gustavo, Rafaela carried out the experiment and performed the analysis. Jose Maria wrote the manuscript with input from all authors. Paulo Roberto contributed to the interpretation of the results. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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