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Increasing doses of potassium increases yield and quality of muskmelon fruits under greenhouse

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ABSTRACT

Potassium (K) influences the variables that determine quality of fruit and the concentration of phytonutrients to human health and therefore consumer preferences. The objective of this study was to evaluate the effect of different concentrations of K in the nutrient solution (5, 7, 9 and 11 mM of K) on yield and quality of Cantaloupe fruits under greenhouse conditions. The experiment was conducted in pots using a completely randomized design with 15 replications. Analysis of variance, correlation, regression and multiple comparisons among means (Tukey $p<0.05$) were performed. Results showed higher values of yield, average fruit weight, equatorial diameter, pulp thickness, fruit firmness, soluble solids content, phenolic content and antioxidant capacity of fruits at the concentrations of 9 and 11 mM of K. All variables, except equatorial diameter, increased their values as K concentrations increased, showing a lineal, positive and significant trend, which evidences that the optimal dose of K in muskmelon is higher than 11 mM, being suggested for future research, to evaluate concentrations above this value.

Keywords: *Cucumis melo*, plant nutrition, nutraceutical quality.

RESUMO

Incremento de doses de potássio favorece a produtividade e qualidade de melão em casa de vegetação

O potássio (K) influencia as variáveis que determinam a qualidade dos frutos e a concentração de fitonutriente para a saúde humana e, portanto, as preferencias do consumidor. O objetivo desse estudo foi avaliar o efeito de diversas concentrações de K na solução nutritiva (5, 7, 9 e 11 mM de K) sobre o rendimento e qualidade de frutos de melão Cantaloupe em casa de vegetação. O experimento foi realizado em vasos, em delineamento experimental completamente casualizado, com 15 repetições. Foram analisadas a variância, correlação, regressão e comparação múltipla de médias (Tukey $p<0,05$). Obtiveram-se valores maiores de produtividade, peso médio de frutos, diâmetro equatorial, espessura da polpa, firmeza da polpa, teor de sólidos solúveis totais, teor de compostos fenólicos e capacidade antioxidante dos frutos nas concentrações de 9 e 11 mM de K. Todas variáveis, com exceção de diâmetro polar dos frutos, tiveram seus valores aumentados, com concentrações crescentes de K, evidenciando tendência linear positiva e significativa, indicando que a dose ótima de K em melão é superior a 11 mM. Assim, sugere-se para pesquisas futuras, avaliar concentrações acima de 11 mM..

Palavras chave: *Cucumis melo*, nutricão vegetal, qualidade nutracêutica.

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The Cucurbitaceae family, which includes cucumbers, pumpkins, muskmelons, squash and pumpkins, consists of hundreds of wild and cultivated varieties. Of these, muskmelon (*Cucumis melo*) is an important horticultural crop in arid and semi-arid regions, due to its good adaptation to the soil and climatic conditions (Kusvuran *et al*., 2012), with a total annual production of 31.92 million tons (FAOSTAT, 2014).

However, production under field conditions focuses in a few weeks, mainly due to climatic factors, then, to extend the availability of this product in the market, it is necessary to use other production methods (Arellano *et al*., 2011).

In this situation, horticultural production under protected systems is an alternative to traditional field production, especially in highly profitable crops (Pardossi *et al*., 2002). The development of muskmelon plants under greenhouse conditions compared to those developed in field, have many advantages such as precocity, yield increases and water use and fertilizer efficiency (Preciado-Rangel *et al*., 2011).

The low restrictive environment and the increase of fertilization especially nitrogen, allows high yields (Preciado-Rangel *et al*., 2011); however, this decreases the nutraceutical quality, because of when there is no deficit of nitrogen (N) the production of compounds such as amino acids, proteins, and alkaloids that contain N increased (Hallmann & Rembiałkowska, 2012). Therefore, researches of the factors that enhance the nutraceutical content of fruit were promoted (Navarro *et al*., 2006). In particular, total phenols have a high antioxidant capacity, highly desirable nutraceutical characteristic that can contribute to improved health (Fischer *et al*., 2013; Rinaldi *et al*., 2013). Therefore, a high content of phenols and antioxidants, allow greater competitiveness in domestic and international markets; however, studies using different K concentrations in the nutrient solution and quality of muskmelon were not found.

Muskmelon has low fat and sodium (Na) content, no cholesterol and provides many essential nutrients such as potassium (K), besides being a rich source of beta-carotene and vitamin C. The factors that may affect quality of fruits include genotype, environmental conditions and fertilization (Beckles, 2012).

Regarding fertilization, in recent years, to improve nutritional and nutraceutical quality of vegetable products for human consumption, the bio-fortification programs consisting of cultivation of species to increase their nutritional value, include trace elements such as micronutrients (Montoya *et al*., 2013; Constán-Aguilar *et al*., 2014).

Concerning macronutrients, K is the one that exerts greater influence on the characteristics that determine the consumer's preferences, the quality of the fruits and the concentration of phytonutrients of vital importance to human health (Lester *et al*., 2010).

Under this perspective, the objective of this study was to evaluate the effect of different concentrations of K in the nutrient solution applied during the growth period of muskmelon plants and their effect on yield and nutraceutical quality of fruits.

MATERIAL AND METHODS

Study area

The study was conducted under greenhouse conditions with automated control system of environmental conditions at Instituto Tecnológico of Torreón, México (25°36'37"N, 103°22'32"W, altitude 1123 m). During the growing season, minimum and maximum temperatures inside greenhouse fluctuated between 20 and 35°C, while the minimum and maximum relative humidity ranged from 60 to 80%.

Crop management

Sowing was done directly, placing a seed of Expedition genotype (Harris Moran®, USA) in black polyethylene bags of 20 L, caliber 500 and nursery type, which were used as pots and placed in an arrangement called "quincunx". Density was of six plants per square meter leaving one fruit per plant. Prewashed and sterilized river sand with a solution of 5% of NaClO was used as substrate. The treatments were designed from modifications of the Steiner nutrient solution and consisted of increasing levels of K (5, 7, 9 and 11 mM). Each treatment consisted of one plant/pot, distributed in a completely randomized design with 15 replications (one pot per replication). All nutrient solutions contained (in mM L^{-1}) 8 Fe, 0.865 B, 1.6 Mn, 0.023 Zn, 0.11 Cu and 0.5 Mo and were adjusted to an osmotic potential of -0.073 MPa and pH of 5.5. The nutrient solutions were formulated using high soluble commercial fertilizers, available in the local market. Three irrigations were applied daily, using a drip irrigation system, whose volume ranged from 0.750 L pot^{-1} from sowing to the beginning of flowering (45 days after sowing) and 2.0 L $plant^{-1}$ were provided from flowering to harvesting stage, which began 85 days after sowing. Plants were pruned to a stem and subsequently supported with stakes which were placed using raffia thread, holding one extreme on the stem base and the other to a metal wire which was secured to the firm structure of the greenhouse. Bees were used to pollinate flowers, introducing them to the greenhouse during the flowering stage. Several fruits were set after pollination with bees; however, only one fruit per plant was left. After pollination, fruits were pruned and the biggest one selected, which remained on plant until harvest. Harvest took place when the fruits break of from peduncle.

Fruit average weight and quality

Fruits were harvested at full slip phase, when stem was completely separated. The fruit average weight was expressed in kilograms per plant.

Fruit size (polar and equatorial diameter in cm), pulp thickness (cm), total soluble solids in Brix grades (°Brix) were measured on each harvested fruit. Brix grades were determined with a hand refractometer with scale from 0 to 32% (Atago® Master 2311), on each harvested fruit. Fruit pulp firmness was measured using a penetrometer (Extech®, FHT200) placing a plunger of 8-mm diameter and a 2-cm^2 portion that was removed from the skin on opposite sides of fruit, averaging the two measurements in Newtons (N). Phenols content was quantified according to the methodology of Esparza-Rivera *et al*. (2006) and antioxidant capacity by the method of Brand-Williams *et al*. (1995).

Statistical analysis

Analysis of variance and multiple comparisons (Tukey HSD, $p<0.05$) were performed. All analyses were executed using SAS statistical software v. 9.0. Pearson correlation analysis ($p<0.05$) and simple linear regression were performed considering as independent variable the K concentrations.

RESULTS AND DISCUSSION

Fruit average weight and quality

The results of this study indicate that concentrations of K in the nutrient solutions significantly influenced the fruit average weight ($p<0.05$, Table 1); obtaining the greatest yield those plants treated with the highest concentrations of K. These results were expected because K plays a vital role in the filling of fruits. There is an increase in requirement for K during the plant's production process; so, when the muskmelon plants of this experiment received enough K, the efficiency of water was improved by increasing osmotic pressure of cells, making them more turgid and increasing the weight and size of fruits.

The report of Tuna *et al*. (2010) indicate an increase in muskmelons fruit average weight with high concentrations of K, corroborating results of current study, due to the deficiency or excess of this macroelement limiting growth and crop yield (Tang *et al*., 2012; Hafsi *et al*., 2014). However, there is no dose or unique concentration because of differences found in yield, due to different varieties, soil and weather conditions, crop management (Silva-Dias *et al*., 2005), source and method of fertilizers application (Lester *et al*., 2010). Fruit weight showed significant and positive correlation with concentration of K in the nutrient solution; this means that, fruit weight increases with increasing K concentrations (Table 2). This correlation occurred due to the fact that this element plays a fundamental function in the filling of fruits, promoting greater firmness and resistance of the tissues since potassium is absorbed in large quantities in crops such as muskmelon. Similar results reported Demiral & Köseoğlu (2005).

The fruit polar diameter did not show significant differences among concentrations of K, however, the values varied from highest to lowest as follows: 9>11>7>5 mM of K (Table 1). Although K increases the weight and size of the fruits, the increase of fruit polar diameter was slight with only 4.44% in 9 mM compared to 5 mM of K. The fruit equatorial diameter showed significant differences among the concentrations of K (Table 1) and varied from highest to lowest as follows: 11>9>(7=5). Polar diameter was equal at 7 and 5 mM of K. The fruit equatorial diameter increased 9.10% at 11 mM compared to 7 and 5 mM of K. The fruit polar and equatorial diameters were greatest in those plants treated with concentrations of 9 and 11 mM of K, respectively. The fruits size in our study was similar to those reported by Moreno-Resendez *et al*. (2010).

The fruit equatorial diameter showed a significant and positive correlation with the concentration of K and increased as the concentration of K increased (Table 2); nevertheless, correlation among fruit polar diameter and K concentration was not significant. The fruit yield achieved in those plants treated with 11 mM of K, exceeds 41% of those obtained in field (Camberos & Rios, 2000). This result confirms that under protected conditions and using nutrient solutions, the fruit average weight increases. The results of present study are consistent with Preciado-Rangel *et al*. (2002) who reported that some muskmelon hybrids, showed greatest demand of K and that the different hybrids require different nutritional conditions to show their full potential.

Fruit pulp thickness showed significant differences among the different concentrations of K getting the greatest values in those plants treated with 9 and 11 mM of K (Table 1). Fruit pulp thickness showed significant and positive correlation with the concentration of K in the nutrient solution, displaying a linear relationship, because of, increasing K concentrations

Table 1. Effect of potassium (K) concentrations in the nutrient solution, on fruit average weight, polar and equatorial diameter, pulp thickness, total soluble solids, firmness, phenols content and antioxidant capacity of muskmelon fruits. Mexico, Instituto Tecnológico de Torreón, 2015.

K (mM)	Fruit average weight (kg)	Diameter (cm)		Pulp thickness (cm)	Firmness (N)	TSS (°Brix)	Phenols content (mg equivalent Gallic acid 100 g FB^{-1})	Antioxidant capacity (µM equiv Trolox/100 g FB)
		Polar	Equatorial					
5	1.01 b	13.50	11.10 b	2.95 b	18.11 b	11.90 b	31.46 b	114.90 c
7	0.95 b	13.51	11.10 b	2.95 b	18.58 b	11.90 b	30.79 b	162.90 b
9	1.11 a	14.10	11.70 ab	3.45 a	20.88 b	12.20 ab	33.22 b	191.40 ab
11	1.12 a	13.64	12.11 a	3.12 ab	23.92 a	12.70 a	39.27 a	213.10 a
CV (%)	4.66	3.46	3.84	6.70	4.45	2.87	7.79	8.95

[1]Data expressed as µM equivalent in Trolox per 100 g. FB= fresh base. Values in each column followed by the same letter(s) are not significantly different at p≤0,05 (Tukey HSD). TSS= total soluble solids. N= Newtons.

Table 2. Correlation coefficient (Pearson), determination coefficient and simple linear regression equation among potassium concentrations (mM) and dependent variables, phenols content, antioxidant capacity, yield, fresh weight, equatorial diameter, pulp thickness, total soluble solids and firmness of muskmelon fruits. Mexico, Instituto Tecnológico de Torreón, 2015.

Dependent variables	Correlation coefficient (r)	Determination coefficient (R^2)	Simple linear regression equation
Phenols content	0.72**	0.52	PC=23.34+1.29×K**
Antioxidant capacity	0.93***	0.86	AC=41.49+16.14×K***
Fresh weight	0.63**	0.39	FW=0.89+0.02×K**
Yield	0.67***	0.46	Y=5.30+0.13×K***
Equatorial diameter	0.59**	0.34	ED=10.41+0.14×K**
Pulp thickness	0.62**	0.38	PT=2.49+0.08×K**
Total soluble solids	0.67***	0.45	TSS=11.06+0.13×K***
Firmness	0.90***	0.81	F=12.49+0.98×K***

Significance level (p)= **p<0.01; ***p<0.001.

resulted in fruit pulp thickness increase (Table 2). These results do not match with those reported by Silva *et al*. (2014) who found a quadratic response for fruit pulp thickness and a linear trend in the fruit size caused by increased fertilization with K.

Pulp firmness showed significant differences between K concentrations, exhibiting greatest value in the concentration of 11 mM of K (Table 1). Pulp firmness showed significant and positive correlation with the concentration of K in the nutrient solution, increasing as the concentration of K increased (Table 2). Also, fruit firmness showed significant and positive correlation with total soluble solids content, because of, as fruit firmness increases, total soluble solids content also increase. In this regard, Lester *et al*. (2010) indicate that fruit firmness is correlated with the pressure potential (ψp) because K increases the accumulation of sugars (solutes) in fruits (Ribas *et al*., 2003). Similarly, Demiral & Köseoğlu (2005) reported this positive relationship among fruit firmness and total soluble solids. From the commercial viewpoint, when fruit firmness increases, acceptance of the muskmelon fruits by the consumer is improved, because they prefer fruits with firm pulp instead of soft and watery (Ribas *et al*., 2003) being 23.6 Newtons the optimal value for fruit firmness in muskmelon (Silva-Dias *et al*., 2005).

Potassium concentrations in the nutrient solution, stimulated significant differences ($p<0.05$; Table 1) in the soluble solids content, getting the greatest values those fruits from plants treated with 11 mM of K, validating the positive effect of K on fruit quality (Demiral & Koseoglu, 2005; Tang *et al*., 2012; Silva *et al*., 2014). Furthermore, the content of total soluble solids showed significant and positive correlation with the concentration of K in the nutrient solution, revealing a linear relationship caused of increasing K concentrations, also the content of total soluble solids increased (Table 2).

The concentration of soluble solids of fruits harvested from plants treated with the concentrations of K exceeded the minimum value (9° Brix) (Table 1) reported as acceptable in market (Mata & Mendez, 2009). This confirms that transport of sugars to fruits was effective since K has an important role in the transport of solutes through phloem (White & Karley, 2010) and these fruits are considered marketable because total soluble solids are one of the main quality criteria for muskmelon fruits (Budiastuti *et al*., 2012).

The results showed that the increase of K concentration, exhibited an increase in phenols content and antioxidant capacity, both characteristics showed greatest values in the concentration of 11 mM of K ($p<0.05$, Table 1); which is an advantage since the fruits with greatest phytonutrients content have great interest because their consumption is associated with a lower risk of cardiovascular diseases and certain cancers types (Llacuna & Mach, 2012). The antioxidant compounds are essential in the nutritional quality of fruits and are rated an essential factor in determining their price in the market (Frusciante *et al*., 2007). Lester *et al*. (2010) found that muskmelon fruits from plants treated with different sources of K had greatest content of antioxidants compared with untreated fruits.

The beneficial effects of K supplement to the plant were presumably result of a combination of an improvement in the assimilation of CO_2, higher photosynthetic activity and greatest translocation of photoassimilates from leaves to fruits, improved water relations, greater enzyme activity and substrate availability for the biosynthesis of bioactive compounds; so the amount of antioxidants of a plant is also a good indicator of stress tolerance (Kusvuran *et al*., 2012).

Phenols content and antioxidant capacity showed significant and positive correlation with the concentration of K in the nutrient solution, with a linear relationship caused by the concentration of K increased in the nutrient solution; the values of both variables also increased (Table 2), demonstrating that K contributes significantly to the antioxidant capacity and phenols content in muskmelon fruits. The current study demonstrated that the concentrations of 9 and 11 mM of K positively influenced the increased yield and fruit quality of muskmelon. The best concentration to maximize yield and quality of muskmelon fruits was 11 mM of K. Given the linear trend of all characteristics (except fruit polar diameter) to increase their values as concentrations of K increased, it evidences that the optimal dose of K in muskmelon is greater than 11 mM, suggesting, for future research, to evaluate concentrations of K above 11 mM.

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