Effects of Foliar Potassium Fertilization on Fruit Growth Rate, Potassium Accumulation, Yield, and Quality of 'Kousui' Japanese Pear

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Additional index words. *Pyrus pyrifola*, sugar, organic acid, amino acid

Summary. A field experiment was conducted over three growing seasons (2012–14) to study the effect of the foliar application of different potassium (K) fertilizers [potassium phosphate monobasic (KH_2PO_4), potassium nitrate (KNO_3), and humic acid potassium (HAK)] on the fruit growth rate, yield, and quality of 'Kousui' japanese pear (*Pyrus pyrifola*) trees. Except the first year of study, foliar application of K fertilizers generally led to an increase in the concentration of fruit total soluble sugar, titratable acidity (TA) and sweetness, along with an elevated K accumulation in leaf and fruit at maturity. In 2013 and 2014, compared with the control, KNO_3 treatment led to an average 16% higher yield, and HAK led to an average 15% higher soluble solid content (SSC). Furthermore, HAK resulted in 26% higher yield in 2014. KNO_3 treatment showed 19% higher leaf K concentration, 38% leaf K accumulation, and 43% fruit K accumulation in maturity than the control in 2014. Different effects were found on the concentration of specific types of sugar and organic acid, of which fructose and malate were consistently increased by the K application. With regard to the amino acids, KNO_3 and HAK treatments led to a significant increase in the concentration of aspartic acid, which was 12% and 22% higher than the control, respectively. In conclusion, foliar application of KNO_3 is an efficient way to increase 'Kousui' japanese pear fruit yield, whereas spraying HAK is an effective way to improve the fruit quality.

Japanese pear is one of the leading cultivated fruit trees in temperate regions. After apple (*Malus ×domestica*) and citrus (*Citrus* sp.), it is the third largest fruit species in China, both in planting areas and fruit yield. As the top producing country, China grows more than 60% of the world pear (*Pyrus* sp.) production (Boyer et al., 1943; Wu et al., 2013). K is highly mobile in plants and constitutes up to 10% of plant dry weight (Adams and Shin, 2014; Shin, 2014; Walker et al., 1996). Regarding the total amount of mineral nutrients required by plants, potassium is required in the largest amount after nitrogen (N) (Zörb et al., 2014); moreover, it is the largest nutrient required by the fruit (Lester et al., 2006; Mpelasoka et al., 2003). K activates numerous enzymes, which are critical for various metabolic processes, such as biosynthesis, transport, and transformation of sugar and starch (Baraldi et al., 1991; Karley and White, 2009; Lester et al., 2010a; Niu et al., 2013; Römheld and Kirkby, 2010). Furthermore, K is an essential nutrient involved in the phloem translocation of assimilates, including sucrose movement from shoot to root and to sink tissues such as fruit (Lebaudy et al., 2007). It is generally considered as a quality element, which could increase fruit development with higher quality and longer shelf life by enhancing synthesis and translocation of carbohydrates in plants (Niu et al., 2008). For example, the fruit of 'Kinnow' mandarin (*Citrus deliciosa* × *Citrus nobilis*) became larger and harder with increasing K supply. In contrast, the number of fruit cells, fruit size, and the SSC were significantly reduced by K deficiency (Ashraf et al., 2010).

In our previous research, we found that fruit K concentration decreased sharply with the increase of fruit size during expansion stage to maturation, which suggested that strong K supply was demanded by fruit. Balanced fertilization is an efficient measure to increase the yield and quality of 'Kousui' japanese pear. However, compared with the amount of N and phosphorus (P) input to the 'Kousui' japanese pear orchard, the supply of K was found to be seriously insufficient. Foliar fertilization was proved to be an efficient way to supplement the nutrients that the plant needed. It is a well-established measure for timely supplement of K to increase yields, fruit size, fruit volume, SSC, and sugar/acid ratio of 'Gala' apple (Reuveni et al., 1998a), 'Valencia' sweet orange [*Citrus sinensis* (Calvert and Smith, 1972)], and 'Williams' european pear [*Pyrus communis* (Hudina and Stampar, 2002)]. KH_2PO_4 (Reuveni et al., 1998b), potassium sulphate

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29,574	fl oz	μL	3.3814×10^{-5}
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	$inch^2$	cm^2	0.1550
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1	micron(s)	μm	1
28.3495	oz	g	0.0353
0.1	ppm	mg/100 g	10
0.001	ppm	$mg \cdot g^{-1}$	1000
1	ppm	$mg \cdot kg^{-1}$	1
1	ppm	$mg \cdot L^{-1}$	1
6.8948	psi	kPa	0.1450
2.2417	ton(s)/acre	$t \cdot ha^{-1}$	0.4461
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

[K_2SO_4 (Sing and McNeil, 1992)], KNO_3 (Mukadam and Haldankar, 2012), potassium chloride [KCl (Gill et al., 2005)], and potassium-complex humic acid (Shahryari et al., 2009) have been commercially used in various crops, of which KH_2PO_4 is routinely used as a foliar fertilizer since it contains both P and K. KCl is the major source of K and usually cheaper than other K sources. However, since it involves chloride ion (Cl^-), it is generally not recommended on fruit trees and Cl^--sensitive crop. KNO_3 is full of ambiguity that, on one hand, it could supply K and nitrate (NO_3^-) simultaneously to plants which benefits the fruit development, and avoid NO_3^- leaching from soil compared with soil application of N (Dong et al., 2005); on the other hand, the foliar application of NO_3^- easily led to negative effects on fruit quality and even postharvest problems for some fruit, such as muskmelon (*Cucumis melo*), whose SSC and firmness were decreased by foliar application of KNO_3 (Jifon and Lester, 2009). However, when applied to mango (*Mangifera indica*) trees, higher SSC, less TA, and less firmness was found (Rebolledo–Martínez et al., 2008). These inconsistent results might be related to the spraying time, application rate, and fruit species. Fructose, glucose, sorbitol, and sucrose are the main sugar types, and malate was the main organic acid produced in 'Huanguan' chinese white pear fruit [*Pyrus bretschneideri* (Song et al., 2012)]. Less attention was paid to the effects of K concentration and accumulation in 'Kousui' japanese pear leaf and fruit by the foliar application of different K sources, as well as the quality characteristics of 'Kousui' japanese pear fruit, such as various sugars, organic acids, and amino acids. The aim of this study was to evaluate the effect of different foliar application strategies of K fertilizers so as to provide a recommendation to growers on how to efficiently increase yield and improve fruit quality.

Materials and methods

Plant material and treatment. The trials were conducted over three successive growing seasons on 10-year-old scaffolding 'Kousui' japanese pear trees in an orchard from 2012 to 2014. The orchard was located in the town of Ersheng in the city of Jurong city, Jiangsu Province, China. Trees were on callery pear (*Pyrus calleryana*) seedling rootstock planted at 4 × 4 m. Soil samples were taken from the soil surface 0–30 cm in Fall 2011 and were determined with the following chemical characteristics (Wells, 2009): pH 5.76, 1.16% organic matter, 69.37 $mg \cdot kg^{-1}$ available N, 11.16 $mg \cdot kg^{-1}$ available P, and 151.93 $mg \cdot kg^{-1}$ available K. The soil fertility was comparatively low. Each tree around the drip line in the orchard was supplied by 40 kg commercial organic fertilizer (45% organic matter and 2N–0.4P–1.7K), 2 kg cooked soybean (*Glycine max*), 2 kg calcium magnesium phosphate, and 0.75 kg K_2SO_4 in the base fertilization, 0.25 kg K_2SO_4 after anthesis, and 0.25 kg urea after fruit harvest.

Four treatments were applied to the same set of trees for 3 years. Three uniform trees were selected as a replicate, for a total of three replicates per treatment. Three foliar K sources [KH_2PO_4, KNO_3, and HAK (Foliwell®K; Omex, London, UK)], which contained 0.08% K were administered as follows: 0.3% KH_2PO_4, 0.22% KNO_3, 0.27% HAK, and water as control. HAK was a new-style liquid K fertilizer made by special organic compounds chelating K and no hormone was included. The foliar fertilizers were applied three times (27 Apr., 19 June, and 11 July) on a sunny day between 1500 and 1700 HR. Each tree was sprayed 2 L liquid fertilizer with 0.1% surfactant with Tween® 20 (Sigma-Aldrich, St. Louis, MO). The phenology of 'Kousui' japanese pear in 2013 and 2014 were both as follows: full of blossom (3 Apr.), young fruit stage (27 Apr.), expansion phase I (3 June), expansion phase II (2 July), maturity (6 Aug.), 1 month after harvest (8 Sept.), 2 months after harvest (10 Oct.), and leaf abscission (4 Nov.). The phenology of 'Kousui' japanese pear in 2012 was 1 week later than that in 2013 and 2014.

Soil chemical parameters. The pH was determined using 1:2.5 (w/v) soil:water extracts. Alkali-hydrolysable N was determined by the method used by Lu (1999). Available phosphorus was measured using extracts of hydrochloric acid–ammonium fluoride [$HCl–NH_4F$ (Horta and Torrent, 2007)]. Available potassium was determined by extracting the soil with 1 $mol \cdot L^{-1}$ ammonium acetate (CH_3COONH_4), and then measured by flame photometry (Allen et al., 1974). All extractions were performed in triplicate. The analysis values from the triplicate extractions were averaged before statistical analysis was performed.

Fruit sample. In 2012–14, 30 'Kousui' japanese pear fruit were collected per tree at maturity stage and weighed. Fruit firmness was assessed with a penetrometer (FT327; Effegi, Alfonsine, Italy) with an 11.3-mm probe. SSC was determined using a refractometer (PAL-1; Atago, Tokyo, Japan). Total soluble sugar was measured using the anthrone–sulphuric acid colorimetric method (Alexander and Edwards, 2003). TA was determined using standard acid–base titration (Sánchez, 2015).

In 2013 growing season, to evaluate the foliar K fertilizers on fruit growth rate and K concentration in fruit and leaves during the fruit development, eight fruits were randomly picked from four orientations on 27 Apr., 3 June, 2 July, and 6 Aug. At the same time, eight mature leaves from the midportion of the bearing branch of every tree were collected. In addition, leaves were also collected on 6 Sept., 6 Oct., and 4 Nov., respectively. After weighing the fruit, one quarter of these fruit were randomly selected, homogenized, and thoroughly dried. Leaves were rinsed twice with tap water and twice with deionized water, wiped with a paper towel, and thoroughly dried. Fruit and leaf samples were digested with a sulfuric acid–hydrogen peroxide ($H_2SO_4–H_2O_2$) assimilating method in a digestion furnace (280 °C, 2 kW, 1 h), and K concentration was determined by a flame photometer (AP1200; Aopu Analytical Instruments, Shanghai, China).

The determination of individual sugars and organic acids. In 2013 growing season, a 2-g portion of the frozen fruit sample was ground with 20 mL of ultrapure water and then centrifuged at 20,000 g_n for 15 min at 4 °C. The supernatant was recovered and immediately filtered through a 0.45-mm filter (SepPak; Waters, Milford, MA) to eliminate large particles. The extraction was stored at –80 °C in a sealed tube for the high-performance liquid chromatography (1200; Agilent, Santa Clara, CA) determination of individual sugar and organic acid concentration. Sweetness value = fructose × 1.75 + glucose × 0.70 + sorbitol × 0.40 + sucrose × 1.00 (Song et al., 2012).

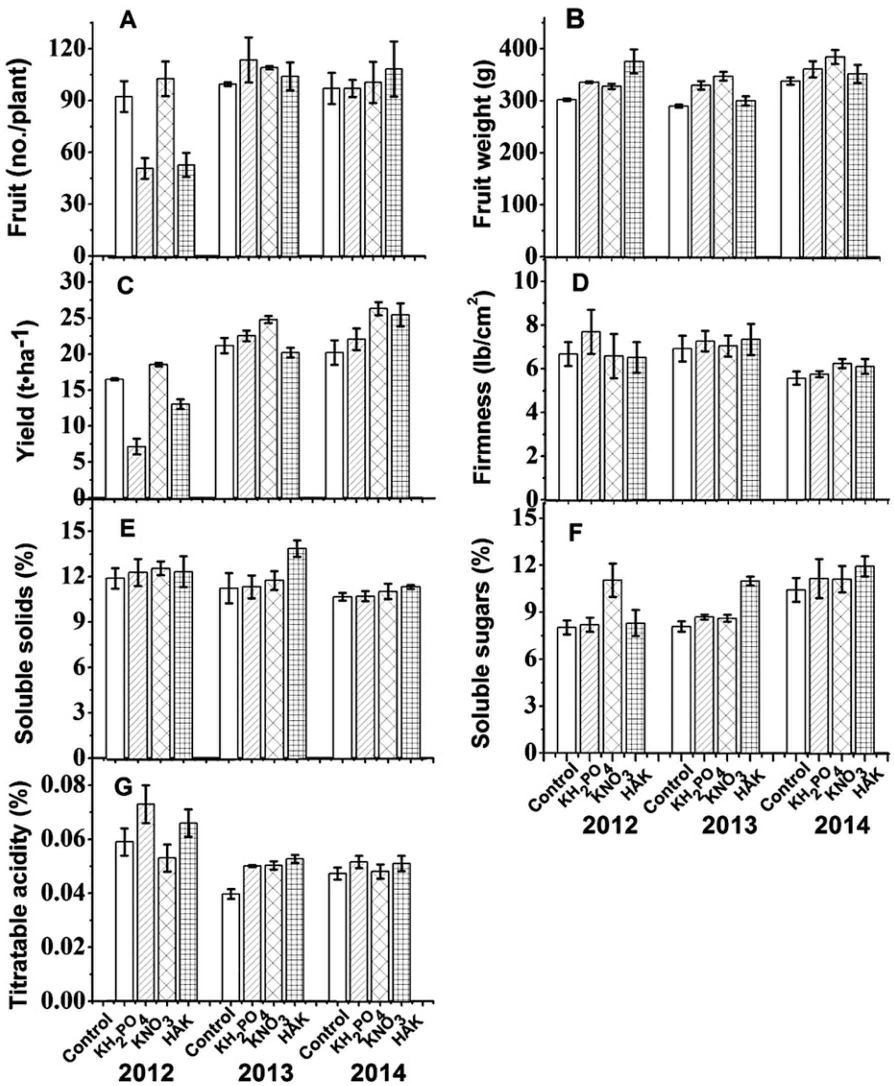

Fig. 1. Effect of different foliar potassium (K) fertilizers on yield and quality: (A) fruit number, (B) fruit weight, (C) yield, (D) firmness, (E) soluble solids, (F) soluble sugars, and (G) titratable acidity of 'Kousui' japanese pear in 2012–14 (KH_2PO_4 = potassium phosphate monobasic, KNO_3 = potassium nitrate, HAK = humic acid potassium). Vertical bars indicate SE; 1 g = 0.0353 oz, 1 $t{\cdot}ha^{-1}$ = 0.4461 ton/acre, 1 lb/cm^2 = 6.4516 psi = 44.4822 kPa.

The individual sugar concentration was determined using the following specific conditions as described by Colaric et al. (2007) with some modifications: 4.6 × 250–mm, 5-µm column (CapCell Pak NH2; Shiseido, Tokyo, Japan), constant temperature of 50 °C, and mobile phase of acetonitrile-water (80/20; v/v). An evaporative light scattering detector (Alltech 3300 ELSD; Grace, Deerfield, IL) was used with a flow rate of 1.0 $mL{\cdot}min^{-1}$, drift tube temperature of 80 °C, and nitrogen flow rate of 2.0 $mL{\cdot}min^{-1}$. The individual organic acid concentration was determined using the following specific conditions as described by Xu et al. (2012) with slight revisions as follows: 4.6 × 250-mm, 5-µm column (C18, Waters) with 1 $mL{\cdot}L^{-1}$ phosphoric acid aqueous solution, flow rate of 0.8 $mL{\cdot}min^{-1}$, column temperature of 45 °C, injection volume of 20 µL, and detection at 210 nm using an ultraviolet spectrophotometer.

THE DETERMINATION OF AMINO ACIDS. According to Coimbra et al. (2011), each fresh fruit sample (2.5 g) was placed in a coated polytetrafluoroethylene test tube with a screw cap. To each sample, 10 mL of 6 M HCl was added. The tube was filled with nitrogen over a 15-min period and sealed. The hydrolysis reaction was performed for 24 h at 110 °C using a heating block. The tube was allowed to cool to room temperature, and the solution was filtered through wet filter paper and collected in a 50-mL volumetric flask. The residue was mixed with 20 mL of citrate buffer (pH 2.2) and the amino acid profile was determined using an automatic amino acid analyzer (Biochrom 30; Biochrom, Cambridge, UK). The 18 L-amino acid standards [i.e., glycine (Gly), alanine (Ala), serine (Ser), proline (Pro), valine (Val), threonine (Thr), cysteine (Cys), leucine (Leu), isoleucine (Ile), aspartic acid (Asp), glutamic acid (Glu), methionine (Met), histidine (His), lysine (Lys), phenylalanine (Phe), arginine (Arg), tyrosine (Tyr), and tryptophan (Trp)] were purchased from Sigma-Aldrich.

OTHER CALCULATIONS. The fruit number per tree was counted during the fruit expansion stage. The biomass of the fruit was calculated by single fruit weight and fruit number. According to the method of leaf-to-fruit ratio (LFR) reported in apple trees by Sabbatini and Flore (2006), we corrected the LFR as 37:1, by which we can calculate the fruit biomass at the base of leaf biomass. The total K accumulation in leaves and fruit were calculated according to the following equations:

$$\text{Leaf K accumulation}\left(\text{kg}\cdot\text{ha}^{-1}\right) = \text{leaf biomass}\left(\text{kg}\cdot\text{ha}^{-1}\right) \times \text{leaf K concentration}(\%) \times 10^{-2}$$

$$\text{Fruit K accumulation}\left(\text{kg}\cdot\text{ha}^{-1}\right) = \text{fruit biomass}\left(\text{kg}\cdot\text{ha}^{-1}\right) \times \text{fruit K concentration}(\%) \times 10^{-2}$$

DATA ANALYSIS. Data were analyzed by analysis of variance using SAS (version 9.3; SAS Institute, Cary, NC). Means were compared for treatment effects using a Fisher's protected least significant difference at $P < 0.05$.

Results

EFFECTS ON FRUIT YIELD AND QUALITY PARAMETERS IN 2012–14. On the whole, in the three growing seasons, foliar K fertilization resulted in an increasing trend in fruit weight (Fig. 1B). In the first growing season (2012), there were large differences in the number of fruit that the trees bore. The number of fruit in the KH_2PO_4 and HAK treatments was almost half of that in the KNO_3 treatment (Fig. 1A), which led to

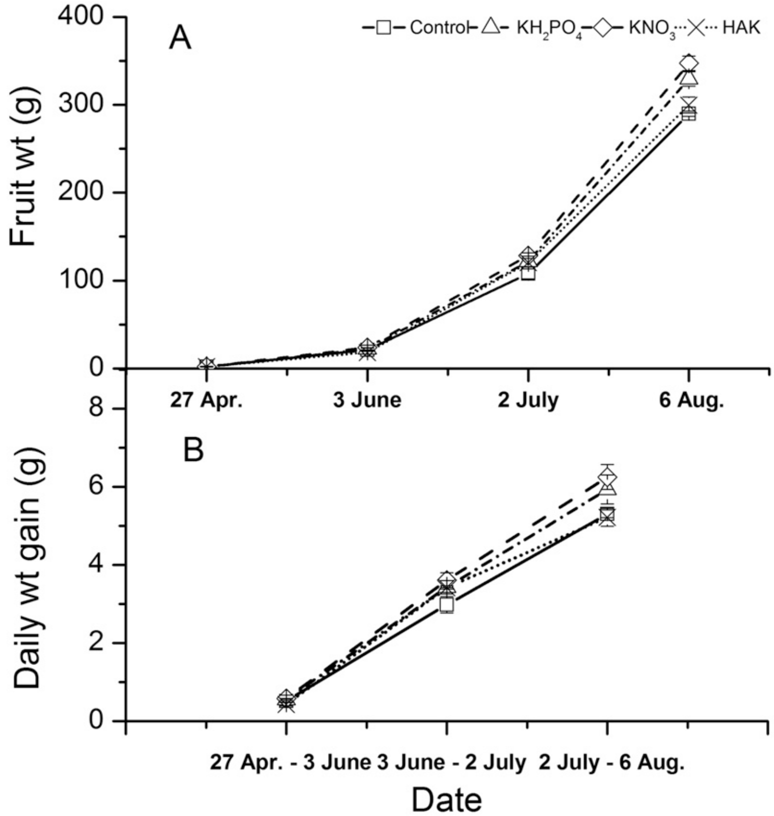

Fig. 2. Effect of different foliar potassium (K) fertilizers on 'Kousui' japanese pear (A) fruit weight and (B) daily weight gain in 2013 (KH_2PO_4 = potassium phosphate monobasic, KNO_3 = potassium nitrate, HAK = humic acid potassium). Daily weight gain was calculated as the difference of weight between the two sampling dates divided by the days. Vertical bars indicate SE; 1 g = 0.0353 oz.

great difference in yield (Fig. 1C). It was suggested that the fruit number was very essential and during the subsequent two seasons, the fruit number was hand controlled around 100. In 2013 and 2014, three foliar K sources led to an increasing trend in fruit yield, firmness (Fig. 1D), SSC (Fig. 1F), and TA (Fig. 1G). The application of KNO_3 in these two seasons led to an average 16% higher yield than the control. The yield of HAK treatment was significantly lower than that of the KNO_3 treatment in 2013, whereas HAK resulted in 26% higher yield than the control in 2014. No significant differences were found in the yield of KH_2PO_4 treatment either in 2013 or 2014. From 2013 to 2014, comparing with the control, SSC (Fig. 1E), total soluble sugar, and TA were increased by an average of 15%, 25%, and 21%, respectively, in HAK treatment.

Fruit weight and daily weight gain. As shown in Fig. 2A and 2B, the single fruit weight and daily weight gains of fruit in the control gradually increased with fruit growth. In maturity, the fruit weight of KNO_3 treatment was significantly higher than that of the control and HAK. The daily weight gain from the expansion phase II to maturity (i.e., 2 July to 6 Aug.) was on average 10 times higher than that from the young fruit stage to the expansion phase I (i.e., 27 Apr. to 3 June), and was on average 0.7 times higher than that from expansion phase I to expansion phase II (3 June to 2 July). Upon foliar application of KH_2PO_4 and KNO_3, the single fruit weights were 16% and 17% higher than the control at the expansion phase II (2 July) and maturity (6 Aug.), respectively. During expansion phase II (2 July) and maturity (6 Aug.), daily weight gains were 21% and 18% higher in plants treated with KNO_3 than in the control.

Dynamic changes in K concentration and accumulation in leaves and fruit. The leaf K concentration in the control plants was among the lowest during all developmental stages (Fig. 3A). From young fruit to maturity, K concentration was significantly increased by foliar KNO_3 and HAK. From fruit harvest to leaf fall, leaf K concentration and accumulation was increased first and then decreased (Fig. 3A and 3C). During fruit development, the fruit K concentration decreased from 2.5% to 0.15%. There was no significant difference in the accumulation of K in leaves between plants treated with KNO_3 and HAK at maturity (i.e., 6 Aug.; Fig. 3C). Furthermore, K accumulation was 38% and 14% higher in the leaves of samples sprayed with HAK (KNO_3) and KH_2PO_4 than in those of the control, respectively (Fig. 3C). However, there was no significant difference between the fruit K accumulation in KNO_3 and KH_2PO_4 (Fig. 3D), which was an average of 22% and 43% higher than that in HAK and the control, respectively. From expansion stage II to maturity, K accumulation in leaves and fruit accounted for 61% and 91% of the total K accumulation. Therefore, it could be concluded that expansion stage II is the critical stage of 'Kousui' japanese pear tree for K demand.

Fruit individual sugar concentration and sweetness. Foliar application of K fertilizers resulted in a significant increase in the concentration of fructose, which was on average 22% higher than in the control (Fig. 4A). The sorbitol concentration of the KH_2PO_4 and HAK treatment groups were an average of 35% higher than in the control (Fig. 4B). The glucose concentration in the fruit of KH_2PO_4 treatment was the highest of all, followed by that of the KNO_3 treatment (Fig. 4C). HAK and KNO_3 treatment resulted in a significant increase in sucrose concentration compared with the control and KH_2PO_4 treatment (Fig. 4D). Total sugar and sweetness of fruit of each treatment were consistent with the fructose concentration, which were both 28% higher than the control (Fig. 4E and 4F).

Fruit individual organic acid concentration. Total acid concentration in fruit was significantly increased by the foliar application of K fertilizers (Fig. 5G). KH_2PO_4 treatment led to a 105%, 61%, 112%, and 59% increase in malate, succinic acid, shikimic acid, and citric acid, respectively (Fig. 5A–C and 5F). However, the concentration of malate and shikimic acid in HAK treatment was 43% and 142% higher than that of the

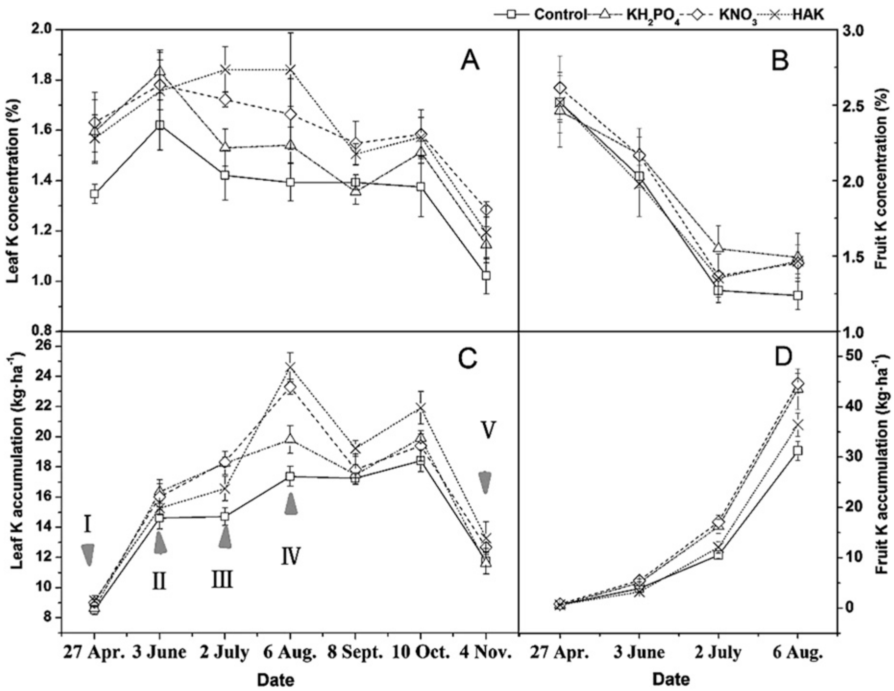

Fig. 3. Effect of different foliar potassium (K) fertilizers on (A) leaf K concentration and (C) leaf K accumulation, and (B) fruit K concentration and (D) leaf K accumulation of 'Kousui' japanese pear in 2013. In Fig. 3C, shaded arrows indicate sampling time, I–III: Spraying time; IV: Fruit harvest; V: Leaf abscission (KH_2PO_4 = potassium phosphate monobasic, KNO_3 = potassium nitrate, HAK = humic acid potassium). Vertical bars indicate SE; 1 kg·ha^{-1} = 0.8922 lb/acre.

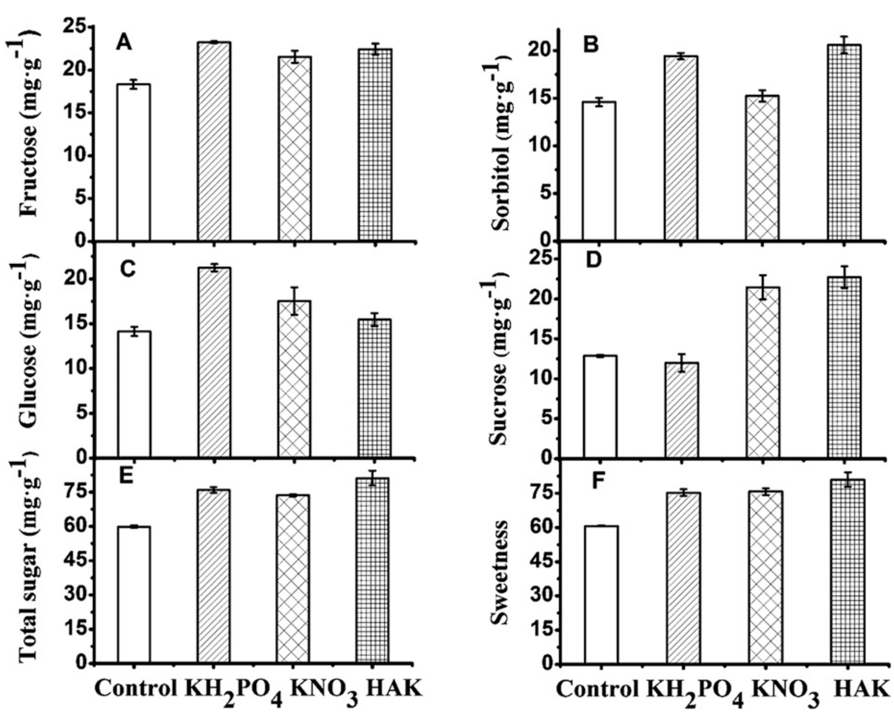

Fig. 4. Effect of different foliar potassium (K) fertilizers on fruit sugar concentration: (A) fructose, (B) sorbitol, (C) glucose, (D) sucrose, (E) total sugar, and (F) sweetness of 'Kousui' japanese pear in 2013 (KH_2PO_4= potassium phosphate monobasic, KNO_3 = potassium nitrate, HAK = humic acid potassium). Total sugar = fructose + sorbitol + glucose + sucrose; sweetness value = fructose × 1.75 + glucose × 0.70 + sorbitol × 0.40 + sucrose × 1.00. Vertical bars indicate SE; 1 mg·g^{-1} = 1000 ppm.

control. Compared with the control, KNO_3 treatment had no significant difference of acid concentration except for malate. Concerning oxaloacetic acid and tartaric acid of the fruit (Fig. 5D and 5E), it was observed that there were no significant differences with different treatments.

FRUIT INDIVIDUAL AMINO ACID CONCENTRATION. Except for the essential amino acid Trp, the concentration of the 17 amino acids was examined in the 'Kousui' japanese pear fruit (Table 1). A significant increase was found in the concentration of some nonessential amino acids, such as Asp, Ser, Glu, and Gly. Asp is in the highest level in nonessential amino acid group, accounting for 67% to 72% of the total nonessential amino acids, and 49% to 55% of total amino acids. Foliar application of KNO_3 and HAK treatments led to 12% and 22% higher Asp, respectively, than in the control, whereas KNO_3 treatment resulted in 25%, 49%, and 23% higher Ser, Glu, and Gly than in the control and in the KH_2PO_4 treatment. However, of all the seven essential amino acids presented in 'Kousui' japanese pear fruit, Val and Thr were the most abundant amino acids, representing 22% and 20% of the total essential amino acid concentration, respectively. Hardly any effect was observed on the essential amino acid concentration by the foliar application of the three K fertilizers, except for the concentration of Thr in HAK treatment, which was 13% higher than that in the control. With regard to the total amino acid concentration, foliar application of KNO_3 and HAK led to 17% and 15% higher amounts than the control, respectively.

Discussion

EFFECTS ON FRUIT GROWTH RATE, YIELD, AND K ACCUMULATION. In the present study, two successive growing seasons (2013 and 2014) of foliar application of KNO_3 fertilizer led to a significant increase in fruit weight and daily fruit weight gain, whereas spraying with KH_2PO_4 had no significant effect. Spraying with KNO_3 was previously reported to increase fruit size in 'Patharnakh' japanese pear (Gill et al., 2012), and the increase was greatest at a dose of 1.5% KNO_3. A study of plum trees [*Prunus salicina* (Southwick et al., 1996)] revealed that there was a correlation among the dry weight, size of fruit,

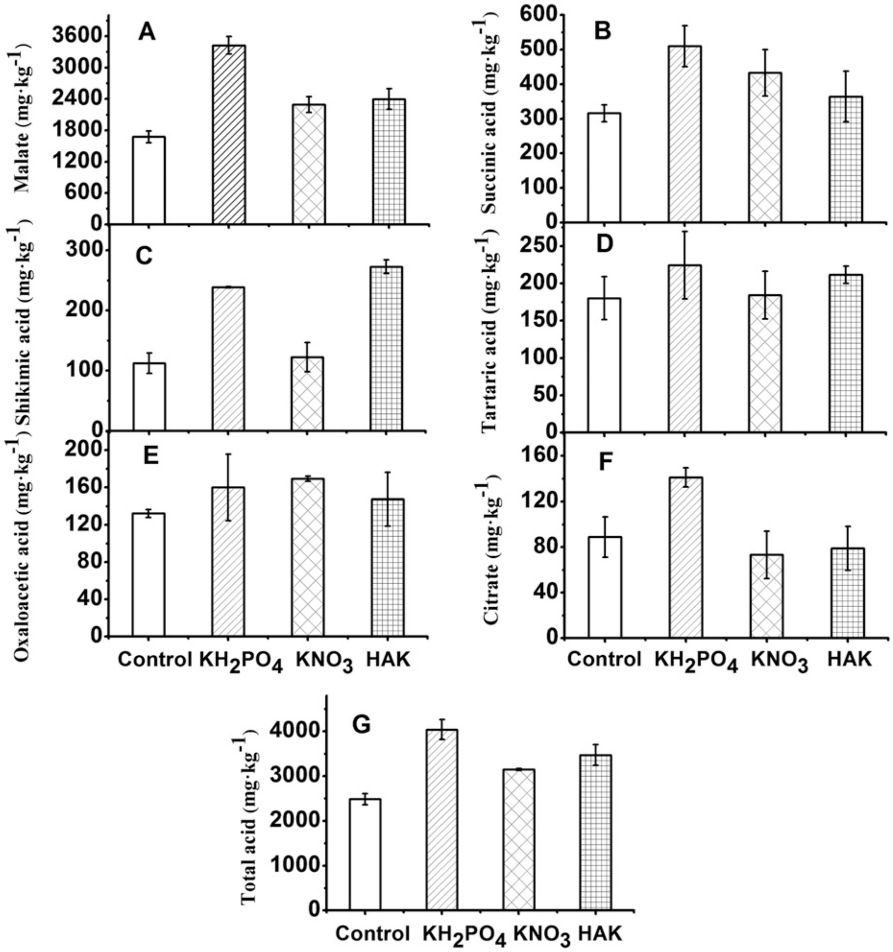

Fig. 5. Effect of different foliar potassium (K) fertilizers on fruit acid concentration: (A) malate, (B) succinic acid, (C) shikimic acid, (D) tartaric acid, (E) oxaloacetic acid, (F) citric acid, and (G) total acid of 'Kousui' japanese pear in 2013 (KH_2PO_4 = potassium phosphate monobasic, KNO_3 = potassium nitrate, HAK = humic acid potassium). Total acid = malate + succinic acid + shikimic acid + tartaric acid + oxaloacetic acid + citric acid. Vertical bars indicate SE; 1 mg·kg^{-1} = 1 ppm.

and the K concentration of leaves, showing that a moderate fruit size required a higher K concentration in the leaves. This was consistent with our results of KNO_3 treatment, which could efficiently increase K levels both in the leaves and the fruit (Fig. 3). From the expansion phase I to leaf abscission (i.e., 3 June to 4 Nov.), the K concentration of leaves significantly decreased in the control, but this reduction could be alleviated by foliar application of K fertilizers. Sufficient K level in the leaves during the expansion phase is critical for fruit development, since a large amount of photosynthetic production is required for fruit enlargement. It has been shown that leaf K concentration had a nutrient backflowing process after fruit harvest, which might be related to the nutrient reflux of K (Fig. 3A). Compared with the control, the foliar application of K fertilizers significantly increased K backflow efficiency in leaves. Proe et al. (2000) found that increasing the nutrient supply increased the amount of K remobilized from 49% to 57% of initial concentration in scots pine. This might reflect the contrasting physiological roles of N and K and the greater proportion of K available for remobilization. In the study, the leaf K concentration in the control was 22% lower than those treated with KNO_3 at the expansion phase I, which was suggested that there might be some risks of K insufficiency if no additional K fertilizer was supplied at the start of expansion phase I.

Effect on fruit sugar and organic acid concentration. K has been widely known as a "quality element" in fruit production, which can significantly improve fruit quality (Zörb et al., 2014). Sugar and acids concentration are regarded as two of the most important parameters of fruit quality. It was shown that in 'Kousui' japanese pear fruit, fructose and malate were dominant in the soluble sugars and organic acids, respectively (Figs. 4 and 5), consistent with the report by Chen et al. (2007) in the fruit of 'Niitaka' japanese pear. In the present study, fructose concentration was found to account for 28% to 31% of the total sugars (Fig. 4A and 4E), and malate 67% to 85% of the total organic acids concentration (Fig. 5A and 5G). It was found that foliar spraying with K fertilizers could increase fruit firmness and total soluble sugar, in agreement with a previous study (Lester et al., 2010b). HAK treatment strongly increased fruit firmness, SSC, and total soluble sugar in 2013 and 2014 (Fig. 1), which was suggested as an efficient measurement to improve fruit quality. The application of K fertilizers all increased the total concentration of organic acids (Fig. 5G), which agreed with Mukadam and Haldankar (2012) in karonda (*Carissa carandas*). It was clearly shown that different accompanied ions might result in a specific difference in the metabolism of various kinds of sugars and organic acids in the fruit (Figs. 4 and 5).

Effects on fruit amino acid concentration. In the present study, foliar application of K fertilizers had no effect on the total concentration of fruit essential amino acids. However, the concentration of Asp, Ser, and Glu, which belong to the nonessential amino acids, increased to various degrees (Table 1). Asp had an important role in fruit flavor (Ardö, 2006), and was the most abundant amino acid in 'Kousui' japanese pear, accounting for a maximum of 75% of the total amino acid concentration. Asp was significantly increased upon spraying with KNO_3 and HAK (Table 1). During NO_3^- assimilation, NO_3^- is first assimilated as ammonia in leaves and is then converted into Glu by the glutamine synthetase and glutamate synthase pathways (Rufty et al., 1981). When ammonia is assimilated into glutamate and glutamine, it can be converted

Table 1. Effect of different foliar potassium (K) fertilizers on 'Kousui' japanese pear fruit nonessential amino acids (NEAA) and essential amino acids (EAA).

Amino acid[z]	Fruit NEAA (mg/100 g FW)[y]				Amino acid	Fruit EAA (mg/100 g FW)			
	Control	KH_2PO_4	KNO_3	HAK		Control	KH_2PO_4	KNO_3	HAK
Asp	98.41 c[x]	97.96 c	110.63 b	120.40 a	Val	10.53 a	11.57 a	10.97 a	11.58 a
Glu	8.77 b	8.77 b	13.04 a	11.09 ab	Thr	9.51 b	9.75 ab	10.40 ab	10.72 a
Ala	8.68 a	9.51 a	9.50 a	9.09 a	Leu	8.56 a	9.20 a	8.43 a	8.93 a
Ser	6.76 b	6.75 b	8.42 a	7.33 ab	Ile	7.17 a	7.04 a	6.70 a	7.15 a
Arg	6.75	6.72 a	7.28 a	7.08 a	Lys	6.09 a	7.07 a	7.16 a	6.98 a
Gly	4.07 b	5.23 a	5.01 a	4.73 ab	Met	3.70 a	3.40 a	2.26 b	3.76 a
Pro	3.87 a	4.72 a	5.20 a	4.97 a	Phe	3.78 b	4.31 ab	4.74 a	4.48 ab
Cys	1.04 a	1.20 a	1.06 a	1.43 a	Total EAA	49.35 a	51.04 a	50.65 a	53.60 a
Tyr	1.99 a	2.22 a	1.94 a	2.10 a					
His	2.83 a	2.81 a	3.17 a	3.07 a	Total amino acids (NEAA+EAA)	192.51 c	198.21 bc	215.89 ab	224.88 a
Total NEAA	143.17 b	148.42 b	162.80 a	171.28 a					

[z]Asp = aspartic acid; Glu = glutamic acid; Ala = alanine; Ser = serine; Arg = arginine; Gly = glycine; Pro = proline; Cys = cysteine; Tyr = tyrosine; His = histidine; Val = valine; Thr = threonine; Leu = leucine; Ile = isoleucine; Lys = lysine; Met = methionine; Phe = phenylalanine.

[y]KH_2PO_4 = potassium phosphate monobasic; KNO_3 = potassium nitrate; HAK = humic acid potassium; 1 mg/100 g = 10 ppm.

[x]Means followed by the same letter within the treatment were not significantly different by Fisher's least significant difference test at $P < 0.05$ (n = 6).

into other amino acids by transamination, and this process is promoted by K (Mengel et al., 1981), since K functions as a cofactor that promotes the assimilation of amino acids. It was discovered by Armengaud et al. (2009) that regulation of enzymes at the level of transcripts and proteins was likely to play an important role in *Arabidopsis* (*Arabidopsis thaliana*) adaptation to K deficiency by decreasing negative metabolic charge, such as Glu, Asp, nitrate, and malate, whereas K supply could increase negative charge. Lin et al. (2004) reported that the taste, aroma, and Glu and Asp concentration of muskmelon could be improved when K was present at a level of 240 $mg \cdot L^{-1}$ in the nutrient solution, which was consistent with our present study.

Conclusion

Comparatively speaking, foliar application of KNO_3 could significantly increase the K accumulation, the fructose and sucrose concentration, and some amino acids in the fruit, such as Asp, Ser, Glu, and Gly. Further, compared with KNO_3, HAK was more helpful to improve the fruit quality by increasing fruit firmness, the total SSC, and sweetness. Farmers should adopt different strategies according to the aim of whether to increase the fruit yield or improve the fruit quality.

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