RESPONDING OF LONG GREEN PEPPER PLANTS TO DIFFERENT SOURCES OF FOLIAR POTASSIUM FERTILISER

MOHAMED M. EL-MOGY*, AZZA M. SALAMA, HANAA F. Y. MOHAMED,
KARIMA F. ABDELGAWAD and EMAD A. ABDELDAYM

Cairo University, Faculty of Agriculture, Giza, Egypt

EL-MOGY, M.M. – SALAMA, A.M. – MOHAMED, H.F.Y. – ABDELGAWAD, K.F. – ABDELDAYM, E.A.: Responding of long green pepper plants to different sources of foliar potassium fertiliser. Agriculture (Pol'nohospodárstvo), vol. 65, 2019, no. 2, pp. 59 – 76.

The aim of this study was to explore the efficiency of foliar potassium fertiliser relative to morphological, physiological and biochemical properties of hybrid long pepper (*Capsicum annuum*). Pepper plants were grown in a greenhouse and supplied with three sources of foliar potassium fertilisers, i.e., potassium-humate (1 g/L = 1,250 g/ha), potassium sulfate (1 g/L = 1,250 g/ha), and potassium chloride (1 g/L = 1,250 g/ha). Water served as control. The impacts of these treatments on the photosynthetic parameters (photosynthetic rate, stomatal conductance, intercellular CO₂, leaf carotenoids) and chlorophyll *a* and *b*, metabolic compounds and nitrogen, phosphorus and potassium were measured. The photosynthetic parameters significantly improved by different foliar potassium application and the highest level of photosynthetic activity was noted in plants supplied with potassium sulfate, followed by potassium-humate and potassium chloride. Plant biomass accumulation, chlorophyll (*a* and *b*), and total yield showed larger increases in plants fertilised with potassium sulfate than those fertilised with potassium-humate; smallest increases occurred with potassium chloride. Concentrations of total sugars, carotenoids, chlorophyll (*a* and *b*), and endogenous level of nitrogen, phosphorus, and potassium contents in plants and fruits were positively influenced by varying sources of potassium. The fruit color parameters and total soluble solid were also significantly increased with all foliar potassium treatments compared with control. Foliar application of potassium sulfate recorded the highest values and significantly increase all anatomical characters for leaf, stem and fruit of pepper plant.

Key words: *Capsicum annum*, nutritional value, leaf pigments, anatomy, photosynthetic parameters

Potassium (K) is the most important mineral element for plant growth and development (Bahmanyar & Mashae 2010). Potassium and other microelements (Zn and Fe) have an essential role as an enzyme activator for cell's metabolic processes, including respiration, protein synthesis and photosynthesis (Farago 2008; Mahmoud *et al.* 2019). Also, K has a significant role in turgor-driven cell growth. Macro or microelements in foliar fertilisers have positive influence on plant growth. K is known as the “quality element” because of its role in improv-

ing the plant quality in general (Lester *et al.* 2006). The availability of K during plant growth is often inadequate because of its poor uptake by roots and the competitive absorption inhibition by calcium and magnesium elements. Therefore, foliar K application could be a supplemental way to increase K element in plant tissues.

Some previous studies have examined the effects of K fertilisers on pepper yield (Golcz *et al.* 2012) and pepper fruit quality (Shehata *et al.* 2018). Reportedly, K fertiliser had positive effects on growth,

Mohamed M. El-Mogy (*Corresponding author), Karima F. Abdelgawad, Emad A. Abdeldaym, Vegetable Crops Department, Faculty of Agriculture, Cairo University, Giza, Egypt. E-mail: elmogy@agr.cu.edu.eg
Azza M. Salama, Agricultural Botany Department, Faculty of Agriculture, Cairo University, Giza, Egypt
Hanana F. Y. Mohamed, Plant Physiology Section, Department of Agriculture Botany, Faculty of Agriculture, Cairo University, Giza, Egypt

yield and quality of the fruit of pepper plant (Bottella *et al.* 2017; Abdelaziz & Abdeldaym 2018). The available sources of K used for plant mineral fertiliser are potassium chloride (KCl), potassium sulfate (K_2SO_4), and potassium nitrate (KNO_3).

Pepper (*Capsicum annuum* L.) is considered one of the most popular horticultural crops in North Africa and the Mediterranean because of its economic value and nutritional properties. Pepper fruit is a good source of many nutrients and antioxidants, such as vitamin C (Vit. C) and phenolic compounds. Some previous works indicated that K fertiliser had a positive effect on fruit size, total soluble solids, ascorbic acid concentration, and fruit surface colour (Lester *et al.* 2006). There are few studies reporting the sources of K and its effects on chemical composition, quality, and anatomy of vegetable crops. Therefore, the aim of this study was to determine if supplemental foliar potassium applications during plant growth and fruit development would enhance growth, yield, and fruit quality of pepper. In addition, comparison of different potassium sources supplements on plant growth and fruit quality of pepper.

MATERIAL AND METHODS

Plant material, growth condition, and treatments

Experiments were conducted in a plastic greenhouse measuring 40 × 9 meters. This study was conducted from the 5th of October 2015 till the end of April 2016 and was repeated from the 10th of October 2016 till the end of April 2017 at the Experimental

station in the Faculty of Agriculture of Cairo University, Giza, Egypt (latitude 30.0131°N, longitude 31.2089°E, 694 m). Seeds of pepper cv. Dolci hybrid were sown on 1st and 5th August 2015 and 2016, respectively, by hand in foam trays (209 wells) filled with peat moss and vermiculite (1:1, v:v). Developing seedlings were irrigated daily and fertilised with NPK (15:15:15) once weekly. The seedlings were transplanted after 45 days in both seasons. The soil properties of experiment were determined and are summarized in Table 1. The experimental soil was deeply plowed and five flat beds (40 m length × 1 m width) were prepared. Two weeks before pepper transplanting (45 days), N (79 kg/ha), P_2O_5 (165.6 kg/ha) and K_2O (60 kg/ha) were applied as per soil analysis results. A randomized complete block design with four replicates was used. The transplants were arranged in two rows on each ridge. The plot area was 4 m² (4 m length × 1 m width); the spacing between plants was 0.30 m and 0.50 m between rows. Weeds were manually removed shortly after emergence. After 15 days of seedlings transplantation, pepper plants were sprayed, once every 10 days for 5 times, with the following treatments: A) K-humate (65% humic acid and 15% potassium) at a rate of 1 g/L (equal 1,250 g/ha), B) K_2SO_4 (48% potassium) at a rate of 1 g/L (equal 1,250 g/ha), C) KCl (52.2% potassium) at a rate of 1 g/L (equal 1,250 g/ha) and D) control was without K application.

Plant growth parameters

Ten plants were randomly sampled from each plot after 70 days of transplanting to determine

T a b l e 1

Chemical analysis of the soil in 2015–2016 and 2016–2017

Available cations [ppm]					Soil electrical conductivity [dS/m]	Soil pH
Year	K ⁺ [ppm]	Na ⁺ [ppm]	Ca ⁺⁺ [ppm]	Mg ⁺⁺ [ppm]		
2015–2016	323	9.2	29	17.02	0.37	7.89
2016–2017	350	10.11	35	18.48	0.44	7.56
Available cations [ppm]						
Year	N	P	Zn	Mn	Cu	Fe
2015–2016	32	20	0.48	0.54	0.65	1.16
2016–2017	27	26	0.33	0.67	0.42	1.10

growth traits. Plant height, number of branches and plant fresh and dry weight were recorded.

Photosynthetic parameters

The fifth leaf of ten plants was selected to assess net photosynthesis (Pn) on an area basis ($\mu\text{mol CO}_2/\text{m}^2/\text{s}$), leaf stomatal conductance to H_2O (Gs) ($\text{mol H}_2\text{O}/\text{m}^2/\text{s}$), and intercellular CO_2 concentration (Ci) ($\mu\text{mol CO}_2/\text{mol}$) using infra-red gas analyser LICOR 6400 Portable Photosynthesis System (IRGA, Licor Inc., USA).

Leaf chlorophyll a, b, and carotenoids content

Fresh leaves and fruits (90 and 120 days after transplanting, respectively) were extracted with acetone (80%) (Sigma-Aldrich Co. LLC) and placed for one hour at 5°C . The extractions were centrifuged for 15 min at $3,000 \times g$. Chlorophyll *a*, *b*, and carotenoids content were measured with a spectrophotometer (Helios UVG1702E, England) at wavelengths 663, 647, and 470 nm, respectively. Chlorophyll and carotenoids were measured according to the method of Lichtenthaler and Wellburn (1983). The calculation was done according to the following equations:

$$\text{Chlorophyll } a = 12.70 \times A_{663} - 2.79 \times A_{647}$$

$$\text{Chlorophyll } b = 20 \times A_{647} - 4.62 \times A_{663}$$

$$\text{Carotenoids} = \{1000 \times A_{470} - (3.27 \text{ chl. } A - 104 \text{ chl. } B)\} / 229$$

Total yield

Total yield were harvested during the season and weighted. The total yield represented in kg per plant.

Colour measurement

The surface colour of pepper fruits was recorded by measuring, *a** (from red to green), *b** (from yellow to blue), and *C** (colour saturation) with a Minolta Chroma Meter (model CR-200, USA). To measure surface colour, three readings were taken from opposite positions of each pepper fruit at mature stage. Ten fruits were analysed for each treatment. The colorimeter was calibrated using a white surface.

Fruit firmness, total soluble solids, and vitamin C content

Ten fruits at mature stage were used for measuring firmness. Three different fixed positions

were used for measuring the firmness on each fruit. Firmness was measured with a fruit pressure tester (FT011, Wagner Instruments, Italy). The results were expressed in Newton (N). The total soluble solids (TSS) in pepper fruit were measured by using a digital refractometer (model PR101, Co. Ltd., Japan). A drop of the juice was placed on the lens and the reading was taken in degrees Brix ($^\circ\text{Bx}$) and expressed as % soluble solids content in the fruit. Calibration made with distilled water and the lens was carefully rinsed, between samples, with distilled water twice. Fruit samples were randomly taken at harvesting time (mature stage) to determine vitamin C content in the fruit as mg/g fresh weight according to the method described by AOAC (1990).

Macro-elements content in plant and fruits (NPK)

Total nitrogen (N), phosphorus (P) and potassium (K) concentrations were determined in leaves, stems and fruits. Leaves, stems and fruits were dried at 70°C for 48 h and wet digestion of 0.2 g fine powder of dry material was carried out with sulphuric and perchloric acids, as described by Piper (1947). Nitrogen was determined with the modified “Micro Kjeldahl” apparatus of Parnas and Wagner as described by Pregl (1945). Phosphorus was determined spectrophotometrically by using stannous chloride method according to (AOAC 1975). Potassium was measured with flame photometer according to the method described by Brown and Lilliland (1964).

Total sugars and total phenols contents

Ethanol extracts of leaves and fruits were used to determine total sugars and total phenols. For preparation of ethanol extract, 5 g of fresh peppers were crushed in a porcelain mortar using 25 ml of 95% ethanol (Sigma-Aldrich, Germany) for 10 min and then filtrated through a sintered glass funnel (G_3). The residue was re-extracted and filtered twice with ethanol (80%), and then the volume was adjusted to 25 ml with ethanol (80%). In the ethanol extract, total sugar was measured via the phosphomolybdic acid method according to AOAC (1975). Total phenol was measured using the Folin–Ciocalteu reagent (Sigma-Aldrich, Germany) according to Swain and Hillis (1959) as follows: ethanolic extract (1 ml) and 1 ml Folin – Denis reagent in a test tube and immediately followed by the addition of 1 ml of 14% sodium carbonate. Tubes were left for 10 min at room

temperature. The absorbance of the developed colour was read at 725 nm using a spectrophotometer (Hitachi, U-1000). A standard curve was carried out using tryptophan (Sigma-Aldrich, Germany) with a suitable concentration which was treated in the same manner as described above. The concentration of total phenols was calculated and expressed as mg/g fresh weight of leaves and fruits of the pepper plant.

Anatomical study

The samples of leaf and stem were taken throughout the 2nd growing season of 2016–2017 from the 4th internode from the top of the main stem at 90 days from sowing. The fruit samples were collected at mature stage (120 days after sowing). The vegetative specimens were fixed in F.A.A. (10 ml formalin, 5 ml glacial acetic acid, 50 ml ethyl alcohol 95%, 35 ml distilled water), washed in 50% ethyl alcohol, dehydrated in a normal butyl alcohol series, embedded in paraffin wax with a melting point of 60–63°C, sectioned into 20 µm in thickness, stained with the double stain method (crystal violet/erythrosine), cleared in xylene and mounted in Canada balsam (Nassar & El-Sahhar 1998). The slides were microscopically examined and photomicrographed at Botany Department, Faculty of Agriculture, Cairo University. Measurements (µm) were taken using a micrometry piece, with average of readings 3 slides per treatment was calculated.

Statistical analyses

The experiment was arranged in a completely randomized block design with four replications. Data were exposed to analysis of variance using Mstat-c program (version 2.1). If the interaction was significant it was used to explain the data. If the interaction was not significant, means were separated using least significant difference by Duncan's multiple range test at $P < 0.05$. Principal component analysis (PCA) was used to determinate the associations between observed variables and a new set of non-correlated parameters (variables).

RESULTS AND DISCUSSION

Plant growth and development

Data in Table 2 shows the effects of year, treat-

ment, and year $\times$ treatment interaction on plant growth parameters. Plant fresh weight was affected only by year. Fresh weight of pepper plants was higher in 2016/2017 than in 2015/2016 (Figure 1A). Plant height was affected only by K treatments. The tallest plants were recorded from plants received K_2SO_4 fertiliser followed by KCl, while the control and K-humate were lower and similar (Table 3). Number of branches affected only by K treatments. All sources of K significantly increased number of branches compared to control plants (Table 3). The highest number of branches values recorded from plants treated with K_2SO_4 followed by K-humate and KCl with no significant difference between them. Dry matter of plants [%] is affected by year and treatment factors (Table 2). Dry matter in the second season (2016/2017) was higher than first seasons (2015/2016, Figure 1B). All foliar K sources treatments were similar in dry matter and higher than control (Table 3). In this study, plant growth parameters of long pepper, including plant height, number of branches and dry biomass accumulation were positively influenced by foliar K fertilisers. The difference between years of study on the fresh weight could be due to the variability of micro-climate conditions surrounding the plants. Accumulation of plant dry matter improved significantly with foliar K treatments. Also, there is a positive association between dry matter, net Pn and photosynthetic pigment (chlorophyll *a*) (Figure 2B). This indicated that enhancement in dry matter of pepper plants supplied with K is highly associated to leaf chlorophyll *a* and photosynthesis rates that increase total sugar accumulation which act as main organic component of the dry matter. Our results in Figure 2B indicated a correlation between leaf K content, chlorophyll *b*, and plant height. The obtained results were in agreement with previous studies reported that K fertiliser increased the plant height and dry weight of tomato plants (Afzal *et al.* 2015; Botella *et al.* 2017). O'Toole *et al.* (1980) mentioned that low levels of K nutrition resulted in a decrease in dry weight of leaves and stems as well as decrease cell size and compaction of cells per unit area and this lead to decreased leaf thickness of bean plants.

Leaf photosynthesis activities

In this study, foliar K treatments only have pos-

itive influence on photosynthesis activity (Table 2). Maximum values of Pn, Gs, and Ci were recorded in pepper plants supplied with K₂SO₄ followed by KCl and K-humate treatments (Figure 3A, B, C). The control was recorded the lowest values. Furthermore, positive correlation was found between photosynthetic parameters (Pn, Gs, and Ci) and leaf K content (Figure 2A and B). It was also noted that Gs and Ci have a positive correlation with net photosynthesis (Figure 2A). This result pointed out that the increase in Pn under foliar K implementation could be attributed to increase in Gs that stimulated

with K (Figure 2B). This improved Ci inside the leaves (Ibrahim *et al.* 2011). These changes could be result from the anions accompanied the K fertilisers, where the high concentration of Cl⁻ anion reduced the leaf chlorophyll concentration which consequently decreased the Pn as suggested by Acosta-motos *et al.* (2017). Generally, net photosynthesis rate of pepper plants supplied with foliar K fertilisers was better than untreated plants (Sun *et al.* 2011). Where, photosynthesis rate improved by K fertiliser through regulating stomata opening and allowing gas exchanges with atmosphere which

T a b l e 2

Analysis of variance (mean square) of pepper plant growth and yield

Source	df	Plant fresh weight [kg]	Plant height [cm]	Number of branches	Dry matter [%]	Yield [kg/plant]	Pn	Gs	Ci
Year (Y)	1	0.39 ⁺	400.16 ^{ns}	0.66 ^{ns}	4.11 ⁺	0.05 ⁺⁺	0.00 ^{ns}	0.00 ^{ns}	0.02 ^{ns}
Treatment (T)	3	0.23 ^{ns}	532.00 ⁺	3.38 ⁺	17.22 ⁺⁺⁺	0.08 ⁺⁺⁺	53.55 ⁺⁺⁺	916.99 ⁺⁺⁺	9,581 ⁺⁺⁺
Y×T	3	0.02 ^{ns}	10.83 ^{ns}	1.00 ^{ns}	2.28 ^{ns}	0.00 ^{ns}	2.13 ^{ns}	0.01 ^{ns}	0.002 ^{ns}

^{ns}, ⁺, ⁺⁺, ⁺⁺⁺ not significant or significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, analysis of variance

T a b l e 3

Effect of different sources of K foliar fertiliser on phytochemicals in shoots of pepper plant. Values within each row followed by the same letter are not statistically different according to Duncan test ($P < 0.05\%$)

Phytochemicals in shoots	Control	K-humate	K ₂ SO ₄	KCl
Plant height [cm]	116.66 ^c	121.45 ^c	138.23 ^a	125.67 ^b
Number of branches	3.66 ^c	4.56 ^b	5.50 ^a	4.52 ^b
Dry matter [%]	18.79 ^b	22.28 ^a	22.71 ^a	21.88 ^a
Total yield [kg/plant]	0.49 ^d	0.65 ^b	0.78 ^a	0.60 ^c
Leaves chlorophyll <i>a</i> content [mg/g fw]	1.02 ^b	1.14 ^a	1.13 ^a	1.10 ^a
Leaves chlorophyll <i>b</i> content [mg/g fw]	1.04 ^c	1.20 ^a	1.18 ^{ab}	1.14 ^{bc}
Leaf N content [mg/g dw]	27.10 ^b	29.35 ^a	25.55 ^b	29.45 ^a
Leaf K content [mg/g dw]	28.21 ^c	31.12 ^{ab}	31.58 ^a	29.45 ^b
Stem N content [mg/g dw]	13.10 ^{ab}	13.82 ^a	10.00 ^c	12.60 ^b
Stem P content [mg/g dw]	9.05 ^b	11.02 ^a	11.20 ^a	10.65 ^a
Stem K content [mg/g dw]	29.81 ^c	32.28 ^{ab}	33.27 ^a	31.79 ^b
Leaf total phenols content [mg/g fw]	2.16 ^b	3.01 ^a	2.93 ^a	2.82 ^a
Leaf total sugar [mg/g fw]	1.04 ^c	1.35 ^b	1.52 ^a	1.07 ^c

Figure 1. Effect of year on (A) plant fresh weight [kg], (B) dry matter [%], (C) total yield [kg/plant], (D) TSS [%], (E) leaf K content in [mg/g dw] and (F) stem K content [mg/g dw]

improves C_i rate and water use efficiency (Abid *et al.* 2016; Coskun *et al.* 2014; Zahoor *et al.* 2017).

Pigments contents in leaves and fruits (chlorophyll a , b and carotenoids)

Plant pigments, including chlorophyll (a and b) and carotenoids are vital molecules that are formed by plants and play an important role in photosynthesis process which is accountable for plant growth (Dobroviczka *et al.* 2013). Our results indicated that K treatments affected chlorophyll (a and b) in leaves while carotenoids were affected by year $\times$ treatment interaction (Table 4). Moreover, all

sources of K significantly increased chlorophyll a and b in leaves. The higher values of leaf chlorophyll b content were recorded in plants treated with K-humate and K_2SO_4 compared to control (Table 3). The lower chlorophyll b level in pepper leaves was found in plants treated with KCl compared to other K treatments. Furthermore, positive correlation between chlorophyll (a and b) accumulation in pepper leaves and leaf K content was observed (Figure 2B). This improvement in chlorophyll (a and b) contents due to K fertiliser could be based on stability of proteins complex and chloroplast structure (Ibrahim *et al.* 2012). Ghasemzadeh *et al.* (2010) reported that

T a b l e 4

Analysis of variance (mean square) of pepper leaves and fruits chemical compositions

Source	df	Chlorophyll a in leaf [mg/g fw]	Chlorophyll b in leaf [mg/g fw]	Carotenoids in leaf [mg/g fw]	Chlorophyll a in fruits [mg/g fw]	Carotenoids in fruits [mg/g fw]
Year (Y)	1	0.00 ^{ns}	0.02 ^{ns}	0.001 ^{ns}	0.001 ^{ns}	0.002 ^{ns}
Treatment (T)	3	0.02 ⁺⁺⁺	0.03 ⁺⁺	0.001 ^{ns}	0.002 ⁺⁺⁺	0.002 ⁺
Y $\times$ T	3	0.00 ^{ns}	0.00 ^{ns}	0.002 ⁺⁺	0.002 ^{ns}	0.002 ^{ns}

ns, +, ++, +++ not significant or significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, analysis of variance

T a b l e 5

Effect of different sources of K foliar fertiliser on phytochemicals in fruits of pepper plant. Values within each row followed by the same letter are not statistically different according to Duncan test ($P < 0.05\%$)

Parameters	Control	K-humate	K_2SO_4	KCl
Chlorophyll a [mg/g fw]	0.067 ^a	0.065 ^a	0.072 ^a	0.045 ^b
Carotenoids [mg/g fw]	0.028 ^c	0.030 ^b	0.038 ^a	0.028 ^b
c^*	43.08 ^c	48.45 ^a	46.69 ^b	48.20 ^a
a^*	-18.70 ^b	-19.96 ^a	-20.70 ^a	-20.10 ^a
b^*	39.67 ^d	47.06 ^a	43.92 ^b	41.60 ^c
TSS ($^{\circ}$ Brix)	4.40 ^b	4.70 ^{ab}	5.20 ^a	4.90 ^a
Vitamin C [mg/100 g fw]	153.70 ^d	156.70 ^c	176.50 ^a	167.30 ^b
N content [mg/g dw]	20.70 ^b	23.90 ^a	19.80 ^b	21.20 ^b
P content [mg/g dw]	6.40 ^b	7.40 ^a	6.50 ^b	6.80 ^{ab}
K content [mg/g dw]	20.00 ^b	23.10 ^a	23.90 ^a	23.00 ^a
Total Phenols content [mg/g fw]	1.08 ^c	1.43 ^a	0.79 ^d	1.25 ^b
Total sugar [mg/g fw]	1.28 ^c	2.60 ^a	2.41 ^a	1.76 ^b

leaf chlorophyll content was increased due to K fertiliser. Potassium activated chlorophyll synthesis such as porphobilinogenase, ALA dehydratase and δ -aminolevulinic acid (ALA) and avoiding decomposition of newly chlorophyll synthesized. On contrary, the lowest values of chlorophyll *a* in pepper fruits were recorded in plants treated with KCl (Table 5). No significant differences were observed among treatments regarding chlorophyll *b*. The reduction of chlorophyll *b* in leaves and chlorophyll *a* in pepper fruit caused by KCl fertiliser was possibly

due to adverse effects of accumulated chloride (Cl^-) ion on chloroplast structure and chlorophyll formation (Salama *et al.* 1994). The highest level of carotenoids was noted in leaves and fruits of pepper plants supplied with KCl treatment than other treatments (Figure 4A and Table 5). This improvement possibly induced due to high salinity of KCl solution than salinity of K_2SO_4 and K-humate solution (Kamburova & Kirilov 2008) which caused more stressful conditions additionally toxicity resulted of Cl^- anion accumulation. Whereas, carotenoids is considered

T a b l e 6

Analysis of variance (mean square) of pepper fruits color and chemical compositions

Source	df	<i>c</i> *	<i>a</i> *	<i>b</i> *	TSS [%]	Firmness (N)	Vit. C
Year (Y)	1	0.22 ^{ns}	4.40 ^{ns}	3.00 ^{ns}	0.54 ⁺⁺	0.00 ^{ns}	0.58 ^{ns}
Treatment (T)	3	29.48 ⁺	4.42 ⁺	60.71 ⁺⁺⁺	0.61 ⁺⁺⁺	0.77 ^{ns}	649.21 ⁺⁺⁺
Y×T	3	1.74 ^{ns}	0.17 ^{ns}	2.28 ^{ns}	0.09 ^{ns}	1.44 ⁺	0.11 ^{ns}

ns, +, ++, +++ not significant or significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, analysis of variance

T a b l e 7

Analysis of variance (mean square) of pepper plant chemical compositions [mg/g dw]

Source	Df	N content in leaf	P content in leaf	K content in leave	N content in stem	P content in stem	K content in stem
Year (Y)	1	0.38 ^{ns}	0.05 ⁺⁺	121.50 ⁺⁺⁺	2.34 ^{ns}	0.03 ^{ns}	80.66 ⁺⁺⁺
Treatment (T)	3	21.32 ⁺⁺	1.12 ⁺⁺⁺	14.48 ⁺⁺	16.87 ⁺⁺⁺	1.45 ⁺⁺⁺	12.70 ⁺⁺⁺
Y×T	3	1.65 ^{ns}	0.02 ⁺⁺	4.94 ^{ns}	1.92 ^{ns}	0.10 ^{ns}	2.33 ^{ns}

ns, +, ++, +++ not significant or significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, analysis of variance

T a b l e 8

Analysis of variance (mean square) of pepper fruits and leaves chemical compositions

Source	df	N content in fruits [mg/g dw]	P content in fruits [mg/g dw]	K content in fruits [mg/g dw]	Phenolic compounds in leaf [mg/g fw]	Phenolic compounds in fruits [mg/g fw]	Total sugar in leaf [mg/g fw]	Total sugar in fruits [mg/g fw]
Year (Y)	1	3.60 ^{ns}	0.66 ^{ns}	1.52 ^{ns}	0.06 ^{ns}	0.01 ^{ns}	0.00 ^v	0.03 ^{ns}
Treatment (T)	3	18.59 ⁺⁺	1.42 ⁺	17.15 ⁺⁺⁺	0.52 ⁺⁺⁺	0.45 ⁺⁺⁺	0.32 ⁺⁺⁺	2.23 ⁺⁺⁺
Y×T	3	10.25 ^{ns}	0.05 ^{ns}	0.25 ^{ns}	0.09 ^{ns}	0.03 ^{ns}	0.00 ^{ns}	0.05 ^{ns}

ns, +, ++, +++ not significant or significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, analysis of variance

one of the most important antioxidant compounds which protects the plant cell against oxidative stress resulted of salinity condition (Giuffrida *et al.* 2014).

Pepper yield

Analysis of variance showed that year ($P \leq 0.01$) and K treatments ($P \leq 0.001$) significantly influenced total yield (Table 2). The total yield of pepper plant was higher in first year (2015/2016) than second year (2016/2017) (Figure 1C). This result might be associated to climate condition generalized during the two seasons. Different sources of K significantly increased total yield per plant compared to control (Table 3). The highest yield was recorded from plants treated with K_2SO_4 followed by K-humate and KCl, respectively. Similar results were obtained in other vegetable crops such as pepper and melon (Golcz *et al.* 2012; Lester *et al.* 2010). Inthichack *et al.* (2012) stated that higher yield of celery was obtained by using K fertiliser in the form of KCl whereas; the highest yield of cabbage and lettuce resulted from K fertiliser form the source of K_2SO_4 . The improvement of fruit yield of pepper plant is strongly correlated with leaf sugar content and Pn as shown in principle component analysis (Figure 2A). This confirms the statement that increased fruits yield of plants supplied with K is associated to photosynthetic assimilations (i.e. sugars) and transloc-

tion of those assimilates towards sink tissues (Zhao *et al.* 2001). Chapagain and Wiesman (2004) also observed that tomato fruit biomasses were increased by foliar K application.

Fruits colour

Our results confirmed that K fertilisers significantly affected the chroma (C^*) and a^* (red to green colour) and b^* (yellow to blue colour) values in fruit pepper skin (Table 6). The distinguish colour for normal fruits is yellowish green colour. Data in Table 5 shows that values of a^* (green colour) and b^* (yellow) were improved by K fertiliser. Similarly, C^* saturation index was also enhanced. The highest value of C^* was recorded by K-humate and KCl. The value of a^* increased in all K treatment compared to control, while the highest a^* value was recorded by K-humate. The enhancement of colour formation by K fertiliser could be due to the role of K element in activation of 60 different enzymes, reduce tissue wilting, and formation of sugars and starch (Fageria 2009).

Fruit firmness, total soluble solid and vitamin C content

Firmness was affected only by year $\times$ treatments interaction (Figure 4B) but the fruit firmness showed similar trends with control. The highest value of

Figure 2. Principal component analysis (PCA) of leaf potassium concentration with different parameters analysed in leaves and fruit of pepper plant

fruit total soluble solid (TSS) was in second season than first season (Figure 1D). Table 5 indicates that TSS in fruits significantly improved with K treatment compared to control as similar findings were obtained by Lester *et al.* (2006). The fruit firmness did not change with K fertiliser because the foliar applied K is not associated to increase membrane integrity or cell wall stability as calcium does (Lester & Grusak 1999). On the other hand, enhancement of fruit TSS is positively correlated to fruit total sugar ($r = 0.82$), Vit. C ($r = 0.72$) and accumulation of other organic osmolytes as well as K ($r = 0.68$) in cells of fruit pepper fruit (Figure 2A). Analysis of variance showed that vit. C accumulation in pepper significantly affected by K fertiliser (Table 6). Content of Vit. C in pepper fruits treated with K-humate, K_2SO_4 and KCl were increased by 4.9, 15.2

and 10.5% compared to control (Table 5). Furthermore, fruit Vit. C is correlated positively with Pn, Ci and leaf K content (Figure 2A). This implies that K sources improve Pn, Ci, and carbohydrate accumulation, assimilates translocation and enzyme activation (Ghasemzadeh *et al.* 2010; Ghasemzadeh & Haafar 2011). High concentration of vit. C in pepper fruits supplied with K probably due to development of total carbohydrate (Norhaiza *et al.* 2009). This is because D-glucose is considered a precursor for vit. C biosynthesis in plants, as more availability of carbohydrate lead to vitamin C might be formed in the L-galactose pathways (Hancock & Viola 2005).

Macro-element content in plant and fruits (N, P, and K)

Nitrogen content in leaves was affected only by K treatments (Table 7). The highest contents of N in

T a b l e 9

Effect of different sources of K foliar fertiliser on histological features of pepper plant leaf

Characters [μm]	Treatments			
	Control	K-humate	K_2SO_4	KCl
Mid vein thick	805 ^d	830 ^b	885.0 ^a	819 ^c
Lamina thick	240 ^d	333 ^b	341.0 ^a	265 ^c
Palisade tissue thick	85 ^b	95 ^a	97.5 ^a	93 ^a
Spongy tissue thick	133 ^c	235 ^a	241.5 ^a	145 ^b
Dimensions of the main Vascular bundle of mid vein				
- Length	120 ^d	185 ^b	200 ^a	128 ^c
- Width	420 ^d	555 ^b	605 ^a	430 ^c

T a b l e 10

Effect of different sources of K foliar fertiliser on histological features of pepper plant stem

Characters [μm]	Treatments			
	Control	K-humate	K_2SO_4	KCl
Main stem diameter	2,365 ^c	2,520 ^b	2,610 ^a	2,508 ^b
Collenchymas thick	105 ^c	129 ^b	150 ^a	125 ^b
Parenchyma thick	143 ^d	180 ^b	210 ^a	160 ^c
Upper phloem tissue thick	57 ^d	95 ^b	110 ^a	75 ^c
Xylem tissue thick	225 ^d	315 ^b	355 ^a	283 ^c
Lower phloem tissue thick	70 ^d	90 ^b	105 ^a	80 ^c

leaves were observed in K-humate and KCl treatments compared to control and K_2SO_4 treatments (Table 3). Also, P content in leaves was affected by year, treatments, and year $\times$ treatments interaction (Table 7). The highest P content was observed in plants treated with K-humate in both years (Figure 4C). Additionally, K content in leaves was affected by year and treatments (Table 7). K content in leaves and stems was higher in 2016/2017 than in 2015/2016 (Figure 1E and F). All K treatments increased K content in leaves compared to control plants (Table 3). In case of fruits, the treatment only affected the macro-element content (Table 8). Table 5 shows that the maximum value of total N and P were recorded in plants treated with K humate with insignificant differences between other treatments (K_2SO_4 , KCl and Control). On the other hand, vary-

ing sources of K treatments significantly increased endogenous K fruit content if compared to control. Our investigation confirmed that foliar K supplementation caused also significant changes in nutrient content in plant tissues (Marschner & Marschner 2012). Nitrogen content in both leaves and fruit tissues of pepper was significantly improved with foliar K fertilisers in forms KCl and K-humate ($P \leq 0.05$) except the form of K_2SO_4 . These results were in agreement with Golcz *et al.* (2004), who found that K_2SO_4 reduced total N in both leaves and fruit of hot pepper than KCl. Previous works confirmed our findings concerning accumulation of K and N in plant organs were significantly increased due to K exposure (Lester *et al.* 2005). Pervez *et al.* (2006) also reported that sufficient rates of K are required for conserving N metabolism. The increasing of K

Figure 3. Effect of different sources of K foliar fertiliser on (A) Net photosynthetic rate (Pn), (B) Stomatal conductance (Gs), and (C) Intercellular CO₂ (Ci), Column with same letter (s) are not significantly different according to Duncan test ($P \leq 0.05$).

concentration in pepper leaves and fruits could be explained by the capability of plant to absorb extra K even adequate soil K fertiliser was added. The similar trend of P was observed in pepper plants treated by foliar K fertiliser. Adequate amount of K is needed for absorption P as well as positive P-K interaction in improving crop yield and had been observed by Pervez *et al.* (2006). Besides, improvement of P and N values in pepper fruits treated with K-humate might be returned to composition of product where it has extra elements as P and N (Tripura *et al.* 2017).

Fruit total sugars content

Data in Table 8 indicated that total sugar in leaves and fruits were affected only by K treatments. Total sugar in pepper leaves due to treatment with K_2SO_4 and K-humate was significantly higher than control and KCl treatments (Table 3). Total sugar contents in fruit of pepper plants treated with different K sources were higher than control plants (Table 5). Foliar K-humate, K_2SO_4 and KCl fertiliser increased total sugar contents by 23, 27.6 and 2.9% in leaf and 50.76, 48.88 and 27.30% in fruits, respectively (Tables 3 and 5). Leaf total sugar concentration is correlated positively with photosynthesis rate (Figure 2A and B). These results confirmed that increasing net photosynthesis rates led to increasing total sugars biosynthesis and tended to accumulate. Similarly, Lester *et al.* (2010) found that trend of sucrose, glucose and fructose in melon were improved with foliar K fertiliser. Higher total sugar content can be explained by role of K as cofactor in activation of

enzymes involved to biosynthesis and hydrolysis of carbohydrates, translocation of their diverters from leaves to fruits and neutralization of important organic acids. A significant reduction in total sugars in leaves and fruits of pepper plants exposed to KCl fertiliser could be explained by the harmful effect of chloride salt stress which might be decreased chlorophyll concentration, reduced photosynthesis activity, disturbed source-sink and sucrose synthase (Lin *et al.* 2004; Peng *et al.* 2016).

Total phenols content

Analysis of variance showed that total phenols in leaves was affected by treatment and in fruits affected by treatments and year $\times$ treatments interaction (Table 8 and Figure 4D). In general, total phenols were increased in the leaves of pepper plants supplied with foliar K fertilisers. The production of total phenols increased with K_2SO_4 , K-humate and KCl supplementation by 26.27, 28.23 and 23.4% in leaves (Table 3). In pepper fruits, the highest total phenols were recorded in K-humate treatment followed by KCl treatment and then the control. Moreover, K_2SO_4 treatment had the lowest value (Table 5). Our results confirmed the earlier studies relating to the influence of K on total phenols accumulation in plant leaves (Ibrahim *et al.* 2012). The increase of total phenols level with foliar K fertiliser in this study could be due to enhancement of total sugar content and photosynthesis as suggested by Ibrahim *et al.* (2011). This might be due to K which plays a vital role in stimulating photosynthesis activity and improving the translocation of sugars into dif-

T a b l e 11

Effect of different sources of K foliar fertiliser on histological features of pepper plant fruit

Characters [μm]	Treatments			
	Control	K-humate	K_2SO_4	KCl
Outer epidermis (exocarp) thick	18 ^b	23 ^a	25 ^a	22 ^a
Collenchyma thick	55 ^d	71 ^b	95 ^a	65 ^c
Parenchyma thick	710 ^c	877 ^a	885 ^a	815 ^b
Vascular bundle diameter	90 ^b	111 ^a	115 ^a	100 ^a
Inner epidermis (endocarp) thick	28 ^b	38 ^a	40 ^a	35 ^a
Whole pericarp thick	1,109 ^d	1,265 ^b	1,430 ^a	1,160 ^c

ferent part of plant. This increment in translocation indirectly improved the biosynthesis of total phenols of pepper supplied with foliar K fertiliser. From PCA (Figure 2) it was shown a positive relationship between Pn and total phenols in leaves of pepper plants (Figure 2B). Carbohydrates are necessary to phenolic substances biosynthesis through the shikimic acid pathway where more carbohydrates derived from glycolysis and the pentose phosphate pathway are transformed into aromatic amino acids (Shui *et al.* 2009). Other studies suggested that total phenols in pepper is positively correlated to high phenylalanine ammonia-lyase (PAL) activity, where, this enzyme uses K as cofactor to synthesis phenolic compounds (Ibrahim *et al.* 2012). The

high activity of this enzyme (PAL) was also noted in maize (Li *et al.* 2009) when plants exposed to high K rates.

Anatomical studies

Anatomical study proven that foliar K fertiliser improved the cell size and thickness of different tissues of pepper leaf and stem. Plants treated with foliar K in form K_2SO_4 recorded the highest values and improved different tissues thickness of pepper leaf and stem than other K treatments (KCl, K-humate). Foliar application with K_2SO_4 showed an increase in thickness of mid vein, lamina, palisade and spongy tissues of leaves by 9.9, 42.0, 14.7 and 81.6%, respectively in comparison to control. The main vas-

Figure 4. Effect of Year $\times$ Treatment interaction on (A) Leaf carotenoids content [mg/g fw], (B) Fruit firmness (N), (C) Leaf P content [mg/g dw] and (D) Leaf phenolics content [mg/g fw]

cular bundle of mid vein increased in length and width by 66.6 and 44.0%, respectively compared to control (Table 9 and Figure 5). Also, plants treated with K_2SO_4 showed an increase in stem diameter, collenchymas and parenchyma thickness, upper and lower phloem and xylem tissues of pepper plant stem by 10.3, 42.8, 46.8, 92.9, 50.0 and 57.7%, respectively more than control (Table 10 and Figure 6). Moreover, the results showed that the anatomical characters of fruit tissues improved with foliar potassium applications (Table 11 and Figure 7). The maximum values of studied characters were recorded with plants treated with K_2SO_4 . The increments over control were, 38.8, 72.7, 24.6, 27.7, 42.8 and 28.9% for thickness of exocarp, collenchymas, parenchyma, vascular bundle, endocarp and whole pericarp, respectively. This improvement in cell size and thickness of fruits could be attributed to increase accumulation of metabolic compounds

(i.e. sugars). Several investigators also reported that growth promotion of numerous crops supplied with sufficient amount of K fertilisers, either as foliar feeding or soil application, could be attributed to its function in activation of many enzymes correlated to leaf pigment formation, photosynthesis processes and biosynthesis of metabolic compounds involved to plant development (Amtmann *et al.* 2008; Kaur *et al.* 2007; Qua *et al.* 2012). Arafa *et al.* (2011) mentioned that potassium fertiliser significantly increased stem and pith diameter, collenchyma thickness, chlorenchymatous layer thickness, length and width of vascular bundle, as well as the thickness of phloem and xylem. Contrary, KCl fertiliser showed lowest value of thickness of different tissues, but the values are higher than control plants. This observation suggested that KCl has a higher salt content than K_2SO_4 (Kamburova & Kirilov 2008) and accumulation of Cl anion inside cells induced the toxic-

Figure 5. Transverse sections through the blade of 4th leaf of pepper plant as affected by foliar application with (1) untreated plant (control), (2) plant treated with potassium humate, (3) plant treated with potassium sulphate and (4) plant treated with potassium chloride. (U.ep.) – Upper epidermis, (Pal.) – Palaside tissue, (Spo.) – Spongy tissue, (Xy.) – Xylem, (Ph.) – Phloem and (L. ep.) – Lower epidermis.

Figure 6. Transverse sections through median portion of the main stem of pepper plant at the age of 90 days as affected by foliar application with (1) untreated plant (control), (2) plant treated with potassium humate, (3) plant treated with potassium sulphate and (4) plant treated with potassium chloride. (Ep.) – Epidermis, (Col.) – Collenchyma, (Par.) – parenchyma, (Ph.) – Phloem, (Xy.) – Xylem and (Pi.) – pith.

Figure 7. Transverse sections through median portion of the fruit of pepper plant at the age of 120 days as affected by foliar application with (1) untreated plant (control), (2) plant treated with potassium humate, (3) plant treated with potassium sulphate and (4) plant treated with potassium chloride. (Exo.) – Exocarp, (Col.) – Collenchyma, (Par.) – Parenchyma, (V.B.) – Vascular bundle, (G.C.) – Giant cell and (End.) – Endocarp.

ity and reduced the cell size and thickness of plant tissues. Cutter and Murphey (1978) indicated that K affected vessel wall thickness and vessel length of pepper that it may affect xylem vessel conductivity.

CONCLUSIONS

The present study indicated that supplementing foliar K sources during the plant growth and fruit development can improve pepper fruit quality parameters and bioactive compounds. All the foliar K sources, especially K_2SO_4 , were effective in improving photosynthetic process, plant biomass, and total yield, total sugars, carotenoids, chlorophyll (*a* and *b*), and endogenous NPK. Moreover, foliar application of K_2SO_4 . Moreover, foliar application of K_2SO_4 recorded the maximum promotion in all anatomical characters for leaf, stem and fruit of pepper plant. Increasing available K element for pepper plant by foliar fertiliser treatment could be an effective easily method that growers can be used for increasing pepper yield and quality.

REFERENCES

- ABDELAZIZ, M.E. – ABDELDAYM, E.A. 2018. Cucumber growth, yield and quality of plants grown in peatmoss or sand as affected by rate of foliar applied potassium. In *Bio-science Research*, vol. 15, no. 3, pp. 2871–2879.
- ABID, M.Z. – TIAN, S.T. – ATA-UL-KARIM, F. – WANG, Y. – LIU, R. – ZAHOR, D. – JIANG, L. – DAI, T. 2016. Adaptation to and recovery from drought stress at vegetative stages in wheat (*Triticum aestivum*) cultivars. In *Functional Plant Biology*, vol. 43, pp. 1159–1169. <https://doi.org/10.1071/fp16150>
- ACOSTA-MOTOS, J.R. – ORTUÑO, M.F. – BERNAL-VICENTE, A. – DIAZ-VIVANCOS, P. – SANCHEZ-BLANCO, M.J. – HERNANDEZ, J.A. 2017. Plant responses to salt stress: Adaptive mechanisms. In *Agronomy*, vol. 7, pp. 1–38.
- AFZAL, I. – HUSSAIN, B. – BASRA, S.M.A. – ULLAH, S.H. – SHAKEEL, Q. – KAMRAN, M. 2015. Foliar application of potassium improves fruit quality and yield of tomato plants. In *Acta Scientiarum Polonorum, Hortorum Cultus*, vol. 14, no. 1, pp. 3–13.
- AMTMANN, A. – TROUFFLARD, S. – ARMENGAUD, P. 2008. The effect of potassium nutrition on pest and disease resistance in plants. In *Physiologia Plantarum*, vol. 133, pp. 682–691.
- AOAC, 1990. *Official methods of analysis of the Association of Official Analytical Chemists*, 15th ed., Association of Official Analytical Chemists, Arlington VA, pp. 1058–1059.
- AOAC, 1975. *Official methods of analysis of the Association of Official Analysis Chemists*, 12th ed., Association of Official Analytical Chemists, Washington. C. 200044.
- ARAF, A.A. – FAROUK, S. – HAGER, S.M. 2011. Effect of potassium fertiliser, biostimulants and effective microorganisms as well as their interactions on potato growth, photosynthetic pigments and stem anatomy. In *Journal of Plant Production*, vol. 8, no. 2, pp. 1017–1035.
- BAHMANYAR, M.A. – MASHAE, S.S. 2010. Influences of nitrogen and potassium top dressing on yield and yield components as well as their accumulation in rice (*Oryza sativa*). In *African Journal of Biotechnology*, vol. 9, no. 18, pp. 2648–2653.
- BOTELLA, M.A. – ARÉVALO, L. – MESTRE, T.C. – RUBIO, F. – GARCÍA-SÁNCHEZ, F. – RIVERO, R.M. – MARTÍNEZ, V. 2017. Potassium fertilization enhances pepper fruit quality. In *Journal of Plant Nutrition*, vol. 40, no. 2, pp. 145–155.
- BROWN, J.D. – LILLILAND, O. 1964. Rapid determination of potassium and sodium in plant materials and soil extracts by flame photometer. In *Proceedings of the Society for Horticultural Science*, vol. 48, pp. 341–346.
- CHAPAGAIN, B.P. – WIESMAN, Z. 2004. Effect of Nutri-Vant-PeaK foliar spray on plant development, yield, and fruit quality in greenhouse tomatoes. In *Scientia Horticulturae*, vol. 102, pp. 177–188.
- COSKUN, D. – BRITTO, D.T. – KRONZUCKER, H.J. 2014. The physiology of channel-mediated K^+ acquisition in roots of higher plants. In *Physiologia Plantarum*, vol. 151, pp. 305–312.
- CUTTER, B.C. – MURPHEY, W.K. 1978. Effects of potassium on growth and wood anatomy of a Populus hybrid. In *Wood Fiber*, vol. 9, pp. 282–288.
- DOBROVICZKA, T. – PIRSELOVÁ, B. – MÉSÁROS, P. – BLEHOVÁ, A. – LIBANTOVÁ, J. – MORAVČÍKOVÁ, J. – MATUŠÍKOVÁ, I. 2013. Effects of cadmium and arsenic ions on content of photosynthetic pigments in the leaves of *Glycine max* (L.) Merrill. In *Pakistan Journal of Botany*, vol. 45, no. 1, pp. 105–110.
- FAGERIA, N.K. 2009. The use of nutrients in crop plants. Boca Raton, FL. : Taylor & Francis Group, 448 p. DOI: 10.201/9781420075113
- FARAGO, M.E. 2008. *Plants and the chemical elements : Biochemistry, uptake, tolerance and toxicity*. Wiley-Blackwell, 302 p. ISBN 978-3-527-61590-2
- GHASEMZADEH, A. – JAAFAR, H.Z.E. 2011. Effect of CO_2 enrichment on synthesis of some primary and secondary metabolites in ginger (*Zingiber officinale* Roscoe). In *International Journal of Molecular Sciences*, vol. 12, pp. 1101–1114.
- GHASEMZADEH, A. – JAAFAR, H.Z.E. – RAHMAT, A. – WAHAB, P.E.M. – HALIM, M.R.A. 2010. Effect of different light intensities on total phenolics and flavonoids synthesis and anti-oxidant activities in young ginger varieties (*Zingiber officinale* Roscoe). In *International Journal of Molecular Sciences*, vol. 11, pp. 3885–3897.
- GIUFFRIDA, F. – GRAZIANI, G. – FOGLIANO, V. – SCUDERI, D. – ROMANO, D. – LEONARDI, C. 2014. Effects of nutrient and NaCl salinity on growth, yield, quality and composition of pepper grown in soilless closed system. In *Journal of Plant Nutrition*, vol. 37, pp. 1455–1474.
- GOLCZ, A. – KUJAWSKI, P. – MARKIEWICZ, B. 2012. Yielding of red pepper (*Capsicum annuum* L.) under the influence of varied potassium fertilization. In *Actas Scientiarum Polonorum, Hortorum Cultus*, vol. 11, no. 4, pp. 3–15.
- GOLCZ, A. – KUJAWSKI, P. – ZIMOWSKA, H. 2004. Effect of potassium fertilizer type on the content of nutritive components in the leaves and fruits of hot pepper (*Capsicum annuum* L.). In *Roczniki Akademii Rolniczej Poznaniu – CCCLVI*, vol. 37, pp. 75–80.

- HANCOCK, R.D. – VIOLA, R. 2005. Biosynthesis and catabolism of L-ascorbic acid in plants. In *Critical Reviews in Plant Sciences*, vol. 24, pp. 167–188.
- IBRAHIM, M.H. – JAAFAR, H.Z. – RAHMAT, A. – RAHMAN, Z.A. 2011. Effects of nitrogen fertilization on synthesis of primary and secondary metabolites in three varieties of Kacip Fatimah (*Labisia pumila* Blume). In *International Journal of Molecular Sciences*, vol. 12, pp. 5238–5254.
- IBRAHIM, M.H. – JAAFAR, H.Z.E. – KARIMI, E. – GHASEMZADEH, A. 2012. Primary, secondary metabolites, photosynthetic capacity and antioxidant activity of the Malaysian herb Kacip Fatimah (*Labisia pumila* Benth) exposed to potassium fertilization under greenhouse conditions. In *International Journal of Molecular Sciences*, vol. 13, pp. 15321–15342.
- INTHICHACK, P. – NISHIMURA, Y. – FUKUMOTO, Y. 2012. Effect of potassium sources and rates on plant growth, mineral absorption, and the incidence of tip burn in cabbage, celery, and lettuce. In *Horticulture Environment and Biotechnology*, vol. 53, pp. 135–142.
- KAMBUROVA, K. – KIRILOV, P.L. 2008. Calculating the salt index of pK and NPK liquid fertilizers from potassium phosphates. In *Journal of Chemical Technology and Metallurgy*, vol. 43, pp. 227–230.
- KAUR, K. – GUPT, A.A.K. – KAUR, N. 2007. Effect of water deficit on carbohydrate status and enzymes of carbohydrate metabolism in seedlings of wheat cultivars. In *Journal of Biochemistry and Biophysics*, vol. 44, pp. 223–230.
- LESTER, G.E. – GRUSAK, M.A. 1999. Postharvest application of calcium and magnesium to honeydew and netted muskmelons: Effects on tissue ion concentrations, quality and senescence. In *Journal of the American Society for Horticultural Science*, vol. 124, pp. 545–552.
- LESTER, G.E. – JIFON, J.L. – MAKUS, D.J. 2006. Supplemental foliar potassium applications with or without a surfactant can enhance netted muskmelon quality. In *Hort Science*, vol. 41, pp. 741–744.
- LESTER, G.E. – JIFON, J.L. – ROGERS, G. 2005. Supplemental foliar potassium applications during muskmelon (*Cucumis melo* L.) fruit development can improve fruit quality, ascorbic acid and beta-carotene contents. In *Journal of the American Society for Horticultural Science*, vol. 130, pp. 649–653.
- LESTER, G.E. – JIFON, J.L. – MAKUS, D.J. 2010. Impact of potassium nutrition on postharvest fruit quality: Melon (*Cucumis melo* L.) case study. In *Plant Soil*, vol. 335, pp. 117–131.
- LI, W. – HE, P. – JIN, J. 2009. Potassium influenced phenylalanine ammonia-lyase, peroxidases and polyphenol oxidases in *Fusarium graminearum* infected maize (*Zea mays* L.). In *Proceedings of the International Plant Nutrition Colloquium XVI*, Davis, CA, USA.
- LICHTENTHALER, H.K. – WELLBURN, A.R. 1983. Determinations of total carotenoids and chlorophylls *a* and *b* of leaf extracts in different solvents. In *Biochemical Society Transactions*, vol. 11, pp. 591–592.
- LIN, D. – HUANG, D. – WANG, S. 2004. Effects of potassium levels on fruit quality of musk melon in soilless medium culture. In *Scientia Horticulturae*, vol. 102, no. 1, pp. 53–60.
- MAHMOUD, A.W.M. – ABDELAZIZ, S.M. – EL-MOGY, M.M. – ABDELDAYM, E.A. 2019. Effect of foliar ZnO and FeO nanoparticles application on growth and nutritional quality of red radish and assessment of their accumulation on human health. In *Agriculture (Poľnohospodárstvo)*, vol. 65, no. 1, pp. 16–29. DOI: 10.2478/agri-2019-0002
- MARSCHNER, P. – MARSCHNER, S. 2012. *Mineral Nutrition of Higher Plants*. 3rd ed. London, UK : Academic Press, pp. 178–189.
- NASSAR, M.A. – EL-SAHAR, K.F. 1998. *Botanical Preparations and Microscopy* (Microtechnique). Dokki, Giza, Egypt : Academic Bookshop, 219 p.
- NORHAIZA, M. – MAZIAH, M. – HAKIMAN, M. 2009. Antioxidative properties of leaf extracts of popular Malaysian herb, Labisiapumila. In *Journal of Medicinal Plants Research*, vol. 3, pp. 217–223.
- O'TOOLE, J.C. – TREHARNE, K. – TURNIPSEED, M. – CROOKSTON, K. – OZBUN, J. 1980. Effect of potassium nutrition on leaf anatomy and net photosynthesis of *Phaseolus vulgaris* L. In *The New Phytologist*, vol. 84, pp. 623–630.
- PENG, J. – LIU, J. – ZHANG, L. – LUO, J. – DONG, H. – MA, Y. – ZHAO, X. – CHEN, B. – SUI, N. – ZHOU, Z. – MENG, Y. 2016. Effects of soil salinity on sucrose metabolism in cotton leaves. In *Plos ONE*, vol. 11, no. 5: e0156241.
- PERVEZ, H. – MAKHDUM, M.I. – ASHRAF, M. – SHABAB, U.D. 2006. Influence of potassium nutrition on leaf area index in cotton (*Gossypium hirsutum* L.) under an arid environment. In *Pakistan Journal of Botany*, vol. 38, no. 4, pp. 1085–1092.
- PIPER, C.S. 1947. *Soil and Plant Analysis*. Adelaide, UK : The University of Adelaide, 368 p.
- PREGL, F. 1945. *Quantitative-organic Micro-analysis*. 4th ed., London : J. and A. Churchill Ltd.
- QUA, C. – LIUA, C. – GONGA, X. – LI, C. – HONG, M. – WANG, L. – HONG, F. 2012. Impairment of maize seedling photosynthesis caused by a combination of potassium deficiency and salt stress. In *Environmental and Experimental Botany*, vol. 75, pp. 134–141.
- SALAMA, S. – TRIVEDI, S. – BUSHEVA, M. – ARATA, A.A. – GRAB, G. – ERDEI, L. 1994. Effects of NaCl salinity on growth, cation accumulation, chloroplast structure and function in wheat cultivars differing in salt tolerance. In *Journal of Plant Physiology*, vol. 144, pp. 241–247.
- SHEHATA, S.A. – EL-MOGY, M.M. – MOHAMED, H.F.Y. 2019. Postharvest quality and nutrient contents of long sweet pepper enhanced by supplementary potassium foliar application. In *International Journal of Vegetable Science*, vol. 25, no. 2, pp. 196–209.
- SHUI, Y.C. – FENG, X. – YAN, W. 2009. Advances in the study of flavonoids in *Ginkgo biloba* leaves. In *Journal of Medicinal Plants Research*, vol. 3, pp. 1248–1252.
- SUN, J. – LI, C.H. – SUN, H.Y. – CAO, M.J. – WANG, X.G. 2011. The effect of low potassium stress on growth and development of different soybean genotypes. In *Chinese Journal of Soil Science*, vol. 42, pp. 431–434.
- SWAIN, T. – HILLIS, W.E. 1959. The phenolic constituents of *Prunus domestica* L. The quantitative analysis of phenolic constituents. In *The Journal of the Science of Food and Agriculture*, vol. 10, pp. 63–68.
- TRIPURA, P. – KUMAR, S. – VERMA, R. 2017. Effect of potassium humate and bio-inoculants on nutrient content, uptake and quality of cowpea (*Vigna unguiculata* (L.) Walp. In *International Journal of Current Microbiology and Applied Sciences*, vol. 6, no. 2, pp. 1735–1741.
- ZAHOR, R. – DONG, H. – ABID, M. – ZHAO, W. – WANG, Y. – ZHOU, Z. 2017. Potassium fertilizer improves drought stress alleviation potential in cotton by enhancing photosynthesis and carbohydrate metabolism. In *Environmental and Experimental Botany*, vol. 137, pp. 73–83.
- ZHAO, D. – OOSTERHUIS, D.M. – BEDNARZ, C.W. 2001. Influence of potassium deficiency on photosynthesis, chlorophyll content, and chloroplast ultrastructure of cotton plants. In *Photosynthetica*, vol. 39, pp. 103–109.

Received: October 20, 2019
Accepted: June 6, 2019