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# Fruit yellow-shoulder disorder as related to mineral element uptake of tomatoes grown in high temperature

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## ABSTRACT

In order to reduce yellow-shoulder (YS) disorder by regulating nutrient solution in high temperature, effects of potassium (K) and phosphorus (P) supplementation on YS index were investigated. Experiments were conducted in an optimum temperature condition under 20 °C, and in a high temperature condition under 31 °C. Nutrient solution of EC 0.9 dS m$^{-1}$ ($PO_4$-P 1.5 me L$^{-1}$, K 3.0 me L$^{-1}$), EC 0.9 + P ($PO_4$-P 4.6 me L$^{-1}$, K 3.0 me L$^{-1}$), EC 0.9 + K ($PO_4$-P 1.5 me L$^{-1}$, K 5.8 me L$^{-1}$), and EC 0.9 + P + K ($PO_4$-P 4.6 me L$^{-1}$, K 5.8 me L$^{-1}$) were used. Each tomato (*Solanum lycopersicum* L. 'CF Momotaro York') plant was grown in 250 mL pot combining three trusses and high-density planting. Results showed that K uptake amount was significantly higher at EC 0.9 + P + K than at EC 0.9, EC 0.9 + P and EC 0.9 + K. K uptake efficiency was higher at EC 0.9 + P than that at EC 0.9, although the application concentraiton of K were identical in them. YS disorder was more severe in 31°C than 20°C temperatures condition in the case of nearly similar uptake of K per plant. The YS index showed a significantly negative linear correlation with K uptake ($R^2 = 0.81$, $P < 0.01$) in 31 °C, which was not found in 22 °C or other mineral elements. These results indicated that the K uptake was significantly improved. YS disorder was correspondingly reduced by increasing P or/and K concentration in 31 °C high temperature condition. In conclusion, we recommended the nutrient solution formula (EC 0.9 + P)/(EC 0.9 + P + K) to reduce the YS disorder in high temperature growing season, because its K uptake efficiency was improved as compared with EC 0.9 + P + K.

## 1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important horticultural crops in Japan and year round supply is desired by consumers. However, coloring disorder of tomato fruit is a major limitation to success of marketable value, especially in summer growing season (Maezawa et al., 1993; Suzuki et al., 2013). This called as yellow-shoulder (YS) disorder was also reported in many other countries (Francis et al., 2000; Alba et al., 2007; Mulholland et al., 2003). The YS disorder is characterized by sectors of yellow or green tissue under the peel near the shoulder of the fruit, and as the fruit ripens it tends to turn a more intense yellow. These areas will never ripen properly, and the tissue is often hard even when the rest of the tomato is ripe (Francis et al., 2000).

The cause of this disorder is complex, several evidences showed that nutritional status, weather, plant genetics, and their interactions are important influence factors (Hartz et al., 1999; Sacks and Francis, 2001; Dumas et al., 2003; Yui et al., 2009; Jarquín-Enríquez et al., 2013; Shaheen et al., 2015; Maynard et al., 2016). In the literature, it is indicated that high temperatures and direct sunlight affected the development of plastids, reduced the lycopene (red pigment of the tomato fruit) content, and caused yellowing most often in the shoulders of tomato, as this part is commonly exposed to direct rays of the sun (Suzuki et al., 2013).

In addition, tomato fruits exhibiting YS disorder often contains lower potassium (K) concentration than normal fruit, suggesting important role of K for this disorder (Picha, 1987; Maynard et al., 2016). One of the best recommendations for alleviating the disorder was suggested to apply additional K to plants, and several evidences showed that YS disorder was reduced by K fertilization in soil (Taber et al., 2008; Helyes et al., 2009). Furthermore, phosphorus (P) also has a positive correlation with tomato fruit color, and higher soil exchangeable P status increased the percentage of fruit free from YS disorder (Alba et al., 2007).

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In our previous research (Egishi et al., 2012), deficiency symptoms of K (yellow-shoulder fruit and leaf margin chlorosis) and P (purple color of the veins and stem, thin stem and poor cluster development) often appeared in tomato plants after they suffered from continuous rainy or cloudy weathers. We speculated that the deficiency symptoms were usually caused by a low nutrient solution fertigation amount, and poor ability of water and nutrient conservation for plants in our growing system than for the conventional NFT or DFT system.

In another our previous research, YS disorder was greatly reduced by supplementation of K or/and P to the nutrient solution of Enshi formula at EC 0.9 dS m$^{-1}$ ($NO_3$-N = 6.0 me L$^{-1}$, P = 1.5 me L$^{-1}$, K = 3.0 me L$^{-1}$, Ca = 3.0 me L$^{-1}$ and Mg = 1.5 me L$^{-1}$) in autumn-winter growing season (Zhang et al., 2015a) and spring-summer growing season (Zhang et al., 2015b).

As mentioned above, single factor such as temperature or K induced YS, but whether excessive application of K or P could overcome YS at high temperature is still unknown, which are very essential because this disorder was most often observed during hot seasons (Suzuki et al., 2013). In the present study, in order to reduce YS disorder during hot season through regulating nutrient solution, supplementation of K or/and P in nutrient solution was investigated during the summer growing season, which constitute a comparable experiment to previous research of autumn-winter growing season (Zhang et al., 2015a).

## 2. Materials and methods

### 2.1. Nutrient solution treatments

Five treatments were consisted of EC 0.9, EC 0.9 + P, EC 0.9 + K, EC 0.9 + P + K and (EC 0.9 + P)/(EC 0.9 + P + K), as shown in Table 1. The basal composition of Enshi formula nutrient solution at EC 0.9 dS m$^{-1}$ contained the following elements in ppm: 84 $NO_3$-N, 6.8 $NH_4$-N, 15.5 P, 117 K, 18 Mg, 60 Ca, 1.1 Fe, 0.2 Mn, 0.02 Zn, 0.01 Cu, 0.2 B, and 0.003 Mo. At EC 0.9 + K, EC 0.9 + P and EC 0.9 + P + K treatments, K or/and $PO_4$-P concentration were increased up to 5.8 or/ and 4.6 me L$^{-1}$ as proposed in our previous paper of autumn-winter growing season (Zhang et al., 2015a). At (EC 0.9 + P)/(EC 0.9 + P + K), EC 0.9 + P was applied during anthesis period (week No. 1 to 3) and EC 0.9 + P + K was applied during fruit enlargement and ripening periods (week No. 4 to 9 as shown in Table 1). Experimental design was adopted with three replicates for each treatment, and each replicate contained 10 plants.

### 2.2. Plant material and growth conditions

Tomato seedlings ‘CF Momotaro York’ with five fully expanded true leaves were planted into extremely low-volume pot (Zhang et al., 2015a) filled with 250 mL of granular rock wool on 1 May 2013 at the experimental site of the Shizuoka University in Japan. Cultivation system and management for greenhouse were the same as in a previous paper (Zhang et al., 2015a). Plants were supplied with the 1/2 strength Enshi formulation nutrient solution (Egishi et al., 2012) from germination to the beginning of treatments. Treatments as shown in Table 1 were initiated from 27 May at anthesis period of the first truss and terminated on 22 July. Nutrient solution distributed through drip fertigation system to each plant were recirculated with a pump at a flow rate of approximately 25 mL min$^{-1}$. The fertigation frequency was controlled by using a solar radiance controller for 90 s each time 1.0 MJ m$^{-2}$ solar radiation had accumulated. As a result, fertigation occurred approximately 20 to 25 times per day on completely sunny days. Every 10 plants were kept in one container and fertigated with recirculated 35 L nutrient solution. The solution in each container was refilled with original solution to compensate for crop water consumption every day and renewed weekly. Plants were trained vertically with a single stem and topped at the 2nd upper leaf above the third truss and each truss was adjusted to have four fruits.

### 2.3. Measurement and statistical analysis

In the greenhouse, EC and pH of residual solution in reservoir, nutrient solution fertigation volume and refilled volume of each reservoir were recorded every day. Internal temperature was collected by data logger (TR-73U, T&D Co. Ltd., Nagano, Japan). Duration of sunshine per day was recorded by AMeDAS (automated meteorological data acquisition system).

The concentration of nutrient solution in each container was measured weekly. The level of K was determined by an atomic absorption spectrometry method (iCE 3000 Series, Thermo-Fisher Scientific Ltd., Cambridge, UK). K uptake rate per plant per week (me/plant/week) and YS index were calculated as described in previous paper (Zhang et al., 2015a). K uptake amount (me/plant) during fruit enlargement and entire growing period were calculated by sum of the weekly amount from the 4th to 6th week and 1st to 9th week, respectively. K uptake efficiency (%) was calculated in average uptake concentration (me L$^{-1}$) divided by application concentration (me L$^{-1}$) (n = 3).

Data were analyzed by one-way ANOVA, and significant differences of the mean values were evaluated using Scheffe’s multiple range test. Linear regression was used to evaluate the relationship between uptake of K and YS index of fruit.

## 3. Results

Average daytime temperature inside the greenhouse during fruit enlargement and ripening was consistently higher (31 °C) in summer growing season (Fig. 1A) than in Autumn-winter (20°C) (Zhang et al., 2015a). The maximum temperature once reached up to 34 °C in summer (Fig. 1A). Average duration of sunshine were 4 h in summer (Fig. 1A) and 6 h in autumn-winter.

Characteristics of K uptake pattern was reexamined in the present research, it was firstly increased along with successively anthesis of

**Table 1**
Composition of nutrient solution.

| Treatment | EC | Mineral nutrients (me L$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | (dS m$^{-1}$) | $NO_3$-N | $NH_4$-N | $PO_4$-P | K | Mg | Ca |
| EC0.9[a,b] | 0.9 | 6.0 | 0.5 | 1.5 | 3.0 | 1.5 | 3.0 |
| EC0.9 + P[a,b] | 1.2 | 6.0 | 0.5 | 4.6 | 3.0 | 1.5 | 3.0 |
| EC0.9 + K[a,b] | 1.2 | 6.0 | 0.5 | 1.5 | 5.8 | 1.5 | 3.0 |
| EC0.9 + P + K[a,b] | 1.4 | 6.0 | 0.5 | 4.6 | 5.8 | 1.5 | 3.0 |
| (EC0.9 + P)/(EC0.9 + P + K)[a,c] | 1.2 | 6.0 | 0.5 | 4.6 | 3.0 | 1.5 | 3.0 |
| | 1.4 | 6.0 | 0.5 | 4.6 | 5.8 | 1.5 | 3.0 |
| Water used | 0.2 | 0.0 | 0.0 | 0.1 | 0.5 | 0.3 | 0.5 |

[a] Summer growing season of 2013.

[b] Autumn-winter growing season of 2012.

[c] K concentration was increased from 3.0 me L$^{-1}$ to 5.8 me L$^{-1}$ during fruit enlargement and ripening periods.