Can Potassium Application Affect the Mineral and Antioxidant Content of Horticultural Crops?

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Abstract

As consumers become increasingly aware of the importance of diet in avoidance of chronic diseases, the content of vitamins, minerals, and antioxidants in fruits and vegetables can greatly affect consumer demand. In humans, potassium (K) is needed to regulate enzyme function, enable muscle contraction, and transmit nerve impulses. Increased K intake may lower hypertension. Good sources of K from fruits and vegetables are bananas, melons, tomatoes, potatoes, squash, citrus, and spinach. Potassium has multiple enzymatic and catalytic functions in plants. Increased K fertility has been reported to decrease beta-carotene and increase lycopene content in tomato, and enhance the levels of vitamin C and carotenoids in carrots, tomatoes, and citrus. Additionally, the U.S. Food and Drug Administration (FDA) has approved the use of K as a health claim if the food contains at least 350 mg K, less than 140 mg sodium (Na), no more than 20 mg cholesterol, no more than 3 g saturated fat, and no more than 15% of calories from saturated fat per serving. Several fruits and vegetables qualify for this health claim. The effect of K fertility on watermelon was studied to determine if modification of commonly accepted farm practices could enhance K content and lycopene of fruit without negative effects on quality. Application of K at high rates (>280 kg K_2O/ha) decreased yield and fruit tissue pH. The K content of leaf petiole sap, length to diameter ratio of fruit, and fruit rind thickness increased with high application of K.

Introduction

Nutritional imbalances can cause or contribute to many human diseases. These include chronic conditions such as osteoporosis, obesity, heart disease, and mineral or vitamin deficiency such as anemia (iron deficiency) or vitamin A-deficient blindness. Potassium is used to maintain electrolyte balance in the body and may help prevent bone demineralization by preventing calcium loss from urine (Tucker et al., 1999; He and MacGregor, 2001). Potassium can lower blood pressure, especially when used as a substitute for Na in Na-sensitive patients (Appel, 1999). These benefits resulted in approval by the FDA for a K health claim. This claim can be used on approved foods if the following criteria are met: 1) a serving contains at least 10% of the recommended daily intake (RDI) of 3,500 mg K; 2) a serving contains no more than 140 mg sodium; 3) the food contains no more than 3 g saturated fat; 4) the food contains no more than 20 mg cholesterol; and 5) total saturated fatty acids contribute no more than 15% of the total caloric intake per serving (FDA, 2000).

Many fruits and vegetables meet the FDA criteria for low fat and for high K (**Table 1**). Additionally, fruits and vegetables contain other vitamins and minerals, and non-nutritive compounds (phytochemicals) (Hasler, 1998; Craig and Beck, 1999). These phytochemicals appear to have health-beneficial properties, such as glucosinolates found in broccoli, lycopene found in tomatoes and watermelon, and quercetin in onions (Gerster, 1997).

In the past, identification of foods high in specific nutrients has meant little to most except those individuals careful to tailor their diet for existing medical conditions. Fortunately, the swell of consumers interested and willing to pay for a diet designed to prevent chronic disease has created a new market niche for health-functional fruits and vegetables (Shaffer, 2001a,b).

The benefit of K as a soil amendment (fertilizer) to increase yields of crops has been known for several hundred years, as reviewed by Mengel and Kirkby, 1980. Studies from the 1930s through the 1960s were done to establish the amounts of K needed for best crop response on K deficient soils. Requirements for K depend largely on the soil type, as crops grown on soils with high K fixation show less response to applied K. The recommended rate for many fruits and vegetables grown on sandy or sandy loam soils is usually 100 to 300 kg K_2O/ha.

Potassium is considered a macronutrient in plants. It is used in many photosynthetic and metabolic processes, and has a more general use rather than the specific cofactor or enzymatic uses of other minerals such as iron or magnesium. Potassium acts as an

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Table 1. Potassium content of fruits and vegetables, and contribution to % RDI of 3,500 mg.

Crop	Serving size	Weight of serving size (g)	Potassium per serving (mg)	% RDI per serving
Squash	1 cup	205	896	26
Potato	1 potato	202	844	24
Spinach	1 cup	180	840	24
Beets	1 cup	170	509	14
Sweet potato	1 potato	146	508	14
Banana	1 banana	118	461	13
Muskmelon	1 cup	160	494	14
Papaya	½ fruit	152	390	11
Watermelon	2 cups	304	352	10
Tomato	1 medium	123	273	8

Source: USDA Nutrient Database for Standard Reference, Release 14, Potassium Content of Selected Foods per Common Measure. 2002.

Table 2. Reported effects of potassium on horticultural crops.

Crop	Type of K application	Response	Reference
Grape (*V. labruscana*, var. Concord L.)	Field, 0 or 450 kg K_2O/ha	increased juice pH, K increased 15 to 50%, reduced uneven ripening	Morris and Cawthon, 1982
Grape (*V. Vinifera*, var. Shiraz, Sultana L.)	Greenhouse, perlite, with 0.25 or normal K application as Hoagland's solution.	Increased juice pH and titratable acidity increased K content of grapes	Hale, 1977
Grapefruit (*Citrus paradesi*)	Field, fertigation, foliar sprays	increased lycopene, b-carotene, vitamin C	Patil, 2002
Pistachio (*Pistacia vera* L.)	Field application, 0 to 330 kg/ha	decreased nut stain	Zeng et al., 2001
Strawberry (*Fragaria ananassa* Duch.)	Field application, matted row system	increased titratable acidity relative to no K	Haut et al., 1935;
	Greenhouse sand culture	increased soluble solids, titratable acidity, earliness, relative to no K	Ricketson, 1966;
	Field application, annual hill system (KCL, K_2SO_4, KNO_3, 60 to 180 lb/A)	increased titratable acidity with increased K	Saxena and Locasio, 1968
Strawberry (*Fragaria Vesca* var. Semperflorens Duch.)	Greenhouse sand culture (0 to 15 meq/L K)	K increased, titratable acidity increased, nonvolatile acids increased with increased K	Choureitah and Bünemann, 1972.
Tomato (*Lycopersicon esculentum* L.)	Hydroponic (0 to 10 meq/L K)	Lycopene, total carotenoids increase up to 8 meq/L	Trudel and Ozbun, 1971
Tomato	Field, fertigation (0 to 400 kg/ha)	decreased pH, increased titratable acidity with increased K	Fontes et al., 2000;
	Field, KCl or K_2SO_4	less white and yellow color disorder	Francis, 2002
Watermelon (*Citrullus lanatus*)	Field, KCl (0 to 209 kg/ha)	increased resistance to rind rupture, increased rind thickness with K	Sundstrom and Carter, 1983

osmoticum in plant cells to regulate water and solute uptake, and is used for ATP formation, respiration, and enzyme activation. Most reports on K amendment for horticultural crops have centered on the yield response rather than quality. Potassium effects on composition and quality have been documented in strawberries, grapes, grapefruit, pistachio, watermelon, and tomatoes (**Table 2**). Potassium appears to most affect acidity, pH, and carotenoid content, and may promote disease resistance in the plant.

In most instances, additional K will decrease the fruit pH and increase acidity. This may be due to a general increased synthesis of organic acids from up-regulation of the tricarboxylic acid pathway (TCA), as has been suggested for tomatoes (Hobson and Davies, 1971). In grapes, about 70% of the total mineral content is K, which increases as grapes ripen (Hale, 1977), and can combine with tartaric acid to form K tartarate. Tartaric and malic acid are the primary organic acids in wine grapes, and these and their salts determine the titratable acidity and pH of grapes. Hale (1977) concluded that K increased malic acid concentration through increased membrane permeability and subsequent release of malic acid from the vacuole, rather than from increased acid synthesis.

In watermelons, K content just meets the 10% RDI in a 2 cup serving size (**Table 1**). Preliminary results indicate that K can differ substantially among watermelon varieties (900 to 2000 mg/kg edible flesh), but does not appear to change with ripeness. Lycopene is the carotenoid imparting red color to watermelons and tomato (Perkins-Veazie et al., 2001). In tomatoes, increasing K hydroponically increases K content, flesh color, and lycopene content (Trudel, 1972). While Sundstrom and Chisholm (1982) found that increased K could increase rind thickness in a small sample of watermelons, they found no change in subjectively rated flesh color. The following study was done to determine if K content of watermelon could be increased by increasing soil K content, without detrimental effects on melon quality.

Materials and Methods

Plant material

Seeded watermelon 'Sangria' transplants were planted in a Bernow silty loam soil (fine-loamy, siliceous, thermic Glossic Paleudalf, CEC of 4 meq/100 g) with in-row spacing of 91 cm, 274 cm between rows, and 610 cm between plots. The field, previously in bermudagrass, and unamended with fertilizer, had a base level of 34 kg/ha available K. Treatments were arranged in a randomized complete block design, with four blocks per treatment, and consisted of 34, 140, 280, 560, and 840 kg K_2O /ha using KCl as the source. Potassium was applied preplant by spreading fertilizer over the plot area then tilling in. Nitrogen (a total of 120 kg/ha) was applied as split applications, with a broadcast application of 60 kg/ha preplant, then sidedressed with 30 kg/ha at vine running and 30 kg/ha at fruit set. Recommended fertility rates for this soil type and crop was 280 kg/ha K_2O. Phosphorus was applied preplant by broadcast at a rate of 160 kg P_2O_5/ha.

Leaf petiole sap K

Eight to ten leaves (most recently expanded leaf per vine) from each plot were harvested weekly from watermelon plants starting 30 days after planting, placed in plastic bags, held on ice until returning to the lab, and processed within an hour following the method of Hochmuth (1994). Stages of growth over the sampling period represented vines 20 cm long to fruit at first harvest. Leaves were gently rinsed in deionized water to remove excess soil and the petioles were cut from the leaves. Petioles were crushed in a garlic press and expressed sap placed on a portable K meter (Cardy Ion Meter, Spectrum Technologies, Plainfield, IL). Values for petiole sap K were in the 3,000 to 5,000 mg/kg range reported for watermelon (Hochmuth, 1994).

Melon measurements

Total melons, including those sunburned, poorly pollinated, or otherwise unmarketable due to injury or blossom end rot were counted in each block. Melons free of injury were harvested from plots, weighed, and length (blossom end to stem end) and circumference measured around the center of the melon. Melons were cut in half transversely and thickness of the rind (between outer epidermis and pink colored flesh) measured with calipers at the ground spot and directly opposite the ground spot. Diameter of the cut surface (including epidermis) was measured with a tape measure marked in cm. The ratio of length to diameter, a gauge of melon shape, was determined from above measurements. Flesh samples (about 300 g) were taken from the center of each melon (locule and heart) and held at -80°C until analyzed. Frozen samples were thawed, homogenized, pH of puree measured by electrode, and total soluble solids content measured by digital refractometer (Atago, Plainfield, NY).

Mineral Analysis of Leaf and Fruit Tissue

Leaves used for petiole sap extraction were dried at 60°C. A 1 to 2 g sample was then ashed at 500°C in a muffle furnace for 12 hours and nutrients were extracted using a double acid Mehlich III extractant. Tissues from both leaves and fruit were analyzed for K using an atomic absorption spectrophotometer at 769.9 nm wavelength.

Results and Discussion

The K content of leaf petiole sap ranged from 2,700 to 5,000 mg/kg, depending on stage of development (**Figure 1**). These levels were similar to those reported by Hochmuth et al. (1994) for watermelon. Leaf petiole sap K content was highest in leaves from high K application, and lowest in leaves from plots with no K applied. The K content of leaf tissue was similar to that of petiole sap (data not shown).

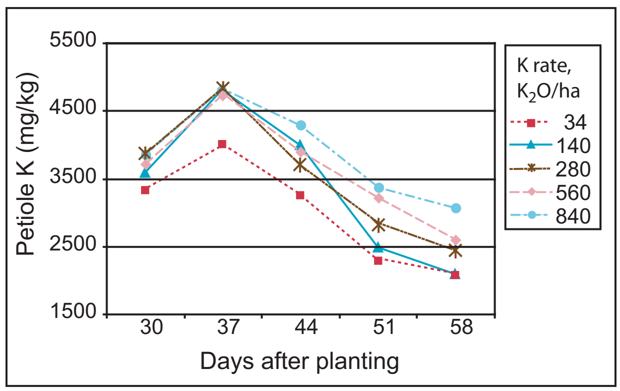

Figure 1. Petiole sap potassium content (mg/kg) of watermelon leaves harvested at intervals of growth.

The number of watermelons per plant decreased as K application increased over 280 kg K_2O/ha (**Figure 2A**). The length/diameter of watermelons increased in plots with more than 280 kg K_2O/ha (**Figure 2B**). This difference was due largely to the smaller diameter of the melons with increasing K rate (data not shown). At least 140 kg K_2O/ha was needed for full fruit set and growth of watermelons. Sundstrom and Carter (1982?) found reduced watermelon yield at K application above 139 kg K_2O/ha,

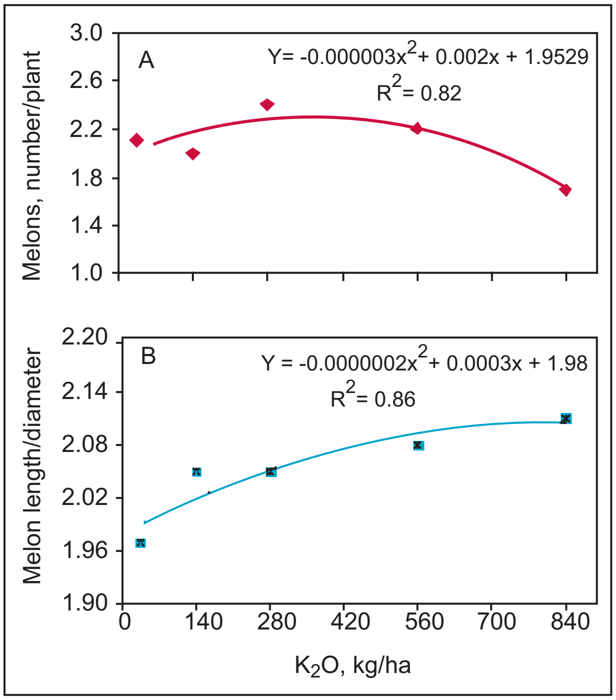

Figure 2. The relation of potassium application (kg/ha) to (A) yield (watermelons per plant), and (B) melon size, measured as the ratio of cm length to cm diameter.

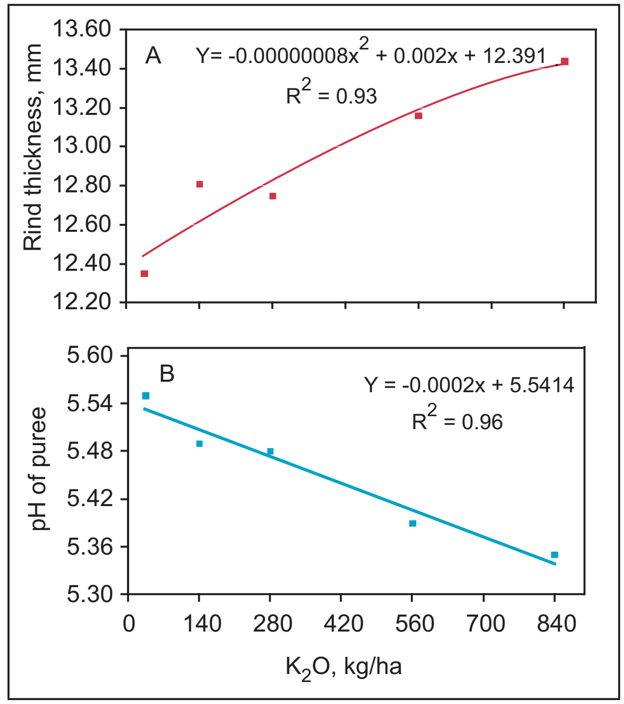

Figure 3. The relation of potassium application (kg/ha) to (A) transverse rind thickness (mm) of watermelons and (B) puree pH of watermelon placental tissue (heart and locular tissue).

and Zeng et al. (2001) found decreased pistachio nut yields when K application exceeded 220 kg K_2O/ha. Our results show that K rates above 280 kg K_2O/ha are detrimental to watermelon yield and size.

Rind thickness increased with K treatment (**Figure 3A**). The puree pH decreased as K treatment increased (**Figure 3B**). Normally, rind thickness and pH decrease with ripeness in watermelon. These results indicate that the watermelons from plots with 560 or 840 kg K_2O/ha K may have been less ripe than those from other plots. However, total soluble solids content, also a measure of ripeness, was similar among all treatments (about 11%). The K content of fruit flesh increased slightly (68 to 82 mg/100g) as K fertility increased from 31 to 280 kg K_2O/ha, but did not increase as fertility increased from 280 to 840 kg K_2O/ha (data not shown). It is possible that the chloride form of K used may have caused some toxicity to the watermelon plants.

Conclusions

Potassium contributes to the health of plants and humans. Use of K in hydroponic or soil applications increased the carotenoid and vitamin C content of tomatoes and grapefruit, and increased the K content of grapes and strawberries. The ability to use K as a health claim on fruits and vegetables offers new opportunities to explore environmental, genetic, and production manipulation for increased K content. Results from our study with watermelons indicate that application of K above recommended rates may effectively alter fruit characteristics and composition, but yields may be reduced.

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