FOLIAR APPLIED POTASSIUM: EFFECTS ON CANTALOUPE QUALITY, SUGAR CONTENT AND RELATED COMPOUNDS

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Abstract

Cantaloupe fruit sugar content is directly related to potassium (K)-mediated phloem loading and unloading of sucrose into the fruit. Improving K content in melons, during fruit growth and maturation through soil applied fertilization, is a problem, as root uptake of K is poor at this stage of growth and K competes with the uptake of Ca and Mg, two essential minerals needed for melon fruit membrane structure, function and post-harvest shelf life. Netted, orange-flesh muskmelon [*Cucumis melo* L. (Reticulatus Group) 'Cruiser'] fruits were grown in the greenhouse during the spring of 2003 and received regular N-P-K soil fertilization throughout the study. Three to 5 days after anthesis (fruit set) and up to 3 to 5 days prior to abscission (full-slip), amino acid complexed potassium (Metalosate® Potassium 24% K) at 4.0 $mL^.L^{-1}$ (0.51 $oz^.gal^{-1}$) was sprayed on the entire plant until run-off. Plants were sprayed either weekly, biweekly or not sprayed (control). Fruit from plants receiving weekly applications of foliar K matured two days earlier, and had significantly higher fruit K content, soluble solids concentration, total sugars, ascorbic acid (vitamin C), and beta-carotene content than fruit from plants not receiving foliar K applications.

Introduction

Potassium (K) is required in large amounts by plants, although it has no structural involvement, it is involved in a number of catalytic roles (Bidwell, 1974). These roles are clearly defined, but the exact nature of the large K requirement remains unknown. Potassium is needed for the activation of pyruvate kinase, which is essential in respiration and carbohydrate metabolism (Bidwell, 1974). Therefore, K is important in the overall metabolism of plants. Potassium uptake by plants is characterized by high mobility at all levels within individual cells, within tissues, and in long-distant transport via the xylem and phloem (Marschner, 1995). Potassium is not metabolized and it makes weak complexes in which it is readily exchangeable (Wyn Jone et al., 1979). Due to its high concentration in the cytoplasm (100 to 200 nM) and chloroplasts (100 to 200 nM) it stabilizes the pH, between 7 and 8, in these organelles and therefore optimizes enzyme activities (Marschner, 1995). In these cellular functions, K is involved in enzyme activation, protein synthesis, photosynthesis, osmoregulation, cell extension, stomatal movement, light-driven and seismonastic movements, the production of chloroplasts, phloem transport (particularly sugars and amino

acids), phloem loading and unloading (particularly sugars) and cation-anion balance. Plant K is normally derived primarily via the soil; and its availability in the soil is based on soil K concentration, pH, moisture conditions, and K buffering capacity (Mengel and Kirkby, 1980). The quantity of K absorbed by plant roots is related to root age (root tips of older plants are less capable of absorbing K than root tips of younger plants), root metabolism (some species may differ in the capability of extracting soil K), root growth stages (active root growth during later stages of plant development uptake more K than non actively growing roots), soil type (clay soils have more available K than loam or sandy soils), soil pH (neutral and acid soils release more K than alkaline soils), adequate soil oxygen supply, and xylem transport demand (influenced by environmental conditions such as high light, wind, and temperature) conditions (Mengal and Kirby, 1980). Potassium is mainly taken up during the vegetative stage of plant growth (Beringer et al., 1986). Therefore, soil derived K, which is essential for sugar transport to, and unloading into fruit, during fruit growth and development is not always optimal. Additionally, during root nutrient uptake, K competes with magnesium and calcium (Watkins, 1984), two essential minerals needed for melon fruit membrane structure, function and postharvest shelf-life (Lester and Grusak, 1999).

In an effort to overcome soil potassium uptake inadequacy during cantaloupe fruit development we designed a greenhouse study to examine the effect of foliar applied organic-complexed potassium (Metalosate Potassium) in combination with soil supplied potassium. Foliar applied K was delivered to the entire plant during fruit growth and maturation, and its effect on earliness, fruit size, fruit weight, and fruit sugar, ascorbic acid and beta-carotene contents were examined.

Materials and Methods

Plant material and greenhouse conditions. Seeds of 'Crusier' netted muskmelon were planted in a glass greenhouse in 15-L black plastic pots containing Sunshine mix #2 (Sun Gro Horticulture, Bellevue, Wash.). Pots were fertigated twice a week with half strength 20N-20P-20K nutrient solution during vegetative and fruit growth stages or half strength 9N-45P-15K nutrient solution during flowering and fruit set stages. Irrigation occurred daily for 15 minutes at 8:00, 11:00, and 15:00 hour at flow rate of 200 mL·min^{-1}. Plants were maintained under a 12-hour photoperiod. Natural daylight in the glasshouse was supplemented by 400-W, high-pressure sodium-vapor lamps (300 μE·s^{-1}·m^{-2} radiation), and the daily average photosynthetic photon flux density (PPFD) at the canopy level was 15 + 3.8 mol·m^{-2}; total PPFD for the entire growth period was 1156 mol·m^{-2}. Day/night average temperatures were 28.8 ^{o}C $\pm$ 4.4 ^{o}C / 21.7 ^{o}C $\pm$ 3.2 ^{o}C (84 ^{o}F $\pm$8 ^{o}F / 71 ^{o}F $\pm$6 ^{o}F) and average day/night relative humilities (RH) were 48% $\pm$11%/ 68%$\pm$11%. Flowers were hand-pollinated, and one fruit per plant was allowed to develop.

Treatments. Three to 5 days after anthesis (fruit set), and up to 3 to 5 days prior to abscission (full-slip), amino acid complexed potassium (Metalosate Potassium 24% K) at 4.0 mL·L^{-1} (0.51 oz·gal^{-1}) was sprayed on the entire plant until run-off. Plants were sprayed either weekly, biweekly, or no spray (control). Ten fruit (replicates) from each treatment were tagged and monitored for days to full-slip and at harvest, fruit size and weight were recorded, then stored for three days at 4°C (39 ^{o}F) plus 95% + 5% RH. Fruit tissue, sampled from the equatorial middle mesocarp (edible) region of each fruit, was used for all tissue analyses (tissue % dry weight, K concentration, soluble solids concentration, sucrose, glucose, fructose, ascorbic acid, and beta-carotene) as detailed below.

Fruit analyses. Percent dry weight (as % of tissue analyzed) was determined on 1 to 10 g of lyophilized mesocarp tissue. Soluble solids concentration, in juice from fresh tissue expressed through hand held garlic press, was determined using a temperature-corrected digital refractometer (Reichert Scientific Instruments, Buffalo, N.Y.). Fruit sugars were extracted from 0.3 g lyophilized tissue by stirring with 5 mL of 90 ^{o}C (194 ^{o}F), 80% ethanol for 2 minutes. The solution was filtered (Whatman, No.1; Maidstone, United Kingdom) and the residue washed with additional 5 mL hot 80% ethanol. One mL of the extract was filtered through a pre-wetted, with 80% ethanol, C18 Sep-Pak (Waters Corp., Milford, Mass.) before determination of fructose, glucose and sucrose using the high-performance liquid chromatography procedure previously described by Lester and Dunlap (1985).

Potassium concentrations were determined on fresh weight tissue taken from the equatorial region of the fruit. Tissues were weighed immediately to determine fresh weight, and then dried at 70 ^{o}C (158 ^{o}F) for 48 hours. Total mg potassium per gram dry weight was determined, using atomic absorption spectroscopy, by a commercial plant tissue analysis lab. (Plant and Soil Analyses, Edinburg, Texas)

Free ascorbic acid and dehydroascorbic acid were extracted from 7.5 g of frozen tissue in 15 mL ice-cold 5% (w/v) meta-phosphoric acid and homogenized using a polytron homogenizer (Brinkman Instruments, Westbury, N.Y.) at medium speed for 5 seconds. Homogenized tissue was centrifuged at 7000 *gn* for 15 minutes at 4 ^{o}C (39 ^{o}F). Detection of free ascorbic acid and dehydroascrobic acid was at 525 nm according to Hodges et al. (2001) and concentrations were calculated using a standard curve.

Beta-carotene, was extracted, under low light conditions, as modified from Gruel et al (1999), using 0.020g of lyophilized mesocarp tissue in 1.0 mL ice-cold heptane plus 0.5 mL of 40 μg·mL^{-1} internal standard trans Apo-8'-carotene (Sigma Chemical Co. St. Louis, MO.). The internal standard stock solution was made by dissolving Apo-catotene in 1.0 mL methanol then bringing to volume (250 mL) with heptane then stored in the dark at -20 ^{o}C (-4 ^{o}F). The melon tissue cocktail was vortexed for 1 minute, then centrifuged at 3000 *gn* for 10 minutes at 0 ^{o}C (32 ^{o}F). One mL of supernatant was removed and 1.5 mL fresh, ice-cold heptane was added to the pellet, vortexed for 1 minute, then centrifuged as

above. One mL of supernatant was removed and 1.0 mL fresh, ice-cold heptane was added to the pellet, vortexed 1 minute, then centrifuged as above. One mL of the combined 3 mL supernatant was passed through a 0.2 nylon Millex-LCR 13 filter (Millipore Corp., Bedford, Mass.) and injected into a high performance liquid chromatograph (HPLC) or held in the dark at -20 ^{o}C (-4 ^{o}F) until HPLC determination. Beta-carotene was separated in a mobile phase of methanol at a flow rate of 2.0 mL$^{.}$min^{-1} using a Discovery C18, 5 μm column (15 cm X 4.6 mm) equipped with a Discovery C18, 5 μm guard column (2 cm X 4.0 mm) (Supelco, Bellefonte, PA.). Detection of beta-carotene was at 454 nm according to Grela et al., 1999).

Results and Discussion

Fruit having received weekly foliar applications of 24% K, during growth and maturation, reached harvestable maturity (full-slip) significantly earlier ($P\leq$ 0.05), almost two days earlier, than control, water sprayed fruit (Table 1). This, K-induced earliness of maturation is an interesting phenomenon that has not been previously reported in the literature. Fruit receiving bi-weekly applications of foliar K also matured slightly earlier than controls. The weight of fruit receiving weekly K applications was slightly lower than that of controls or biweekly treated fruit. Again, the later observation has not been reported in the literature. Potassium concentrations in the edible portion of the fruit were affected by K treatments. Fruit receiving weekly K treatments had significantly higher (15%) K concentration than controls, whereas the K concentration in bi-weekly treated fruit was intermediate. Beringer et al., (1986) found that in sugar beet (*Beta vulgaris*) root tissue concentration of 38 mg$^{.}$K.g^{-1} dry wt was required to achieve maximum root and sugar yield. This study also demonstrates that the application of K can increase melon fruit sugar levels; as shown by the significant correlation between fruit K and SSC (r = 80; $P\leq$ 0.001). Unlike sugar beets which were heaver following K applications vs. control, melon fruit from plants receiving the highest K rate were equal in weight to those receiving less or no foliar applied K.

Soluble solids concentration (SSC) was significantly higher in fruit receiving weekly foliar K applications, higher than the fruit from control plants (Table 1). This higher SSC (9 SSC vs. 8 SSC) would allow these fruit to be legally marketable, whereas, the lower SSC would not (Lester and Shellie, 2002).

Table 1

Differences in Maturation (Days to Abscission), Fruit Weight, Edible Tissue K Concentration, Soluble Solids Concentration (SSC) and the Correlation Coefficient of Potassium: SSC of 'Cruiser' Muskmelon Fruit Following Weekly, Biweekly or No Applications of Amino Acid Chelated Potassium, Applied from Fruit Anthesis (Pollination) to Fruit Abscission (Harvest).

Foliar application	Maturity (days to harvest)	Fruit weight (g)	Potassium conc. ($mg \cdot g^{-1}$ dry wt.)	SSC (%)	Correlation mg K:SSC
Weekly	35.2 b[Z]	2068 a	37.3 a	9.0 a	0.80[***]
Bi-weekly	36.3 ab	2134 a	37.0 a	8.4 ab	
None	37.0 a	2354 a	32.0 b	8.0 b	

[Z] Means with the letter, within a column, are not statistically significant at Duncan's MRT at the 95% probability level. (n=10). [***] Correlation (r) significant at $P \leq 0.001$.

Potassium is an essential element that plays a vital role in photosynthesis, phloem loading and unloading, as well as long-distance translocation of sugars to fruits (Marschner, 1995). Total sugars in fruit, receiving weekly applications of K, were significantly greater (8% more sugars) than in control, non treated fruit (Table 2). This positive affect of K applications on melon fruit sugar content, during fruit growth and maturation, is evident in the significant positive correlation between fruit K concentration and fruit total sugars (r=90, $P \leq 0.001$). Fructose and glucose were 17% and 8% greater, respectively, in fruit receiving weekly applications of K versus no treatment. Sucrose levels were not affected by supplemental foliar K applications. The significant response of reducing sugars (fructose and glucose), compared to non-reducing sugar (sucrose) suggests that acid invertase (EC 3.2.1.26) activity is retained longer in fruit with higher K concentrations. Muskmelon fruit with higher fructose and glucose to sucrose concentrations ratios, but similar total sugar concentrations, is due to higher acid invertase activities at maturation (Lester, et al. 2001). High fructose content in melons is a positive fruit characteristic, as such, fruit may be perceived as being sweeter. Fructose is perceived to be 42% sweeter than sucrose and 57% sweeter than glucose (Shallenberger, 1980). Thus, a high fructose melon should taste sweeter than a melon with equal total sugars but less fructose. The specific role(s) that K plays, if any, in affecting the acid invertase (sucrose catabolism) and sucrose phosphate synthase (EC 2.3.1.14) (sucrose accumulation) within the melon fruits is currently unknown.

Table 2

Differences in Edible Tissue Fructose, Glucose, Sucrose and Total Sugars, and the Correlation of Mg Potassium: Total Sugars of 'Crusier' Muskmelon Fruit Following Weekly, Biweekly or No Applications of Amino Acid Chelated Potassium, Applied from Fruit Anthesis (Pollination) to Fruit Abscission (Harvest).

Foliar application	Fructose (mg·g^{-1} dry wt.)	Glucose (mg·g^{-1} dry wt.)	Sucrose (mg·g^{-1} dry wt.)	Total sugar (mg·g^{-1} dry wt.)	Correlation mg K: T. Sugar
Weekly	154 a^Z	89 a	300 a	543 a	r=0.90**
Bi-weekly	153 ab	87 a	290 a	531 ab	
None	128 b	82 b	292 a	502 b	

^{Z} Means with the same letter, within a column, are not statistically significant at Duncan's MRT at the 95% probability level. (n=10). *** Correlation (r) significant at $P \leq 0.001$.

The reporting of sugars on a dry weight basis and the resulting sweet taste difference between the relatively high fructose fruit vs. low fructose fruit is likely perceivable to consumers, and would be independent of fruit size. In addition, total fruit dry weights were similar between treatments (Table 3). Therefore, there is no dilution of sweetness due to higher fruit moisture content. Thus, the higher fructose and total sugar containing fruits should taste sweeter.

Two important human wellness compounds; ascorbic acid (vitamin C) and beta-carotene (provitamin A), essential in the human diet and synthesized only in plants, are found in very high concentrations in orange-fleshed muskmelon types (Lester and Eischen, 1996; Lester and Crosby, 2002). Both ascorbic acid, derived from glucose (Hopkins, 1963) and beta-carotene, derived from chloroplasts (Gross, 1991) are products of photosynthesis, which is regulated in part by K. Potassium, therefore, is highly influential in the accumulation of both human wellness compounds (ascorbic acid and beta-carotene) in melon fruit (Table 3). Ascorbic acid was 13% higher ($P \leq 0.05$) in fruit receiving weekly applications of foliar applied K compared to controls. Ascorbic acid in humans is critical in maintaining a healthy immune system by protecting against damage from free radicals (Larson, 1997). In plants, ascorbic acid plays a similar role in retarding tissue senescence (Hodges et al., 2001). Beta-carotene was 22% higher ($P \leq 0.05$) in fruit receiving weekly K applications vs. bi-weekly applications, and 45% higher than in control fruit. Beta-carotene, in humans, after conversion to vitamin A, protects cell membranes and fatty tissues from oxidative damage, helps repair damage caused by air pollutants, and boosts the immune system. (Raloff, 1997). In melon fruit, the enzyme lipoxygenase associated with cellular membrane breakdown through the production of free radicals and fruit senescence, is absent in fruit rich in beta-carotene (Lester, 1990) thus, beta-carotene, an antioxidant, may also play a role in the regulation of melon fruit senescence. Enhancing the accumulation of beta-carotene in fruits, through

carefully-timed, controlled K fertilization, should enhance the marketable shelf-life as well as the human wellness potential of melons.

Table 3

Differences in Edible Tissue Percent Dry Weight, Total Ascorbic Acid and Beta-Carotene Concentration of 'Crusier' Muskmelon Fruit Following Weekly, Biweekly or No Applications of Amino Acid Chelated Potassium, Applied From Fruit Anthesis (Pollination) to Fruit Abscission (Harvest).

Foliar application	Dry weight (%)	Ascorbic acid (mg·g^{-1} dry wt)	Beta-carotene (µg·g^{-1} dry wt)
Weekly	10.0 a [Z]	25.4 a	39.5 a
Bi-weekly	10.0 a	24.4 ab	30.8 b
None	10.0 a	22.0 b	21.6 c

[Z] Mean with the letter, within a column, are not statistically significant at Duncan's MRT at the 95% probability level. (n=10).

Conclusion

This controlled environment greenhouse study demonstrated that foliar applied K can increase cantaloupe fruit quality, by increasing simple carbohydrate content, ascorbic acid and beta-carotene levels. These studies will be repeated in both greenhouse as well as in field trials. It is expected that these foliar K applied trials, will be as encouraging, in demonstrating the dramatic benefit to muskmelon fruits (both cantaloupe and perhaps honey dew melons) in improving K content and subsequently increasing soluble solids concentration, total sugars, ascorbic acid and beta-carotene contents. Thus, melon fruit quality and marketability are expected to benefit by following this a relatively simple and inexpensive management tool.

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