Impact of Potassium Nutrition on Food Quality of Fruits and Vegetables: A Condensed and Concise Review of the Literature

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Among the many plant mineral nutrients, K stands out as a cation having the strongest influence on quality attributes that determine fruit marketability, consumer preference, and the concentration of critically important human health-associated phytonutrients. However, many plant, soil, and environmental factors often limit uptake of K from the soil in sufficient amounts to satisfy fruit K requirements during development to optimize the aforementioned quality attributes. This was demonstrated in a study reported in this publication in 2007 (Lester et al., 2007) where foliar K markedly improved several cantaloupe fruit quality parameters, despite sufficient soil test K levels. This article expands on the previously reported work from the Rio Grande Valley of Texas by providing a review of published study abstracts on the effects of soil and/or foliar K fertilization on several fruit and vegetable quality characteristics, including phytonutrient concentrations.

Potassium is an essential plant mineral element (nutrient) having a significant influence on many human-health related quality compounds in fruits and vegetables (Usherwood, 1985). Although K is not a constituent of any organic molecule or plant structure, it is involved in numerous biochemical and physiological processes vital to plant growth, yield, quality, and stress (Marschner, 1995; Cakmak, 2005). In addition to stomatal regulation of transpiration and photosynthesis, K is also involved in photophosphorylation, transportation of photoassimilates from source tissues via the phloem to sink tissues, enzyme activation, turgor maintenance, and stress tolerance (Usherwood, 1985; Doman and Geiger, 1979; Marschner, 1995; Pettigrew, 2008). Adequate K nutrition has also been associated with increased yields, fruit size, increased soluble solids and ascorbic acid concentrations, improved fruit color, increased shelf life, and shipping quality of many horticultural crops (Geraldson, 1985; Lester et al., 2005, 2006, 2007; Kanai et al., 2007).

Even though K is abundant in many soils, the bulk of soil K may be unavailable to plants, in part, because the pool of plant-available K is much smaller compared to the other forms of K. Potassium exists in several forms in the soil, including mineral K (90 to 98% of total), nonexchangable K, exchangeable K, and dissolved or solution K (K^+ ions), and plants can only directly take-up solution K (Tisdale et al., 1985). Uptake in turn depends on numerous plant and environmental factors (Tisdale et al., 1985; Marschner, 1995; Brady and Weil, 1999). For instance, adequate soil moisture supply is necessary to facilitate diffusion of K (which usually accounts for > 75% of K movement) to plant roots for uptake. Mass flow, which also accounts for some soil K transport, also requires sufficient water in the soil. Skogley and Haby (1981) found that increasing soil moisture from 10 to 28% more than doubled total soil K transport. Therefore, soil moisture deficits can limit soil K transport as well as uptake into the plant, thereby causing K deficiency.

Soil properties also have a strong influence on K availability. For instance, clay soils may have high K-fixing capacities and thus can show little response to soil-applied K fertilizers because much of the available K quickly binds to clays (Tisdale et al., 1985; Brady and Weil, 1999). Such K retention can help

Abbreviations and notes: K = potassium.

Dr. Lester checks on muskmelon plants in a glasshouse experiment. Fine-tuning plant nutrition practices is an important consideration for improving fruit quality (inset).

reduce leaching losses and be beneficial in the long-term as storage reservoirs of K for subsequent crops. Sandy soils, on the other hand usually have a low K-supplying power because of low cation exchange capacity.

Calcareous soils tend to have high concentrations of calcium ions (Ca^{2+}) that dominate clay surfaces and other exchange sites. Even though this can limit K sorption and increase solution K, high concentrations of cationic nutrients...particularly Ca^{2+} and magnesium (Mg^{2+})...tend to limit K uptake by competing for binding sites on root surfaces. Consequently, crops grown on highly calcareous soils can show K-deficiency symptoms even though the soil test may report sufficient K (Havlin et. al., 1999).

Potassium uptake also depends on plant factors, including genetics and developmental stage (vegetative versus reproductive stages; Rengel et al., 2008). In many fruiting species, uptake occurs mainly during vegetative stages, when ample carbohydrate supply is available for root growth and uptake processes. Competition for photoassimilates between developing fruits and vegetative organs during reproductive growth

Table 1. Review of published abstracts on the influence of K: effects by crop, K application, and K form on fruit attributes.

Crop	K application	K form[a]	Attributes (improved)[b]	Reference[c]
Apple *(Malus X domestica)*	Soil	KCl; K_2SO_4; K_2SO_4;	Color, firmness, sugar; Size, color, firmness, sugars; Wt. yield, firmness, sugars	Nava (2009); El-Gazzar (2000); Attala (1998)
Apple	Foliar	Unknown; KCl	Size, color, firmness, sugars; No change	Wojcik (2005); Hassanloui (2004)
Banana *(Musa sp.)*	Soil	Unknown; KCl	Quality; Size, sugars, acid	Naresh (1999); Suresh (2002)
Citrus *(Citrus sinensis)*	Foliar	KCl, KNO_3; Unknown; K_2SO_4	No change; Yield, quality; Quality	Haggag (1990); Dutta (2003); Shawky (2000)
Citrus *(Citrus reticulata)*	Soil	Unknown; Unknown	Yield, quality; Quality, shelf-life	Lin (2006); Srivastava (2001)
Citrus *(Citrus reticulata)*	Foliar	KCl >KNO_3	Peel thickness, quality	Gill (2005)
Cucumber *(Cucumis sativus)*	Soil	K_2SO_4 > KCl; KCl	Amino acids, quality; No change	Guo (2004); Umamaheswarappa (2004)
Cucumber	Foliar	KCl >KNO_3	"Quality", disease tolerance	Magen (2003)
Grapes *(Vitis vinifera)*	Soil	K_2SO_4	"Quality", sensory	Sipiora (2005)
Guava *(Psidium guajava)*	Soil	Unknown	Yield, weight, "quality"	Ke (1997)
Guava	Foliar	K_2SO_4 > KCl	Acidity, "quality"	Dutta (2004)
Kiwifruit *(Actinidia deliciosa)*	Soil	K_2SO_4 > KCl	Firmness, acid, grade	He (2002)
Litchi *(Litchi chinensis)*	Foliar	KNO_3	Weight., yield,	Ashok (2004)
Mango *(Mangifera indica)*	Soil	KNO_3	No change	Simoes (2001)
Mango	Foliar	KNO_3; Unknown	No effect; Texture, flavor, color shelf-life	Rebolledo-Martinez (2008); Shinde (2006)
Muskmelon *(Cucumis melo)*	Soil	Unknown	Yield	Demiral (2005)
Muskmelon	Foliar	Gly-amino-K; Gly-amino-K > KCl; Gly-amino-K = K_2SO_4 > KCl > KNO_3	Firmness, vitamins; Firmness, sugars, vitamins; Firmness, vit. sugars, yield, marketable fruit	Lester (2005); Lester (2006); Jifon (2009)
Nectarine *(Prunus persica)*	Soil	Unknown	Firmness, shelf-life, reduced cracking	Zhang (2008)
Okra *(Abelmoschus esculentus)*	Foliar	Naphthenate-K	Chlorophyll, protein, carotene	Jahan (1991)
Passionfruit *(Passiflora edulis)*	Hydroponic	K_2SO_4	Yield, seed number, "quality"	Costa-Araujo (2006)
Papaya *(Carica papaya)*	Soil	Unknown	Weight, sugars, "quality"	Ghosh (2007)
Pears *(Pyrus communis)*	Soil	K_2SO_4	No change	Johnson (1998)
Phalsa *(Grewia subinaequalis)*	Foliar	K_2SO_4	Size, weight, "quality"	Singh (1993)
Pepper *(Capsicum annuum)*	Soil	KCl; K_2SO_4; K_2SO_4 > KNO_3; K_2SO_4	Little change; Pungency, "quality"; Pungency, yield, weight; "Quality"	Hochmuth (1994): Ananthi (2004); Golcz (2004); El-Masry (2000)
Pepper	Hydroponics	KNO_3	No change	Flores (2004)
Pineapple *(Ananas comosus)*	Soil	KCl	Vit. C, and reduced internal browning	Herath (2000)
Pomegranate *(Punica granatum)*	Foliar	K_2SO_4 > KCl	Growth, yield, "quality"	Muthumanickam (1999)
Strawberry *(Fragaria X ananassa)*	Soil; Fertigation	KCl; KCl >KNO_3	No change; "Quality"	Albregts (1996); Ibrahim (2004)
Strawberry	Hydroponics	K_2SO_4	Yield, total quality	Khayyat (2007)
Tomato *(Lycopersicon esculentum)*	Soil	KCl; K_2SO_4; K_2SO_4;	Lycopene; "Quality"; Yield, earliness, quality	Taber (2008); Si (2007); Hewedy (2000)
Tomato	Fertigation/soilless	KCl >KNO_3; KCl >KNO_3; K_2SO_4; Unknown; Unknown	Appearance, quality; Yield, "quality"; Carotenoids, vit.E, Antioxidants; Lycopene; "quality"	Chapagain (2003); Chapagain (2004); Fanasca (2006); Li (2006); Yang (2005)
Tomato	Foliar	Unknown	Growth, protein, vit. C, sugar, acid	Li (2008)
Vegetables	Soil	K_2SO_4 > KCl	Dry weight., vitamin C	Ni (2001)
Watermelon *(Citrullus lanatus)*	Soil	KCl; KCl	No change; No change	Locascio (2002); Perkins-Veazie (2003)

[a]Sources from different studies are separated by a semi-colon; K form attributing to improved quality greater than another K form is indicated by the > symbol.
[b]Attributes from different studies are separated by a semicolon. The word "quality" indicates the authors listed no specific attributes, or the attributes were too numerous to list.
[c]References from different studies are separated by a semi-colon, and only first author names are listed for brevity.

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stages can limit root growth/activity and K uptake. Under such conditions, increasing soil K fertilization may not be enough to alleviate this developmentally-induced deficiency partly because of reduced root growth/activity during reproductive development and also because of competition from other cations for binding sites on roots (Marschner, 1995).

A study reported in this magazine and elsewhere (Lester et al., 2005, 2006, 2007) showed that foliar K improved cantaloupe fruit marketable quality by increasing firmness and sugar content, and fruit human health quality by increasing ascorbic acid, beta-carotene, and K levels in a soil that tested high in K. Nevertheless, there remains confusion in the literature regarding the benefit of K fertilization due to different K sources, soil vs. foliar applications, the environment (season), and timing and frequency of application. This review summarizes some of the published abstracts on K fertilization of several fruit crops, with special attention given to the effectiveness of various K fertilizer sources, and soil vs. foliar application on fruit quality.

Fruit Studies Comparing K Sources

Although many examples have been reported on the positive effects of K fertilization improving fruit disease control, yield, weight, firmness, sugars, sensory attributes, shelf-life, and human bioactive compound concentrations, the scientific literature also contains examples of studies with conflicting results of the beneficial effects of K fertilization on fruit quality **(Table 1)**. These conflicting results cannot be resolved, but they can be explained by differences in modes of fertilization (e.g., soil vs. foliar, fertigation or hydroponic applied), and differences in sources of K fertilizer (e.g. KCl, K_2SO_4, KNO_3, Glycine-complexed K).

A review of published abstracts spanning the last 20 years is shown in **Table 1**. The vast majority of the papers reviewed showed that K fertilization had an effect on some crop quality attribute. However, eight particular studies [apple, (Hassanloui, et al., 2004); cucumber, (Umamaheswarappa and Krishnappa, 2004); mango, (Rebolledo-Martinez et al., 2008); pear, (Johnson et al., 1998); bell pepper, (Hochmuth et al., 1994); strawberry, (Albregts et al., 1996); and watermelon, (Locascio and Hochmuth, 2002; Perkins-Veazie et al., 2003)] stand out because of their conclusions: there is 'little or no change' (i.e. improvement) in fruit quality due to K fertilization. Interestingly, except for the apple study, these studies have a common denominator in that K was applied directly to the soil and in many cases little information was given regarding timing of application or soil chemical and physical properties. These factors can influence soil nutrient availability and plant uptake, and soil fertilizer K additions under some conditions may have little or no effect on uptake, yield, and fruit quality (Tisdale et al., 1985; Brady and Weil, 1999).

In a number of studies involving several fruiting crops (e.g. cucumber, mango, and muskmelon) where soil-applied fertilizer K was compared to foliar K applications, the latter approach consistently resulted in improved fruit quality attributes. On the other hand, soil applications generally had little or no effects (Demiral and Koseoglu, 2005; Lester et al., 2005, 2006; Jifon and Lester, 2009; **Table 1**).

Furthermore, in studies where several fertilizer K salts were evaluated, fruit quality improvements appeared to depend on K source. For instance, Jifon and Lester (2009) showed that when mid-to-late season soil or foliar K applications were made using KNO_3 there were little or no improvements in fruit marketable or human-nutritional quality attributes and in some instances, these attributes were actually inferior compared to fruit from control plots.

This article demonstrates that when making K fertilization decisions, the practitioner should be aware that soil test data alone might not be sufficient to make the best decisions. Soil test information is certainly important and useful in decision-making, but accounting for other factors such as timing, crop demand dynamics, and source are all important as well. High soil K level alone does not always guarantee there will be no response to K fertilizer. Moreover, where there is a high demand for K during fruit development foliar K can improve several fruit quality attributes. BC

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