

Effect of calcium, potassium and some antioxidants on growth, yield and storability of sweet potato:

1- Vegetative growth, yield and tuber root characteristics.

El-Seifi, S. K.¹; M. A. Hassan¹; Sawsan M. H. Serg¹; U. M. Saif El-Deen² and M. A. Mohamed¹

¹ Dept. of Hort., Fac. of Agric., Suez Canal Univ. Ismailia, Egypt.

² Veg. Res. Dep., Hort. Res. Inst., Agric. Res. Center, Giza, Egypt.

Abstract

Two field experiments were carried out at El-Bramoon Agricultural Research farm of Mansoura Horticultural Research station, during the two successive summer seasons of 2011 and 2012 on sweet potato (*Ipomoea batatas*, L.) plants cv. Beaugard. The aim of this study was to study the effect of foliar spray of calcium at (0, 1000 and 2000 ppm), potassium fertilization at (0, 48, 72 kg K₂O/fed.), and foliar spray of antioxidants (control, ascorbic acid at 200 ppm and salicylic acid at 200 ppm) on plant growth, yield and its components as well as tuber root characters. The obtained results showed that foliar spray of only 2000 ppm of calcium or with the interaction among 1000 ppm of calcium, potassium fertilization at 72 kg K₂O/fed. and foliar spray of antioxidants as ascorbic acid at 200 ppm or salicylic acid at 200 ppm recorded the highest values of the above-cited indices compared with the control. Positive interaction between foliar spray of calcium and potassium fertilization and foliar spray of antioxidants were often observed.

The best results were obtained by foliar spray of only 2000 ppm of calcium or with the interaction among 1000 ppm of calcium, potassium fertilization at 72 kg K₂O/fed. and foliar spray of antioxidants as ascorbic acid at 200 ppm or salicylic acid at 200 ppm.

Key words: sweet potato (*Ipomoea batatas*, L.), foliar spray, antioxidants, ascorbic acid, salicylic acid.

Introduction

Sweet potato (*Ipomoea batatas* L.) is a dicotyledonous root crop and a member of the family Convolvulaceae. Moreover, sweet potato is the seventh most important food crop in the worldwide, after wheat, rice, maize, potato, barley and cassava. The primary importance of sweet potato is cultivated in poor regions of the world. It is the fourth most important food crop in developing tropical countries and is grown in most of the tropical and subtropical regions of the earth, where the vine, as well as the roots, is consumed by humans and livestock (Woolfe, 1992).

In Egypt, it is considered a very important popular vegetable crop, it has been generally cultivated for both food and starch manufactures, while the foliage parts and other refuse are utilized in feeding. Great efforts have been directed to improve sweet potato production and quality for the purpose of increasing exported yield. The applied Ca, K and antioxidants are among the major factors affecting plant growth and tuber root yields of sweet potato (El-Sayed 1991; Abd El-Baky *et al.*, 2010., Njiti *et al.*, 2013).

Calcium is an essential macronutrient required for plant growth and has been implicated as a factor influencing tuber quality (Lang *et al.*, 1999). Moreover, calcium has attracted much interest in plant physiology and molecular biology because of its function as a second messenger in the signal conduction between environmental factors and plant

responses in terms of growth and development (Reddy, 2001). Moreover, Ca²⁺ plays a pivotal role in membrane stabilization and in regulation of enzymes synthesis e.g. protein-kinase or phosphatase (Schmitz-Eiberger *et al.*, 2002).

Potassium is an essential plant nutrient that plays a very important role in plant growth and development. Its role is well documented in photosynthesis, increasing enzyme activity, improving synthesis of protein, carbohydrates and fats, translocation of sugars, enabling their ability to resist pests and diseases (Dkhil *et al.*, 2011). Also, potassium has an established reputation as a major controlling effect on tuber production in plant and it is the most important nutrient element needed by sweet potato in terms of nutrient uptake per unit area per unit tuber production. Since sweet potato is generally grown on highly weathered and leached soils where available K status is low, management of K assumes greatest significance (Byju and George, 2005).

Ascorbic acid (Vit. C) has a wide range of important functions as antioxidant defense, photoprotection, regulation of photosynthesis, affects nutritional cycle's activity in higher plants, electron transport system, as a cofactor for a large number of key enzymes in plants, also developmental senescence, programmed cell death and responses to pathogens (Blokhina *et al.*, 2003).

Salicylic acid (SA) naturally occurs in plants in very low amounts and participates in the regulation of physiological processes in plant such as stomatal

closure, photosynthesis, transpiration, nutrient uptake, chlorophyll and protein synthesis, inhibition of ethylene biosynthesis, resistance to pathogens plant disease and increased longevity of storage period (**Hayat and Ahmad, 2007**).

From the foregoing, the present study is very important to evaluate the effects of different rates of calcium fertilizer as foliar spray with different rates of potassium fertilizer as soil application either alone or in combination with some antioxidants; i.e., salicylic acid and ascorbic acid as foliar spray on plant growth, yield and tuber root characteristics of sweet potato plants cv. Beauregard.

Materials and Methods

Two field experiments were carried out at El-Bramoon farm of Mansoura Horticultural Research

station, during the two successive summer seasons of 2011 and 2012. The experiments were designed to investigate the effects of some nutrients treatments namely calcium and potassium besides two antioxidants; i.e., ascorbic and salicylic acid along with their interactions, on plant growth, yield and its components, as well as some chemical constituents and tuber roots storability of sweet potato (*Ipomoea batatas*, L.) cv. Beauregard.

Experimental Soil Analysis:

Randomized samples were collected from the experimental soil at 0.0 to 50.0 cm depth, before planting to determine its physical and chemical properties in accordance to the methods of **Black (1965) and Jakson (1967)**, respectively. Data of soil analysis is presented in Table (1):

Table 1. Some physical and chemical properties of experimental soil.

Soil properties	Value	Soil properties	Value
Physical		Soluble anions (meq/l)	
Coarse sand	7.71 %	CL ⁻	3.56
Fine sand	18.14 %	HCO ₃	3.20
Silt	33.65 %	CO ₃ ⁻²	0.00
Clay	40.50 %	SO ₄ ⁻²	5.16
Texture	Clay-loam	Soluble cations (meq/l)	
Chemical		Ca ⁺²	4.03
Organic matter (%)	1.95	Mg ⁺²	1.35
CaCO ₃	4.55	Na ⁺	1.21
E.C. (dsm ⁻¹ at 25°C)*	1.12	K ⁺	5.33
PH (1:2.5 w/v)**	7.91		
Total – N (%)	0.20		
Available – P (ppm)	11.72		

*E.C: Electrical conductivity (in 1:5 soil water extract).

**In the 1:2.5 soil/water suspension.

The values are the average of the two growing seasons.

Experimental design and tested treatments:

The experiments were designed as split-split-plot with 3 replicates. The different rates of calcium occupied the main plots, which subsequently subdivided into 3 sub-plots; each contained one of the potassium rates, while antioxidants treatments were assigned to the sub-sub-plots.

Each sub-sub-plot area 17.5 m² and contained 5 rows, with 5 m in length and 0.7 m in width for each row. The experiment included 27 treatments which were 3 calcium rates (tap water, 1000 and 2000 ppm), 3 potassium rates (0, 48 and 72 kg K₂O/fed.) and 3 rates of antioxidants (tap water, ascorbic acid at 200 ppm and salicylic acid at 200 ppm).

Time and method of treatments:

- Calcium: Calcium citrate (21 %) was used as source of calcium at the rates of 0, 4.76 and 9.52 g. calcium citrate were dissolved in litter distilled water to obtain calcium at the rates of 0, 1000 and

2000 ppm, respectively and applied to plants as foliar spray at 60 and 90 days after sowing.

- Potassium: Potassium sulphate (48 %) was used as source of potassium at the rates of 0, 48 and 72 kg K₂O/fed., were obtained from 0, 100 and 150 kg potassium sulphate, respectively were equally divided and applied at planting and 30 days later.
- Antioxidants: Antioxidants were obtained from El Nasr Pharmaceutical Chemicals Co. Egypt and used at the rates of 0.2 g. ascorbic was dissolved in litter distilled water and 0.2 g. salicylic acid was dissolved in alcohol and added to litter distilled water to obtain the rates of ascorbic acid at 200 ppm and salicylic acid at 200 ppm, applied to plants as foliar spray at 15, 45, 75 days after sowing.

Cultural practices:

Sweet potato stem cuttings, about 20 cm length, were planted on the third top of slope ridges, at 25 cm apart, on the 20, 21 of April of both growing seasons of the study. Growing plants were

fertilized with 300 kg/fed. Calcium super phosphate (15.5 % P₂O₅) and 200 kg/fed. ammonium sulphate (20.5 % N). Other inter-cultural practices including weed and pest control will be followed as instructed by the Ministry of Agriculture. Harvesting of tuber roots was done on the 23, 24 of August (125 days after planting) in both seasons.

Recorded data:

1- Vegetative growth parameters:

Five representative plants were randomly picked up from sub-sub-plot, 100 days after planting to measure, plant length, number of branches/plant, leaf area/plant (according to the method of **Koller, 1972**), dry weight per plant and total chlorophyll a + b (according to the method of **Moran, 1982**).

2- Yield and its components:

At harvest, 125 days from planting, all tuber roots of plants of each sub-sub-plots were dug up, classified into two categories; i.e., marketable and non-marketable roots then weighted to determine the total yield per feddan (tons). Marketable roots have a diameter of 3.5 to 6.5 cm, while non-marketable roots have a diameter of less than 3.5 cm or more than 6.5 cm according to the method described by **Grang (1963)**. In addition, plant yield as tuber root number and weight (kg) was determined.

3- Tuber root characters:

Tuber root samples (each of 10 storage roots) were randomly chosen at harvesting time from each treatment, to determine average tuber root weight (g), length (cm), diameter (cm) and shape (length/diameter). Dry matter percentage was determined by drying 100 gm fresh tuber roots at 70 °C for until constant weight is obtained.

Statistical analysis:

All recorded data were subjected to statistical Analysis of Variance and least significance differences (Duncan's) at 0.05 level of probability were used to separate means, as mentioned by **Snedecor and Cochran (1980)**.

Results and Discussion

1- Vegetative growth parameters:

Data presented in Table 2 show that vine length, leaf area, canopy dry weight/plant and total chlorophyll content of leaves were significantly increased, in both growing seasons, in response to foliar spray of calcium at 2000 ppm compared with the control except for number of branches/plant, in the first growing season, and there were no significant differences between foliar spray of calcium at 1000 or 2000 ppm on number of branches/plant in both growing seasons and canopy dry weight/plant in the first growing season. Also

there were no significant differences between foliar spray of calcium at 1000 ppm and the control on vine length in both growing seasons and number of branches/plant in the first growing season. The positive effect of calcium on plant vegetative growth parameters might be due to the calcium function as a second messenger in the signal conduction between environmental factors and plant responses in terms of growth and development (**Reddy, 2001**).

Data in Table 2 also show that vegetative growth of sweet potato plants received 72 kg K₂O/fed. fertilizer was significantly improved compared with the control plants. It is also clear from the obtained data that increasing the rate of applied K₂O from 48 to 72 kg/fed. was associated with significant simulative effects on plant growth, except for number of branches/plant in the first growing season, also there were no significant differences between applied K₂O at 48 and the control on number of branches/plant in the first growing season. The application of 72 kg K₂O/fed. were superior, it is significantly increased vine length, number of branches, leaf area, canopy dry weight/plant and total chlorophyll content of leaves, compared with the control treatment, in both growing seasons. These increases may be due to potassium role in physiological processes inside the plant, photosynthesis; increasing enzyme activity (K is required as Co-factor for different enzymes. It also helps to main electroneutrality in plant cells), improving synthesis of protein, carbohydrates and fats, translocation of sugars, enabling their ability to resist pests and diseases (**Dkhil et al., 2011**). Moreover, potassium control of ionic balance, regulation of plant stomata and water use, activation of plant enzymes to metabolize carbohydrates for the manufacture of amino acids and proteins, increases root growth (**Marschner, 2013**). The increase in leaves and shoots number due to mineral fertilization might be referred to the favorable effect of N, P and K on the meristematic activity of the sweet potato plant tissues.

These results are in agreement with those of **Mukhopadhyay et al., (1992)**, **Chakrabarty et al. (1993)**, **Prasad et al. (1997)** and **Al-Easily (2002)** on sweet potatoes, who indicated that vegetative growth of sweet potato plants was increased as potassium levels increased. In addition, **Abd El-Baky et al. (2010)** reported that potassium fertilizer had positive effect on sweet potato plants. The highest values of vegetative growth characters; i.e., vine length, number of leaves and branches, fresh and dry weight of leaves and branches as well as total fresh weight and leaves area were recorded in plants received 150 kg k₂O/fed.

Data presented in Table 2 reveal that foliar spray of sweet potato with salicylic acid and ascorbic acid at 200 ppm led to significant increases in vine length, number of branches, leaf area, canopy dry weight/plant and total chlorophyll contents of leaves

as compared with the control, in both growing seasons. Also the highest values of vine length, leaf area, canopy dry weight/plant and total chlorophyll contents of leaves were obtained from foliar spray of sweet potato with ascorbic acid at 200 ppm while the highest values of number of branches/plant were exhibited from foliar spray of sweet potato with salicylic acid at 200 ppm. There were significant differences between both antioxidant of all vegetative growth parameters mentioned above. The superiority effect of ascorbic acid may be due to its wide range of important functions as antioxidant defense, photoprotection, regulation of photosynthesis, its role in nutritional cycle's activity in higher plants, electron transport system and as a cofactor for a large number of key enzymes in plants (Blokhina *et al.*, 2003). Also, the effectiveness of any given antioxidant in the plant depends on which free radical is involved, and where the target of

damage is. Thus, while in one particular system an antioxidant may protect against free radicals, in other systems it could have no effect at all, or in certain circumstances, an antioxidant even act a "Pro-oxidant" that generates toxic oxygen species (Munne-Bosch, 2005). Similar results were reported by Arisha (2000) and Gad El-Hak *et al.* (2002) on potato, Bardisi (2004) and El-Morsy *et al.* (2010) on garlic and Orabi and Mekki (2008) on sugar beet, who pointed out that the use of ascorbic acid markedly increased shoot growth, fresh and dry weight of plants, compared with untreated plants. Similarly, WenYing *et al.* (2008) on sweet potato, found that pre-planting application of salicylic acid significantly increased certain vegetative plant characteristics such as foliage fresh and dry weight/plant and plant height compared with untreated plants.

Table 2. Vegetative growth parameters of sweet potato plants as affected by calcium, potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments	Parameters									
	Vine length (cm)		Number of branches/plant		Leaf area/plant (m ²)		Canopy dry weight/Plant (g)		Total Chlorophyll (A+B) (mg/g. FW)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Calcium										
Control	170.17 b	168.50 b	16.20 a	14.80 b	0.71 c	0.68 c	241.50 b	235.22 c	3.93 c	4.21 c
1000 ppm	171.71 b	170.43 b	17.98 a	16.86 a	0.86 b	0.84 b	256.23 a	254.12 b	4.25 b	4.43 b
2000 ppm	176.36 a	172.94 a	18.79 a	18.00 a	0.90 a	0.88 a	257.75 a	255.96 a	4.43 a	4.59 a
Potassium										
Control	156.98 c	157.86 c	16.21 b	14.39 c	0.69 c	0.65 c	219.05 c	210.19 c	3.73 c	3.94 c
48 kg K ₂ O/fed.	173.62 b	169.16 b	17.91 ab	16.60 b	0.81 b	0.81 b	257.40 b	253.20 b	4.22 b	4.46 b
72 kg K ₂ O/fed.	187.65 a	184.84 a	18.84 a	18.67 a	0.97 a	0.95 a	279.04 a	281.92 a	4.65 a	4.82 a
Antioxidants										
Control	160.88 c	158.44 c	13.81 c	13.84 c	0.68 c	0.65 c	220.79 c	213.92 c	3.79 c	4.04 c
Salicylic acid	175.67 b	172.74 b	20.63 a	18.76 a	0.83 b	0.82 b	247.35 b	246.27 b	4.27 b	4.43 b
Ascorbic acid	181.69 a	180.69 a	18.52 b	17.05 b	0.95 a	0.94 a	287.33 a	285.11 a	4.54 a	4.75 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test. Salicylic acid and Ascorbic acid were applied at 200 ppm.

The effect of the interaction between calcium with potassium on plant vegetative growth parameters of sweet potato is presented in Table 3. The interaction had a positive significant effect on vine length, number of branches, leaf area, canopy dry weight/plant and total chlorophyll content in plant leaves in both growing seasons. Results also indicated that plants treated with foliar spray of calcium at 1000 ppm and 72 kg K₂O/fed. gave the highest values of vegetative growth parameters in both growing seasons, followed by calcium at 2000 ppm and 72 kg K₂O/fed. while the untreated plants (control) yielded the lowest values in both growing seasons, respectively. There were no significant differences between spray of calcium at 1000 and 2000 ppm with 72 kg K₂O/fed. on vine length,

number of branches, leaf area/plant and total chlorophyll, in both seasons. There were no significant differences between sprayed of calcium at 1000 or 2000 ppm with 72 kg K₂O/fed. and calcium at 0 ppm (control) with 72 kg K₂O/fed. on vine length, in both growing seasons and number of branches/plant in the second growing season. Also there were no significant differences between spray of calcium at 1000 ppm with 48 or 72 kg K₂O/fed. and spray of calcium at 2000 ppm with 0 or 48 or 72 kg K₂O/fed. on number of branches/plant, in the first growing season and there were no significant differences between spray of calcium at 0 ppm (control) or 1000 ppm with 72 kg K₂O/fed. and spray of calcium at 2000 ppm with 48 or 72 kg K₂O/fed. on number of branches/plant, in the second

growing season. Similar results were reported by **Gashti et al. (2012)** on peanut (*Arachis hypogaea* L.), they said that efficient application of fertilizers,

especially potassium along with essential elements such as calcium and sulfur is an important factor for increasing of growth.

Table 3. Vegetative growth parameters of sweet potato plants as affected by the interactions between calcium and potassium at different rates during 2011 and 2012 growing seasons.

		Parameters									
Ca.	Po.	Vine length (cm)		Number of branches/plant		Leaf area/plant (m ²)		Canopy dry weight/Plant (g)		Total Chlorophyll (A+B) (mg/g. FW)	
		2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	152.74 e	156.20 d	15.35 d	12.86 e	0.59 g	0.54 h	212.35 h	200.75 i	3.32 g	3.64 g
	48 kg K ₂ O/fed.	170.97 c	166.80 c	16.31 cd	14.31 de	0.69 f	0.68 f	240.21 e	235.41 f	3.98 e	4.32 d
	72 kg K ₂ O/fed.	186.81 a	182.50 a	16.93 bcd	17.22 abc	0.84 c	0.83 d	271.95 c	269.52 c	4.48 b	4.68 b
1000 ppm	Control	155.74 e	156.90 d	15.64 d	14.40 de	0.72 e	0.64 g	216.62 g	209.36 h	3.77 f	3.97 f
	48 kg K ₂ O/fed.	170.12 c	167.80 bc	18.46 abc	16.73 bcd	0.84 c	0.86 c	265.11 d	260.18 e	4.23 c	4.43 c
	72 kg K ₂ O/fed.	189.26 a	186.60 a	19.84 a	19.46 a	1.03 a	1.01 a	286.98 a	292.83 a	4.76 a	4.90 a
2000 ppm	Control	162.45 d	160.50 d	17.64 abcd	15.91 cd	0.77 d	0.75 e	228.18 f	220.46 g	4.09 d	4.22 e
	48 kg K ₂ O/fed.	179.76 b	172.90 b	18.97 ab	18.75 ab	0.88 b	0.88 b	266.88 d	264.03 d	4.46 b	4.65 b
	72 kg K ₂ O/fed.	186.87 a	185.44 a	19.75 a	19.33 ab	1.03 a	1.01 a	278.19 b	283.41 b	4.72 a	4.89 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & Po. = Potassium.

Regarding the interaction between calcium and antioxidants; i.e., salicylic acid or ascorbic acid, the data presented in Table 4, show obviously that a significant increase in vegetative growth of sweet potato plants, expressed as vine length, number of branches, leaf area, canopy dry weight/plant and total chlorophyll content in plant leaves, in both growing seasons. The interaction between calcium at 1000 ppm or 2000 ppm and ascorbic acid at 200 ppm resulted in the highest values of vegetative growth parameters compared with the control except for vine length, in the first growing season. There were no significant differences between sprayed of calcium at 0 ppm (control), 1000 ppm and 2000 ppm with ascorbic acid at 200 ppm on vine length, in both seasons. Also there were no significant differences between sprayed of calcium at 2000 ppm with salicylic acid or ascorbic acid at 200 ppm on vine length, in the first growing season. For number of branches/plant, there were no significant differences between spray of calcium at 1000 or 2000 ppm with salicylic acid or ascorbic acid at 200 ppm and spray of calcium at 0 ppm (control) with salicylic acid at 200 ppm, in both growing seasons while there were no significant differences between sprayed of calcium at 1000 or 2000 ppm with ascorbic acid at 200 ppm on canopy dry weight/plant, in the second growing seasons. Similar results were reported by **El-Sherbini (2011)** on tomato (Castle Rock cv.), who concluded that spray plants with boron at 50 mg/l, calcium at 2000 mg/l, salicylic acid at 100 mg/l

and selenium at concentration of 50 mg/l mixed with vitamin E at concentration of 150 mg/l as foliar application improve tomato vegetative growth under high temperature conditions in summer season.

The effects of the interactions among potassium and antioxidants namely salicylic acid or ascorbic acid on vegetative growth of sweet potato plants are recorded in Table 5. Results show that there is a positive effect for the interaction between potassium and antioxidants on all the studied vegetative growth characters of sweet potato plants in both growing seasons. The highest values of the studied vegetative growth characters were produced when 72 kg K₂O/fed. interacted with ascorbic acid (200 ppm) and the lowest values were produced with the control, except number of branches/plant, where the highest values were produced when 72 kg K₂O/fed. interacted with salicylic acid at 200 ppm. There were no significant differences between applied potassium at 72 kg K₂O/fed. plus sprayed with salicylic acid or ascorbic acid at 200 ppm on vine length, in the first growing season also there were no significant differences between applied potassium at 48 kg K₂O/fed. plus spray with salicylic acid at 200 ppm and applied potassium at 72 kg K₂O/fed. plus spray with salicylic acid or ascorbic acid at 200 ppm on number of branches/plant, in both growing seasons or applied potassium at 0 kg K₂O/fed. (control) plus spray with salicylic acid at 200 ppm, in the first growing season. The obtained results could be explained by the results of **WuZhong et al. (1997)**

who found that K application improved the quality of the products by increasing vitamin C (ascorbic acid) levels in taro plants.

Table 4. Vegetative growth parameters of sweet potato plants as affected by the interactions between calcium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments		Parameters									
		Vine length (cm)		Number of branches/plant		Leaf area/plant (m ²)		Canopy dry weight/plant (g)		Total Chlorophyll (A+B) (mg/g. FW)	
Ca.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Contr	Control	155.34 e	154.40 e	13.08 c	11.80 d	0.59 i	0.54 i	211.03 i	203.46 g	3.52 h	3.86 g
	Sa. acid	172.45 cd	170.90 c	19.48 a	17.77 ab	0.72 g	0.69 g	242.83 f	236.38 e	3.99 f	4.21 e
	As. acid	182.73 a	180.20 ab	16.02 b	14.82 c	0.81 e	0.83 e	270.64 c	265.83 b	4.26 e	4.57 c
1000 ppm	Control	159.64 e	157.60 de	13.64 bc	14.11 cd	0.69 h	0.65 h	224.43 h	219.70 f	3.88 g	4.02 f
	Sa. acid	175.54 bc	172.66 c	21.04 a	19.00 a	0.87 d	0.89 c	246.05 e	248.16 d	4.33 d	4.51 d
	As. acid	179.94 ab	181.03 a	19.26 a	17.48 ab	1.03 a	0.98 b	298.22 a	294.50 a	4.55 b	4.76 b
2000 ppm	Control	167.66 d	163.33 d	14.71 bc	15.62 bc	0.77 f	0.76 f	226.92 g	218.60 f	3.98 f	4.24 e
	Sa. acid	179.03 ab	174.65 bc	21.37 a	19.51 a	0.89 c	0.88 d	253.17 d	254.28 c	4.48 c	4.58 c
	As. acid	182.40 a	180.85 a	20.28 a	18.86 a	1.02 b	1.01 a	293.14 b	295.02 a	4.82 a	4.93 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

Table 5. Vegetative growth parameters of sweet potato plants as affected by the interactions between potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments		Parameters									
		Vine length (cm)		Number of branches/plant		Leaf area/plant (m ²)		Canopy dry weight/Plant (g)		Total Chlorophyll (A+B) (mg/g. FW)	
Po.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	146.54 f	146.43 f	12.44 f	11.60 e	0.54 i	0.49 g	200.29 h	188.27 h	3.40 h	3.58 g
	Sa. acid	158.15 e	158.13 e	19.35 ab	17.24 bc	0.73 g	0.67 f	219.73 g	212.94 g	3.77 g	3.95 f
	As. acid	166.24 d	169.03 d	16.84 cd	14.33 d	0.82 e	0.77 e	237.12 e	229.35 f	4.02 f	4.29 d
48 kg K ₂ O/fed.	Control	163.24 de	158.90 e	13.82 ef	13.73 de	0.69 h	0.68 f	223.15 f	213.24 g	3.80 g	4.08 e
	Sa. acid	176.38 bc	171.36 d	20.86 ab	18.66 abc	0.79 f	0.81 d	251.63 d	247.37 d	4.30 d	4.47 c
	As. acid	181.23 b	177.23 c	19.06 bc	17.40 bc	0.94 c	0.94 c	297.41 b	299.01 b	4.57 c	4.84 b
72 kg K ₂ O/fed.	Control	172.86 c	170.00 d	15.17 de	16.20 cd	0.82 d	0.78 e	238.95 e	240.25 e	4.18 e	4.46 c
	Sa. acid	192.48 a	188.72 b	21.68 a	20.37 a	0.97 b	0.97 b	270.69 c	278.51 c	4.74 b	4.87 b
	As. acid	197.60 a	195.82 a	19.66 ab	19.44 ab	1.11 a	1.11 a	327.47 a	326.99 a	5.04 a	5.13 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Po. = Potassium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

As for the interaction effect among the three studied factors, data in Table 6 reveal that vine length, number of branches, leaf area, canopy dry weight/plant and total chlorophyll content were significantly influenced by the interaction, in both growing seasons. Generally, plants treated with foliar spray of calcium at 1000 ppm, fertilized with 72 kg K₂O/fed. and sprayed with ascorbic acid at 200 ppm resulted in the highest values of studied vegetative growth characters except for number of branches/plant, in both growing seasons and there are no significant differences between sprayed of

calcium at 0 (control), 1000 and 2000 ppm with 72 kg K₂O/fed. plus sprayed with salicylic acid or ascorbic acid at 200 ppm on vine length, in both growing seasons of study. For number of branches/plant, there were no significant differences between spray of calcium at 0 ppm (control) with 48 or 72 kg K₂O/fed. plus sprayed with salicylic acid at 200 ppm, sprayed of calcium at 1000 ppm with 0 (control) or 48 or 72 kg K₂O/fed. plus sprayed with salicylic acid at 200 ppm and sprayed of calcium at 2000 ppm with 0 or 48 or 72 kg K₂O/fed. (control) plus spray with salicylic acid at 200 ppm, in both

growing seasons, there are no significant differences between sprayed of calcium at 1000 ppm with 48 or 72 kg K₂O/fed. plus sprayed with salicylic acid or

ascorbic acid at 200 ppm and sprayed of calcium at 2000 ppm with 0 (control) or 48 or 72 kg K₂O/fed.

Table 6. Vegetative growth parameters of sweet potato plants as affected by the interactions among calcium, potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

			Parameters										
Treatments			Vine length (cm)		Number of branches/plant		Leaf area/plant (m ²)		Canopy dry weight/Plant (g)		Total Chlorophyll (A+B) (mg/g. FW)		
Ca.	Po.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	
Control	Control	Control	139.80 p	145.80 j	12.26 i	9.93 h	0.43 s	0.37 u	189.27 s	180.35 t	3.05 n	3.28 p	
		Sa. acid	150.30 no	152.40 hij	18.60 bcdefg	16.26 bcdefg	0.64 p	0.60 s	211.14 pq	200.82 q	3.34 m	3.63 o	
		As. acid	168.13 hijk	170.40 cdef	15.20 fg	12.40 fgh	0.71 n	0.66 p	236.64 kl	221.08 n	3.58 k	4.01 lm	
	48 kg K ₂ O/fed.	Control	155.50 mn	151.90 hij	13.06 hi	11.26 h	0.61 q	0.59 s	209.64 q	201.56 q	3.54 kl	3.97 m	
		Sa. acid	175.20 efgh	173.00 cde	19.60 abcde	17.33 abcde	0.68 o	0.61 r	239.89 k	238.42 l	4.12 f	4.26 hi	
		As. acid	182.23 cde	175.50 cde	16.26 defghi	14.33 cdefgh	0.79 k	0.83 k	271.09 f	266.25 i	4.27 e	4.73 de	
	72 kg K ₂ O/fed.	Control	170.73 ghij	165.50 efg	13.93 hi	14.20 cdefgh	0.85 i	0.65 q	234.18 lm	228.48 m	3.97 gh	4.35 h	
		Sa. acid	191.86 ab	187.30 ab	20.26 abcde	19.73 ab	0.73 m	0.86 h	277.47 e	269.92 h	4.52 d	4.73 de	
		As. acid	197.83 a	194.70 a	16.60 cdefgh	17.73 abcd	0.94 f	0.99 d	304.19 d	310.16 e	4.94 b	4.98 c	
	1000 ppm	Control	Control	144.46 op	142.80 j	12.20 i	11.93 gh	0.50 r	0.44 t	197.42 r	190.21 s	3.45 lm	3.62 o
			Sa. acid	159.03 lmn	161.10 fgh	18.73 abcdefg	17.33 abcde	0.76 l	0.70 o	215.18 o	209.85 p	3.80 ij	4.08 kl
			As. acid	163.73 jklm	166.80 efg	16.00 efg	13.93 defgh	0.88 g	0.79 l	237.25 kl	228.02 m	4.05 fg	4.22 ij
48 kg K ₂ O/fed.		Control	160.06 klm	157.70 ghi	13.46 hi	13.66 defgh	0.71 n	0.66 pq	229.73 n	216.96 o	3.91 hi	4.00 lm	
		Sa. acid	173.13 fghi	166.60 efg	21.40 ab	18.60 abc	0.82 j	0.94 e	254.12 i	249.77 k	4.27 e	4.48 g	
		As. acid	177.16 defg	179.10 bc	20.53 abcd	17.93 abcd	1.00 e	0.99 d	311.48 c	313.82 d	4.52 d	4.80 d	
72 kg K ₂ O/fed.		Control	174.40 efgh	172.30 cde	15.26 fg	16.73 abcdef	0.86 hi	0.84 j	246.15 j	251.95 jk	4.27 e	4.45 g	
		Sa. acid	194.46 a	190.30 a	23.00 a	21.06 a	1.04 c	1.03 c	268.85 fg	284.88 f	4.93 b	4.97 c	
		As. acid	198.93 a	197.20 a	21.26 ab	20.60 ab	1.20 a	1.17 a	345.94 a	341.66 a	5.09 a	5.27 a	
2000 ppm		Control	Control	155.36 mn	150.70 ij	12.86 hi	12.93 efgh	0.79 k	0.66 p	214.18 op	194.26 r	3.69 j	3.86 n
			Sa. acid	165.13 ijkl	160.90 fgh	20.73 abc	18.13 abcd	0.86 hi	0.72 n	232.88 mn	228.17 m	4.15 f	4.15 jk
			As. acid	166.86 hijkl	169.90 cdef	19.33 abcdef	16.66 abcdef	0.76 l	0.87 g	237.48 kl	238.95 l	4.44 d	4.64 ef
	48 kg K ₂ O/fed.	Control	174.16 efgh	167.10 defg	14.93 ghi	16.26 bcdefg	0.86 h	0.77 m	230.08 n	221.21 n	3.96 gh	4.27 hi	
		Sa. acid	180.83 def	174.50 cde	21.60 ab	20.06 ab	1.03 d	0.88 f	260.88 h	253.92 j	4.50 d	4.68 ef	
		As. acid	184.30 bcd	177.10 cd	20.40 abcd	19.93 ab	0.88 g	0.99 d	309.68 c	316.96 c	4.92 b	5.00 c	
	72 kg K ₂ O/fed.	Control	173.46 efghi	172.20 cde	16.33 defghi	17.66 abcd	1.03 cd	0.85 i	236.51 kl	240.34 l	4.29 e	4.60 f	
		Sa. acid	191.13 abc	188.56 ab	21.80 ab	20.33 ab	1.18 b	1.03 c	265.77 g	280.75 g	4.78 c	4.92 c	
		As. acid	196.03 a	195.56 a	21.13 ab	20.00 ab	0.79 k	1.16 b	332.28 b	329.15 b	5.09 a	5.16 b	

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & Po. = Potassium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

plus spray with salicylic acid or ascorbic acid at 200 ppm, in both growing seasons, also there are no significant differences between spray of calcium at 0 (control) ppm with 72 kg K₂O/fed. plus spray with ascorbic acid at 200 ppm, spray of calcium at 1000 ppm with 72 kg K₂O/fed. and without antioxidants (control) and spray of calcium at 2000 ppm with 72 kg K₂O/fed. and without antioxidants (control), in the second growing season. For total chlorophyll, there were no significant differences between spray of calcium at 1000 or 2000 ppm with 72 kg K₂O/fed. plus spray with ascorbic acid at 200 ppm, in the first growing season.

2- Yield and its components:

Concerning the effect of calcium on yield and its components, data presented in Table 7 indicate that application of calcium at 2000 ppm as foliar spray was generally more effective than the control on yield characters, where it exerted significant increases in total yield by 0.93 %, 0.86 % and marketable yield by 1.29 %, 1.26 % in the first and second growing seasons, respectively. Calcium, also significantly increased total yield/plant, in both growing season, and significantly reduced non-marketable yield by 0.36 %, 0.40 % in the first and second growing seasons, respectively, while number of tubers roots/plant was not significantly influenced by calcium rates in both growing seasons. The superior effects of the used rate of 2000 ppm Ca in enhancing the aforesaid yield characters occurs herein may be due to its physiological effects on sweet potato plants which was found and discussed in the previous parts of plant vegetative growth, which positively affected root tuber yield. Moreover, the improving effect of calcium on yield and its components might be due to that calcium is component of the middle lamella and is essential for intracellular membrane transport. Likewise, calcium is known to act as a signaling molecule that can regulate metabolism, controlling respiration, reducing ethylene production in plant (Marschner, 2013).

This is in coincidence with the findings of Clough (1994) who found that potato yield, size distribution, specific gravity and grade were significantly affected by Ca treatments, also Sulaiman *et al.* (2004) found that tuberous roots in sweet potato varieties at 90 and 120 day after plants were lighter at the high Ca of 28 mg Ca/L than the control of 10 mg Ca/L.

Data in Table 7 also show the effect of potassium on yield and its components of sweet potato. Irrespective of the unfertilized plants, increasing the supplied potassium from 48 to 72 kg K₂O/fed. significantly increased total yield by 1.36 % and 1.82

%, marketable yield/fed, tuber yield/plant and number of tuber roots/plant in both growing seasons. Non-marketable yield significantly reduced, in both growing seasons, by increasing potassium from 48 to 72 kg K₂O/fed. and there were no significant differences between applied K₂O at 48 and 72 kg/fed., also between applied K₂O at 0 (control) and 48 kg/fed. on number of tuber/plant in the second growing season. These increases may be due to that potassium has an established reputation as a major controlling effect on tuber production in plant and it is the most important nutrient element needed by sweet potato in terms of nutrient uptake per unit area per unit tuber production. Since sweet potato is generally grown on highly weathered and leached soils where available K status is low, management of K assumes greatest significance (Byju and George, 2005). Also, the yield increase as a result of K application was mainly due to the increase in root:top ratio which led to greater amount of photosynthate translocation to the storage roots causing their increase in size (George *et al.*, 2002). Moreover, the increase in total yield of sweet potato resulting from K fertilization might be attributed to its favorable effect on the vegetative growth, nutrient content, and DM accumulation throughout plant tissues, also this might be related to the favorable effects of K on photosynthetic pigments, that possibly increased the efficiency of photosynthesis and resulted in more accumulation of stored food in the tubers.

Similar results were reported by Gowda *et al.* (1990) who found that the application of 120 kg K₂O/ha. in 2 equal splits at basal and 30 days after planting produced a high yield of sweet potato, also Mukhopadhyay and Jana (1990) found that applying 75 K₂O/ha. to sweet potato as a basal dressing gave tuber yields of 16.0 t/ha. compared with 10.3 t/ha. without K, Mukhopadhyay *et al.* (1992) reported for sweet potato that number of tubers/plant (4.87) and tuber yield (18.16 t/ha.) were obtained from split application of 75 kg K₂O/ha. and JianWei *et al.* (2001) indicated that sweet potato yield and quality respond strongly to K applications.

As for the effect of antioxidants on yield and its components of sweet potato, data presented in Table 7 reveal that all studied characters of sweet potato yield and its components, except the non-marketable yield, were generally greater with antioxidants treatments than the control. Sweet potato plants sprayed with ascorbic acid at 200 ppm, exerted significant increases over those sprayed with salicylic acid in the total yield, marketable yield and tuber yield/plant in both growing seasons, however, the differences in number of tuber roots/plant did not reach the level of significance in both growing seasons. Non-marketable yield significantly reduced by antioxidants treatments, in both growing seasons. The highest total yield was obtained from plants

sprayed with ascorbic acid at 200 ppm. Plants sprayed with ascorbic acid at 200 ppm increased total yield by 1.75 % and 1.94 % compared with the untreated ones, in the first and second growing seasons, respectively. In additions, a non-marketable yield was reduced by ascorbic acid treatment than without antioxidants by 0.42 % and 0.36 % in both growing seasons. The superior effects of the used rate of 200 ppm ascorbic acid in enhancing the aforesaid yield characters occurs herein may be due to its physiological effects on sweet potato plants which was found and discussed in the previous parts of plant vegetative growth, which positively affected root tuber yield. Moreover, the favorable effect of ascorbic acid on yield and its components of sweet potato may be due to that ascorbic acid (Vit. C) has a wide range of important functions as antioxidant defense, photoprotection, regulation of photosynthesis, affects nutritional cycle's activity in

higher plants, electron transport system, as a cofactor for a large number of key enzymes in plants, also developmental senescence, programmed cell death and responses to pathogens (Blokina *et al.*, 2003).

Also, these results may be attributed to the role of citric acid; it is one of a series of compounds involved in the physiological oxidation of fats, proteins and carbohydrates to CO₂ and water as well as chelation of transition metals, e.g., citric acid. This kind of mode of action depends on the availability of metals in catalyzing amounts. Interference with this process of catalysis by chelation would be expected to have a strong effect on the progress of the radical reaction transition metal ions may either be activated by the chelator increasing the catalyzing potential or may be rendered inactive. The change brought depends on the metal and chelator (Abd Allah *et al.*, 2007).

Table 7. Yield and its components of sweet potato plants as affected by calcium, potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments	Characters									
	Yield/plant				Yield/fed.					
	Weight (g)		Number of tubers/plant		Marketable yield (ton/fed.)		Non-marketable yield (ton/fed.)		Total yield (ton/fed.)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Calcium										
Control	888.60 c	900.90 c	3.84 a	4.10 a	12.74 c	11.96 c	1.32 a	1.50 a	14.07 c	13.46 c
1000 ppm	918.20 b	928.40 b	4.02 a	4.32 a	13.68 b	12.77 b	1.06 b	1.22 b	14.74 b	13.99 b
2000 ppm	930.77 a	940.60 a	4.21 a	4.44 a	14.03 a	13.22 a	0.96 c	1.10 c	15.00 a	14.32 a
Potassium										
Control	789.36 c	872.27 c	3.68 c	3.84 b	12.53 c	11.57 c	1.29 a	1.47 a	13.83 c	13.05 c
48 kg K ₂ O/fed.	913.31 b	932.27 b	4.03 b	4.28 ab	13.66 b	12.59 b	1.12 b	1.26 b	14.78 b	13.86 b
72 kg K ₂ O/fed.	1034.89 a	965.35 a	4.35 a	4.74 a	14.26 a	13.78 a	0.92 c	1.08 c	15.19 a	14.87 a
Antioxidants										
Control	753.06 c	779.79 c	3.56 b	3.71 b	12.37 c	11.37 c	1.35 a	1.45 a	13.72 c	12.83 c
Salicylic acid	965.18 b	970.89 b	4.37 a	4.69 a	13.56 b	12.90 b	1.05 b	1.27 b	14.61 b	14.17 b
Ascorbic acid	1019.32 a	1019.21 a	4.14 a	4.45 a	14.53 a	13.67 a	0.93 c	1.09 c	15.47 a	14.77 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

Regarding the interaction effect of calcium with potassium on sweet potato yield and its components, data in Table 8 show that there were significant effects, in both growing seasons, on total and marketable yield as well as tuber roots weight/plant and number of tuber roots/plant. Non-marketable yield significantly reduced, in both growing seasons, as a result of the interaction of the applied calcium with potassium, generally, most studied characters of yield and its components had the highest values as a result of the interaction of 72 kg K₂O/fed. with foliar spray with calcium at 1000 ppm and there were no significance differences between 72 kg K₂O/fed. plus foliar spray with calcium at 1000 or 2000 ppm on

values of tuber yield/plant, marketable yield, non-marketable yield and total yield in both growing seasons, also there were no significant differences between foliar spray with calcium at 1000 or 2000 ppm plus applied K₂O at 48 or 72 kg/fed. and foliar spray with calcium at 0 ppm (control) plus applied K₂O at 72 kg/fed. on number of tuber/plant, in both growing seasons and there were no significant differences between foliar spray with calcium at 1000 or 2000 ppm plus applied K₂O at 0 kg/fed. (control) and foliar spray with calcium at 0 ppm (control) plus applied K₂O at 48 kg/fed. on number of tuber/plant, in the first season. Similar results were reported by Gashti *et al.* (2012) on peanut (*Arachis*

hypogaea L.), they showed that the yield of pod and kernel increased with increasing of calcium application along with potassium.

Table 8. Yield and its components of sweet potato plants as affected by the interactions between calcium and potassium at different rates during 2011 and 2012 growing seasons.

Treatments	Ca. Po.	Parameters									
		Yield/plant				Yield/plant					
		Weight (g)		Number of tubers/plant		Marketable yield (ton/fed.)		Non-marketable yield (ton/fed.)		Total yield (ton/fed.)	
		2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	762.17 g	844.05 f	3.33 b	3.57 d	11.32 g	10.90 g	1.50 a	1.70 a	12.83 g	12.61 f
	48 kg K ₂ O/fed.	883.28 d	909.82 d	3.88 ab	4.06 bcd	12.93 e	11.88 e	1.35 b	1.53 b	14.29 e	13.41 e
	72 kg K ₂ O/fed.	1020.33 b	948.82 b	4.31 a	4.66 ab	13.97 c	13.11b	1.11 d	1.26 d	15.08 b	14.37 b
1000 ppm	Control	784.94 f	874.04 e	3.66 ab	3.88 cd	12.65 f	11.36 f	1.26 c	1.48 c	13.92 f	12.84 f
	48 kg K ₂ O/fed.	926.18 c	934.92 c	4.02 ab	4.31 abc	13.98 c	12.78 c	1.08 d	1.18 f	15.07 b	13.97 cd
	72 kg K ₂ O/fed.	1043.46 a	976.23 a	4.37 a	4.77 a	14.41 a	14.16 a	0.82 f	0.99 h	15.24 a	15.15 a
2000 ppm	Control	820.97 e	898.71 d	4.06 ab	4.06 bcd	13.63 d	12.46 d	1.12 d	1.23 e	14.75 d	13.70 de
	48 kg K ₂ O/fed.	930.47 c	952.06 b	4.20 a	4.48 abc	14.07 b	13.12 b	0.93 e	1.07 g	15.00 c	14.19 bc
	72 kg K ₂ O/fed.	1040.87 a	971.02 a	4.37 a	4.77 a	14.40 a	14.08 a	0.83 f	0.99 h	15.24 a	15.07 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & Po. = Potassium.

Data illustrated in Table 9 show that total yield of sweet potato roots, marketable yield, plant tuber yield and number of tuber roots/plant significantly increased, while non-marketable yield significantly reduced, in both growing seasons, as a result of the interaction between calcium and antioxidants. The highest total yield, marketable yield and root yield/plant were obtained as a result of the interaction between foliar spray with calcium at 2000 ppm and foliar spray with ascorbic acid at 200 ppm while the highest number of tuber roots/plant were obtained as a result of the interaction between foliar spray with calcium at 2000 ppm and foliar spray with salicylic acid at 200 ppm. There were no significant differences between foliar spray with calcium at 0 (control) or 1000 or 2000 ppm plus foliar spray with salicylic acid or ascorbic acid at 200 ppm on number of tuber roots/plant, in both growing seasons and foliar spray with calcium at 2000 ppm without antioxidants (control) on number of tuber roots/plant, in the first growing season. There were no significant differences between foliar spray with calcium at 1000 or 2000 ppm plus foliar spray with ascorbic acid at 200 ppm on non-marketable yield, in the first growing season, also there were no significant differences between foliar spray with calcium at 0 (control) or 1000 ppm plus foliar spray with ascorbic acid at 200 ppm and foliar spray with calcium at 2000 ppm plus foliar spray with salicylic acid or ascorbic acid at 200 ppm on total yield, in the second growing season. These results are in agreement with those obtained by **El-Sherbini (2011)** concluded that spray tomato plants with boron at 50 mg/l, calcium at 2000 mg/l, salicylic acid at 100 mg/l (as antioxidant) and selenium at concentration of 50 mg/l mixed with

vitamin E at concentration of 150 mg/l as foliar application improve tomato fruit yield (ton/fed.).

Data presented in Table 10 show the interaction effect between potassium and antioxidants on sweet potato yield and its components. This interaction caused significant increase in total yield, marketable yield/fed, plant tuber yield and number of tuber roots/plant, in both growing seasons. On the other hand, non-marketable yield was significantly reduced as a result of the interaction, in both growing seasons. It is notable that plants fertilized with 72 kg K₂O/fed. with foliar sprayed with ascorbic acid at 200 ppm, achieved higher yield/fed, marketable yield and plant tuber yield compared with the control except number of tuber roots/plant, the highest values obtained by fertilizing with 72 kg K₂O/fed. with foliar spray with salicylic acid at 200 ppm. There were no significant differences between applied K₂O at 48 kg/fed. plus foliar sprayed with salicylic acid at 200 ppm and applied K₂O at 72 kg/fed. plus foliar spray with salicylic acid or ascorbic acid at 200 ppm on number of tuber roots/plant, in both growing seasons, also there were no significant differences between applied K₂O at 0 (control) or 72 kg/fed. plus foliar spray with salicylic acid at 200 ppm and applied K₂O at 48 kg/fed. plus foliar spray with ascorbic acid at 200 ppm on number of tuber roots/plant, in the first growing season. Such results were previously explained by **WuZhong et al. (1997)** on taro, showed that K application improved the quality of the produce by increasing vitamin C (ascorbic acid) levels, **Imas (1999)** showed that applying K fertilizer to potato significantly increased the vitamin C contents and **El-Morsy et al. (2010)** on garlic, showed that the

interactions between PK-rates and antioxidants had a significant effect on total yield and number of cloves/bulb in the second growing season only. Whereas, bulb weight, bulb diameter and clove

weight were significantly affected by the interaction in both growing seasons.

Table 9. Yield and its components of sweet potato plants as affected by the interactions between calcium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments		Parameters									
		Yield/plant				Yield/fed.					
		Weight (g)		Number of tubers/plant		Marketable yield (ton/fed.)		Non-marketable yield (ton/fed.)		Total yield (ton/fed.)	
Ca.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	724.74 i	765.27 g	3.33 c	3.60 c	11.21 h	10.27 e	1.64 a	1.69 a	12.85 i	11.96 e
	Sa. acid	937.36 f	935.71 e	4.24 ab	4.48 ab	13.04 f	12.05 d	1.26 c	1.52 b	14.30 f	13.58 c
	As. acid	1003.68 c	1001.71 c	3.95 abc	4.22 abc	13.97 c	13.57 b	1.07 d	1.28 d	15.04 c	14.85 a
1000 ppm	Control	758.95 h	784.66 f	3.53 bc	3.66 c	12.75 g	11.78 d	1.33 b	1.39 c	14.08 h	13.17 d
	Sa. acid	974.05 e	983.50 d	4.35 ab	4.75 a	13.65 d	13.01 c	0.96 e	1.19 e	14.61 e	14.21 b
	As. acid	1021.58 b	1017.03 b	4.17 ab	4.55 ab	14.65 b	13.50 b	0.88 f	1.07 f	15.53 b	14.58 a
2000 ppm	Control	775.48 g	789.43 f	3.82 abc	3.88 bc	13.14 e	12.07 d	1.10 d	1.29 d	14.24 g	13.37 cd
	Sa. acid	984.13 d	993.47 cd	4.53 a	4.84 a	13.99 c	13.64 b	0.93 e	1.09 f	14.92 d	14.73 a
	As. acid	1032.71 a	1038.88 a	4.28 ab	4.60 a	14.97 a	13.95 a	0.85 f	0.91 g	15.83 a	14.86 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

Table 10. Yield and its components of sweet potato plants as affected by the interactions between potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments		Parameters									
		Yield/plant				Yield/fed.					
		Weight (g)		Number of tubers/plant		Marketable yield (ton/fed.)		Non-marketable yield (ton/fed.)		Total yield (ton/fed.)	
Po.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	657.13 i	738.16 g	3.26 d	3.44 f	11.52 i	10.00 g	1.56 a	1.64 a	13.08 h	11.65 g
	Sa. acid	821.42 g	907.44 d	4.02 abcd	4.15 cde	12.62 g	11.86 e	1.20 c	1.45 b	13.82 g	13.31 e
	As. acid	889.54 e	971.20 c	3.77 bcd	3.93 def	13.46 e	12.86 d	1.13 d	1.32 c	14.59 e	14.19 d
72 kg K ₂ O/fed	Control	762.35 h	787.88 f	3.57 cd	3.71 ef	12.47 h	11.41 f	1.35 b	1.45 b	13.82 g	12.86 f
	Sa. acid	968.88 d	983.31 c	4.37 abc	4.71 abc	13.71 d	12.93 d	1.08 e	1.26 d	14.79 d	14.20 d
	As. acid	1008.71 c	1025.61 b	4.15 abc	4.44 bcd	14.80 b	13.44 c	0.94 f	1.07 e	15.74 b	14.52 c
48 kg K ₂ O/fed	Control	839.70 f	813.32 e	3.84 bcd	4.00 def	13.11 f	12.71 d	1.15 d	1.28 d	14.27 f	13.99 d
	Sa. acid	1105.24 b	1021.93 b	4.73 a	5.22 a	14.35 c	13.92 b	0.87 g	1.09 e	15.22 c	15.01 b
	As. acid	1159.73 a	1060.82 a	4.48 ab	5.00 ab	15.33 a	14.72 a	0.74 h	0.87 f	16.07 a	15.59 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Po. = Potassium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

Interaction effect among all studied factors; i.e., calcium, potassium and antioxidants on sweet potato yield and its components was presented in Table 11. The data indicate that total yield, marketable yield, plant tuber yield and number of tuber roots/plant were significantly influenced by the interaction, in both growing seasons. On the other hand, non-marketable yield was significantly reduced by the interaction, in both growing seasons. Plants sprayed with 1000 ppm calcium, received potassium at 72 kg K₂O/fed. plus sprayed with 200 ppm ascorbic acid produced the highest total yield, marketable yield

and plant tuber yield except number of tuber roots/plant in both growing seasons.

As for the interaction effect, it is obvious from the same data in Table 11 that all treatments were generally more effective in plants sprayed with 1000 ppm calcium than those sprayed with 2000 ppm calcium and the control. There were no significant differences between sprayed with 1000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus sprayed with 200 ppm ascorbic acid and sprayed with 2000 ppm calcium, applied potassium at 48 or 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid on

plant tuber yield as a weight, in the second growing season. There were no significant differences between spray with 2000 ppm calcium, applied potassium at 0 (control) or 48 or 72 kg K₂O/fed. plus spray with 200 ppm salicylic acid or ascorbic acid and spray with 0 (control) or 1000 ppm calcium, applied potassium at 0 (control) or 48 or 72 kg K₂O/fed. plus spray with 200 ppm salicylic acid or ascorbic acid on plant number of tuber roots/plant, in the first growing season, also there were no significant differences between spray with 2000 ppm calcium, applied potassium at 0 (control) or 48 or 72 kg K₂O/fed. without antioxidants (control) and spray with 0 (control) or 1000 ppm calcium, applied potassium at 48 or 72 kg K₂O/fed. without antioxidants (control) on plant number of tuber roots/plant, in the first growing season, on the other hand there were no significant differences between spray with 1000 or 2000 ppm calcium, applied potassium at 48 or 72 kg K₂O/fed. plus sprayed with 200 ppm salicylic acid or ascorbic acid and spray with 0 (control) ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm salicylic acid or ascorbic acid on plant number of tuber roots/plant, in the second growing season. Also there were no significant differences between sprayed with 1000 or 2000 ppm calcium, applied potassium at 0 kg K₂O/fed. (control) plus sprayed with 200 ppm salicylic acid and sprayed with 0 (control) ppm calcium, applied potassium at 48 kg K₂O/fed. plus sprayed with 200 ppm salicylic acid on plant number of tuber roots/plant, in the second growing season. There were no significant differences between sprayed with 1000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid and spray with 0 (control) or 2000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid on marketable yield, in the second growing season, on the other hand there were no significant differences between spray with 1000 or 2000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid and sprayed with 1000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm salicylic acid on non-marketable yield, in the first growing season, while in the second season there were no significant differences between spray with 1000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid and spray with 2000 ppm calcium, applied potassium at 48 or 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid, also for total yield there were no significant differences between spray with 1000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid and spray with 2000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid, in the first growing season, while in the second growing season there were no significant differences between spray with 1000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus

spray with 200 ppm salicylic acid or ascorbic acid and spray with 0 (control) or 2000 ppm calcium, applied potassium at 72 kg K₂O/fed. plus spray with 200 ppm ascorbic acid. The positive results of calcium on yield and its components might be due to that calcium is component of the middle lamella and is essential for intracellular membrane transport. Also, calcium is known to act as a signaling molecule that can regulate metabolism, controlling respiration, reducing ethylene production and mitigate the effect of heat and cold stresses on plant (Marschner, 2013). Potassium has an established reputation as a major controlling effect on tuber production in plant and it is the most important nutrient element needed by sweet potato in terms of nutrient uptake per unit area per unit tuber production. Since sweet potato is generally grown on highly weathered and leached soils where available K status is low, management of K assumes greatest significance (Byju and George, 2005). These results also, may be due to the simulative effect of ascorbic acid (Vit. C) which has a wide range of important functions as antioxidant defense, photoprotection, regulation of photosynthesis, affects nutritional cycle's activity in higher plants, electron transport system, as a cofactor for a large number of key enzymes in plants, also developmental senescence, programmed cell death and responses to pathogens (Blokhina *et al.*, 2003).

3- Tuber root characters:

Data illustrated in Table 12 show the physical properties of sweet potato roots, expressed as weight, length, diameter, shape and dry matter of tuber root. Application of calcium rates resulted in significant increases in average weight, average root length, diameter and dry matter of tuber root, in both growing seasons, while root shape increased significantly in the second growing season only and there were no significant differences between spray with 1000 ppm calcium and spray with 2000 ppm calcium on root shape, in the first growing season. The improvement effect of calcium may be due to that it is an essential macronutrient required for plant growth and has been implicated as a factor influencing tuber quality (Lang *et al.*, 1999). These results are accordance with those of Clough (1994) who found that potato size distribution, specific gravity and grade were significantly affected by Ca treatments.

Effect of potassium on tuber root characteristics was presented in Table 12. The obtained results revealed that weight, length, diameter and dry matter of tuber root were increased significantly as the applied potassium increased from 0 to 72 kg K₂O/fed. in the two growing seasons. However, all tested potassium levels did not significantly affect shape of tuber roots in the first growing season only, but in the second one the increase was significant and the highest values obtained from the control in both

growing seasons. The obtained increases in tuber root characteristics may be attributed to the role of potassium which has considered as a major controlling effect on tuber production in plant and it is the most important nutrient element needed by sweet potato in terms of nutrient uptake per unit area per unit tuber production. Since sweet potato is

generally grown on highly weathered and leached soils where available K status is low, management of K assumes greatest significance (Byju and George, 2005). Similar results were reported by Abd El-Baky *et al.* (2010) showed that potassium played an important role in yield and quality of sweet potato.

Table 11. Yield and its components of sweet potato plants as affected by the interactions among calcium, potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments			Parameters											
			Yield/plant				Marketable yield (ton/fed.)		Yield/fed.		Total yield (ton/fed.)			
Ca.	Po.	An.	Weight (g)		Number of tubers/plant		2011	2012	2011	2012	Non-marketable yield (ton/fed.)		2011	2012
Control	48 kg	Control	2011	601.90 q	725.13 m	2.93 c	3.20 f	10.00 u	8.98 m	1.80 a	1.88 a	11.80 q	10.86 m	
			2012	788.76 m	841.20 h	3.66 abc	3.93 cdef	11.65 s	10.92 k	1.42 de	1.67 bc	13.07 o	12.60 ij	
			As. acid	895.86 i	965.83 ef	3.40 abc	3.60 def	12.32 q	12.80 gh	1.29 f	1.56 d	13.61 m	14.37 de	
		O/fed.	2011	737.13 n	766.50 k	3.33 abc	3.60 def	11.08 t	10.22 l	1.66 b	1.71 b	12.74 p	11.94 kl	
			2012	929.50 h	967.13 ef	4.33 abc	4.46 abcde	13.13 n	11.97 ij	1.29 f	1.56 d	14.43 hi	13.53 gh	
			As. acid	983.23 g	995.83 d	4.00 abc	4.13 bcdef	14.57 f	13.44 def	1.11 gh	1.32 gh	15.68 c	14.77 cd	
	72 kg	Control	2011	835.20 kl	804.20 ij	3.73 abc	4.00 cdef	12.57 p	11.60 j	1.45 d	1.47 e	14.02 k	13.08 hi	
			2012	1093.83 e	998.80 d	4.73 a	5.06 abc	14.34 g	13.27 defg	1.06 hij	1.34 gh	15.41 d	14.61 de	
			As. acid	1131.96 c	1043.46 bc	4.46 ab	4.93 abc	15.01 c	14.46 ab	0.81 n	0.96 l	15.82 b	15.43 ab	
		O/fed.	2011	668.96 p	736.80 lm	3.20 bc	3.40 ef	11.94 r	10.03 l	1.55 c	1.63 c	13.49 n	11.67 l	
			2012	821.70 l	931.43 g	4.00 abc	4.20 abcdef	12.62 p	11.69 j	1.14 g	1.46 e	13.76 l	13.16 h	
			As. acid	864.16 j	953.90 f	3.80 abc	4.06 cdef	13.40 kl	12.34 hi	1.09 ghi	1.36 g	14.50 h	13.70 fg	
1000 ppm	48 kg	Control	2011	772.90 m	793.90 j	3.53 abc	3.60 def	12.97 o	12.00 ij	1.36 ef	1.33 gh	14.33 j	13.34 gh	
			2012	987.16 g	985.36 de	4.33 abc	4.73 abcd	13.96 i	13.07 fg	1.01 jk	1.17 j	14.98 f	14.24 e	
			As. acid	1018.50 f	1025.50 c	4.20 abc	4.60 abcd	15.01 c	13.28 defg	0.88 mn	1.05 k	15.89 b	14.33 de	
		O/fed.	2011	835.00 kl	823.30 hi	3.86 abc	4.00 cdef	13.33 m	13.31 defg	1.07 hij	1.20 ij	14.40 ij	14.51 de	
			2012	1113.30 d	1033.70 c	4.73 a	5.30 a	14.37 g	14.28 b	0.73 o	0.94 l	15.10 e	15.23 abc	
			As. acid	1182.10 a	1071.70 a	4.53 ab	5.00 abc	15.53 a	14.89 a	0.67 o	0.82 m	16.21 a	15.71 a	
	72 kg	Control	2011	700.53 o	752.56 kl	3.66 abc	3.73 def	12.61 p	10.98 k	1.32 f	1.41 f	13.94 k	12.40 jk	
			2012	853.80 j	949.70 fg	4.40 ab	4.33 abcdef	13.60 j	12.96 fg	1.03 ij	1.22 i	14.64 g	14.19 ef	
			As. acid	908.60 i	993.86 d	4.13 abc	4.13 bcdef	14.66 e	13.44 def	1.00 jkl	1.06 k	15.67 c	14.50 de	
		O/fed.	2011	777.03 m	803.26 ij	3.86 abc	3.93 cdef	13.36 lm	12.00 ij	1.02 jk	1.30 h	14.38 ij	13.31 gh	
			2012	990.00 g	997.43 d	4.46 ab	4.93 abc	14.03 h	13.76 cd	0.94 lm	1.06 k	14.97 f	14.83 cd	
			As. acid	1024.40 f	1055.50 ab	4.26 abc	4.60 abcd	14.81 d	13.59 de	0.83 n	0.86 m	15.65 c	14.45 de	
2000 ppm	48 kg	Control	2011	848.90 jk	812.46 ij	3.93 abc	4.00 cdef	13.44 k	13.22 efg	0.95 kl	1.16 j	14.39 ij	14.39 de	
			2012	1108.60 de	1033.30 c	4.73 a	5.26 ab	14.33 g	14.20 bc	0.81 n	0.98 l	15.14 e	15.19 bc	
			As. acid	1165.13 b	1067.30 a	4.46 ab	5.06 abc	15.45 b	14.81 a	0.73 o	0.83 m	16.18 a	15.64 ab	
	72 kg	Control	2011	700.53 o	752.56 kl	3.66 abc	3.73 def	12.61 p	10.98 k	1.32 f	1.41 f	13.94 k	12.40 jk	
			2012	853.80 j	949.70 fg	4.40 ab	4.33 abcdef	13.60 j	12.96 fg	1.03 ij	1.22 i	14.64 g	14.19 ef	
			As. acid	908.60 i	993.86 d	4.13 abc	4.13 bcdef	14.66 e	13.44 def	1.00 jkl	1.06 k	15.67 c	14.50 de	
O/fed.	2011	777.03 m	803.26 ij	3.86 abc	3.93 cdef	13.36 lm	12.00 ij	1.02 jk	1.30 h	14.38 ij	13.31 gh			
	2012	990.00 g	997.43 d	4.46 ab	4.93 abc	14.03 h	13.76 cd	0.94 lm	1.06 k	14.97 f	14.83 cd			
	As. acid	1024.40 f	1055.50 ab	4.26 abc	4.60 abcd	14.81 d	13.59 de	0.83 n	0.86 m	15.65 c	14.45 de			

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & Po. = Potassium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid. Salicylic acid and Ascorbic acid were applied at 200 ppm.

Concerning the effect of antioxidants on tuber root characteristics of sweet potato, data in Table 12 indicate that plants sprayed with antioxidants resulted in significant increase in weight, length, diameter, shape and dry matter of tuber root, in both growing seasons. The highest values of weight, length, diameter, shape and dry matter of tuber root were obtained from plants sprayed with ascorbic acid at 200 ppm in both seasons. Such results may suggest that ascorbic acid (Vit. C) has a wide range of important functions as antioxidant defense, photoprotection, regulation of photosynthesis, affects nutritional cycle's activity in higher plants, electron

transport system, as a cofactor for a large number of key enzymes in plants, also developmental senescence, programmed cell death and responses to pathogens (Blokhina *et al.*, 2003). Some investigators came to nearly similar results, where El-Morsy *et al.* (2010) indicate that total yield and its components were better with foliar application of antioxidants comparing with the untreated ones. Moreover, application of ascorbic acid at 150 ppm was more beneficial treatment to increase total yield and improving its components than the other substances of garlic (*Allium sativum* L.).

Table 12. Tuber root characteristics of sweet potato plants as affected by calcium, potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments	Parameters									
	Average root weight (g)		Average root length (cm)		Average root diameter (cm)		Root shape (length/diameter)		Dry matter (%)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Calcium										
Control	170.45 c	182.59 c	15.38 c	14.36 c	3.95 c	4.24 c	3.88 a	3.40 c	22.75 c	23.25 c
1000 ppm	200.21 b	204.77 b	17.62 b	17.25 b	4.75 b	4.92 b	3.70 b	3.50 b	26.45 b	26.51 b
2000 ppm	210.51 a	213.89 a	18.56 a	18.86 a	5.02 a	5.12 a	3.69 b	3.68 a	27.75 a	28.31 a
Potassium										
Control	165.62 c	177.13 c	14.30 c	14.13 c	3.76 c	3.71 c	3.79 a	3.76 a	23.21 c	23.07 c
48 kg K ₂ O/fed.	194.01 b	204.07 b	17.51 b	16.66 b	4.70 b	5.08 b	3.72 a	3.25 c	25.68 b	26.21 b
72 kg K ₂ O/fed.	221.52 a	220.04 a	19.74 a	19.68 a	5.25 a	5.48 a	3.75 a	3.56 b	28.05 a	28.78 a
Antioxidants										
Control	165.35 c	169.63 c	14.17 c	13.09 c	4.14 c	4.31 c	3.43 c	3.03 c	21.99 c	21.74 c
Salicylic acid	200.52 b	208.59 b	17.80 b	17.50 b	4.70 b	4.85 b	3.80 b	3.62 b	26.31 b	26.56 b
Ascorbic acid	215.28 a	223.02 a	19.57 a	19.87 a	4.87 a	5.10 a	4.04 a	3.92 a	28.64 a	29.77 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test. Salicylic acid and Ascorbic acid were applied at 200 ppm.

Data presented in Table 13 show the interaction effect between calcium and potassium on tuber root characteristics. Generally, there were significant effects for the interaction on weight, length, diameter and dry matter of tuber root. It was clear also that plants sprayed with calcium at 1000 ppm and fertilized with 72 kg K₂O/fed. gave the highest values of tuber root features except root shape, in both growing seasons, while the lowest values were obtained from the control plants that did not receive calcium or potassium fertilizer. There were no

significant differences between spray with calcium at 1000 ppm plus applied 72 kg K₂O/fed. and spray with calcium at 2000 ppm plus applied 72 kg K₂O/fed. on length and diameter of tuber root, in both growing season, and on weight and dry matter of tuber root, in the second growing season, also there were no significant differences between spray with calcium at 0 ppm (control) plus applied 0 or 48 or 72 kg K₂O/fed. and spray with calcium at 1000 ppm without K₂O (control) on root shape, in the first growing season.

Table 13. Tuber root characteristics of sweet potato plants as affected by the interactions between calcium and potassium at different rates during 2011 and 2012 growing seasons.

Treatments	Ca. Po.	Parameters									
		Average root weight (g)		Average root length (cm)		Average root diameter (cm)		Root shape (length/diameter)		Dry matter (%)	
		2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	147.05 i	158.05 h	12.18 g	11.90 f	3.19 h	3.18 g	3.81 abc	3.72 b	21.09 i	20.25 g
	48 kg K ₂ O/fed.	170.13 g	182.21 f	15.86 e	14.32 d	4.01 f	4.52 d	3.94 a	3.15 e	22.49 h	23.19 e
	72 kg K ₂ O/fed.	194.16 e	207.50 d	18.09 c	16.84 c	4.63 d	5.00 c	3.89 ab	3.34 d	24.66 f	26.31 d
1000 ppm	Control	164.61 h	177.57 g	14.42 f	13.76 e	3.76 g	3.67 f	3.81 abc	3.70 b	22.97 g	22.79 f
	48 kg K ₂ O/fed.	200.13 d	209.98 c	17.77 c	16.77 c	4.92 c	5.33 b	3.58 e	3.12 e	26.50 d	26.69 c
	72 kg K ₂ O/fed.	235.88 a	226.75 a	20.66 a	21.20 a	5.56 a	5.74 a	3.69 cde	3.67 b	29.87 a	30.04 a
2000 ppm	Control	185.21 f	195.77 e	16.31 d	16.71 c	4.33 e	4.29 e	3.76 bcd	3.87 a	25.56 e	26.16 d
	48 kg K ₂ O/fed.	211.78 c	220.04 b	18.90 b	18.88 b	5.17 b	5.37 b	3.65 de	3.49 c	28.05 c	28.75 b
	72 kg K ₂ O/fed.	234.53 b	225.87 a	20.46 a	20.98 a	5.55 a	5.69 a	3.67 cde	3.67 b	29.64 b	30.01 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test. Ca. = Calcium & Po. = Potassium.

It is evident from Table 14, that the interaction between calcium and antioxidants greatly affected most characteristics of sweet potato tuber roots. Average weight, length, diameter and dry matter of tuber root, in both growing seasons were significantly increased by foliar spray of calcium at 2000 ppm in the presence of ascorbic acid at 200 ppm than in the absence of them (control). On the other hand, tuber root shape, in the first growing season was significantly increased in the absence of calcium in the presence of ascorbic acid at 200 ppm, but in the second growing season the highest value obtained from foliar spray of calcium at 1000 ppm in the presence of ascorbic acid at 200 ppm. There were no significant differences between foliar spray of calcium at 2000 ppm in the presence of ascorbic acid at 200 ppm and foliar spray of calcium at 1000 ppm in the presence of ascorbic acid at 200 ppm on average length of tuber root, in the first growing season, also there were no significant differences between foliar spray of calcium at 2000 ppm in the presence of ascorbic acid or salicylic acid at 200 ppm on average diameter of tuber root, in the first growing season, on the other hand, there were no significant differences between foliar spray of

calcium at 1000 ppm in the presence of ascorbic acid at 200 ppm and foliar spray of calcium at 2000 ppm in the presence of ascorbic acid at 200 ppm on tuber root shape, in the second growing season. The superiority effect of the interaction between calcium and antioxidants could be explained in the light of the great roles played by calcium on plant growth and has been implicated as a factor influencing tuber quality (Lang *et al.*, 1999), also calcium has attracted much interest in plant physiology and molecular biology because of its function as a second messenger in the signal conduction between environmental factors and plant responses in terms of growth and development (Reddy, 2001). Similar results were reported by Lin *et al.* (2008) they reported that the level of activity of the antioxidative system in sweet potato leaves was related to CaCl₂ pretreatment during flooding. The ascorbate peroxidase, superoxide dismutase, glutathione reductase, reduced ascorbate, total ascorbate, reduced glutathione and malondialdehyde contents of the three sweet potato varieties under flooding stress significantly increased because of pretreatment with 60 and 120 kg ha⁻¹ of CaCl₂.

Table 14. Tuber root characteristics of sweet potato plants as affected by the interactions between calcium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments		Parameters									
		Average root weight (g)		Average root length (cm)		Average root diameter (cm)		Root shape (length/diameter)		Dry matter (%)	
Ca.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	140.78 i	153.27 h	12.71 g	11.09 h	3.56 f	3.70 g	3.56 e	2.98 f	19.71 h	19.51 i
	Sa. acid	178.07 g	189.77 f	15.55 e	14.94 f	4.07 e	4.36 f	3.83 cd	3.48 d	23.56 f	23.78 g
	As. acid	192.49 e	204.72 e	17.87 d	17.04 e	4.21 e	4.64 d	4.25 a	3.74 c	24.97 e	26.46 e
1000 ppm	Control	168.51 h	166.32 g	13.91 f	13.36 g	4.38 d	4.52 e	3.17 f	2.95 f	22.78 g	21.63 h
	Sa. acid	209.59 d	216.98 d	18.64 c	17.74 d	4.82 c	5.04 c	3.88 c	3.52 d	26.74 d	27.06 d
	As. acid	222.51 b	231.00 b	20.30 a	20.64 b	5.04 b	5.18 b	4.04 b	4.02 a	29.82 b	30.83 b
2000 ppm	Control	186.77 f	189.29 f	15.91 e	14.83 f	4.48 d	4.72 d	3.56 e	3.15 e	23.48 f	24.08 f
	Sa. acid	213.89 c	219.03 c	19.21 b	19.81 c	5.21 a	5.16 b	3.68 de	3.87 b	28.62 c	28.83 c
	As. acid	230.85 a	233.35 a	20.55 a	21.94 a	5.36 a	5.47 a	3.83 c	4.01 a	31.15 a	32.01 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

Data illustrated in Table 15 reveal that average root weight, length, diameter, shape and dry matter of tuber root were significantly increased, in both growing seasons, by the interaction between potassium and antioxidants. In general, plants fertilized with 72 kg K₂O/fed. in the presence of ascorbic acid at 200 ppm, almost gave the highest values of tuber root features, except root shape, in

both growing seasons, plants sprayed with ascorbic acid at 200 ppm in the absence of potassium gave the highest values of root shape, in both growing seasons. Also there were no significant differences between applied 72 kg K₂O/fed. in the presence of salicylic acid at 200 ppm and applied 72 kg K₂O/fed. in the presence of ascorbic acid at 200 ppm on average root diameter, in the first growing season.

The significant increase in average tuber root weight may be due to that potassium is an essential plant nutrient that plays a very important role in plant growth and development. Its role is well documented in photosynthesis, increasing enzyme activity, improving synthesis of protein, carbohydrates and fats, translocation of sugars, enabling their ability to resist pests and diseases (Dkhil *et al.*, 2011). Also, potassium is considered as major osmotically active cation of plant cell where it enhances water uptake and root permeability and acts as guard cell

controller, beside its role in increasing water use efficiency (Mengel and Kirkby, 1987). These results are in harmony with those of WuZhong *et al.* (1997) they found that K application improved the yield and quality of the produce of onion and taro by increasing vitamin C (ascorbic acid) levels, and El-Morsy *et al.* (2010) they showed that the interactions between PK-rates and antioxidants had a significant effect on bulb weight, bulb diameter and clove weight.

Table 15. Tuber root characteristics of sweet potato plants as affected by the interactions between potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Treatments	Parameters										
	Average root weight (g)		Average root length (cm)		Average root diameter (cm)		Root shape (length/diameter)		Dry matter (%)		
Po.	An.	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	138.79 i	150.90 i	11.71 h	10.67 i	3.44 f	3.47 h	3.39 e	3.05 f	20.12 h	18.80 h
	Sa. acid	170.68 g	183.24 g	14.73 f	14.71 g	3.85 e	3.71 g	3.84 c	3.94 b	23.97 e	23.48 f
	As. acid	187.41 f	197.25 e	16.47 e	17.00 e	3.99 e	3.96 f	4.15 a	4.30 a	25.53 d	26.92 d
48 kg K ₂ O/fe	Control	166.26 h	171.41 h	14.28 g	13.17 h	4.29 d	4.38 e	3.36 e	3.00 f	22.10 g	22.01 g
	Sa. acid	199.73 d	213.70 d	18.25 d	17.52 d	4.78 c	5.29 c	3.82 c	3.30 e	26.26 c	26.84 d
	As. acid	216.05 c	227.11 c	19.99 c	19.27 c	5.04 b	5.55 b	3.99 b	3.46 d	28.68 b	29.78 b
72 kg K ₂ O/fe	Control	191.02 e	186.58 f	16.53 e	15.43 f	4.69 c	5.09 d	3.54 d	3.03 f	23.75 f	24.40 e
	Sa. acid	231.15 b	228.83 b	20.42 b	20.25 b	5.47 a	5.56 b	3.73 c	3.63 c	28.70 b	29.36 c
	As. acid	242.39 a	244.70 a	22.26 a	23.34 a	5.59 a	5.78 a	3.98 b	4.02 b	31.72 a	32.59 a

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Po. = Potassium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

Results presented in Table 16 show the effect of the interaction among all studied factors viz. calcium, potassium and antioxidants on tuber root characteristics of sweet potato. The obtained results indicate that all characteristics of tuber root were significantly affected by the three ways interaction, in both growing seasons. Plants sprayed with calcium at 1000 ppm, supplied with 72 kg K₂O/fed. and sprayed with ascorbic acid at 200 ppm achieved great values except root shape, in both growing seasons. The highest value of root shape obtained from sprayed with calcium at 0 ppm (control), supplied with 48 kg K₂O/fed. and sprayed with ascorbic acid at 200 ppm, in the first growing season while in the second growing season, the highest value obtained from spray with calcium at 1000 ppm, without K₂O (control) and spray with ascorbic acid at 200 ppm, also there were no significant differences between spray with calcium at 0 ppm (control), supplied with 48 kg K₂O/fed. and spray with ascorbic acid at 200 ppm and sprayed with calcium at 0 ppm (control) or 1000 ppm, without K₂O (control) and spray with ascorbic acid at 200 ppm on root shape, in the first growing season but in the second growing season, there were no significant differences between spray with calcium at 1000 ppm, without K₂O (control) and spray with ascorbic acid at 200 ppm and spray with

calcium at 0 ppm (control), without K₂O (control) and spray with ascorbic acid at 200 ppm on root shape. Also, there were no significant differences between spray with calcium at 1000 ppm, with 72 K₂O and sprayed with ascorbic acid at 200 ppm and spray with calcium at 2000 ppm, with 72 K₂O and sprayed with ascorbic acid at 200 ppm on average root length, in both growing seasons, on the other hand, there were no significant differences between spray with calcium at 1000 ppm, with 72 K₂O and sprayed with salicylic acid or ascorbic acid at 200 ppm and spray with calcium at 2000 ppm, with 72 K₂O and spray with salicylic acid or ascorbic acid at 200 ppm on average root diameter, in the first growing season, while in the second growing season there were no significant differences between spray with calcium at 1000 ppm, with 72 K₂O and spray with ascorbic acid at 200 ppm and sprayed with calcium at 2000 ppm, with 72 K₂O and sprayed with ascorbic acid at 200 ppm on average root diameter. For dry matter of tuber root, there were no significant differences between spray with calcium at 1000 ppm, with 72 K₂O and spray with salicylic acid or ascorbic acid at 200 ppm and spray with calcium at 2000 ppm, with 72 K₂O and spray with salicylic acid or ascorbic acid at 200 ppm, in the second growing seasons.

Table 16. Tuber root characteristics of sweet potato plants as affected by the interactions among calcium, potassium and some antioxidants; i.e., salicylic acid and ascorbic acid, separately at different rates during 2011 and 2012 growing seasons.

Ca.	Po.	An.	Parameters									
			Average root weight (g)		Average root length (cm)		Average root diameter (cm)		Root shape (length/diameter)		Dry matter (%)	
			2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Control	Control	Control	117.48 v	129.50 t	9.98 o	8.77 o	3.09 p	3.06 n	3.23 k	2.86 no	18.29 t	16.61 t
		Sa. acid	154.25 s	166.97 p	12.47 m	12.81 l	3.21 p	3.23 mn	3.89 cdef	3.96 d	21.64 p	21.21 q
		As. acid	169.42 p	177.69 o	14.10 k	14.13 j	3.28 op	3.26 m	4.31 ab	4.33 ab	23.34 n	22.91 n
	48 kg K ₂ O/fed.	Control	138.27 t	150.35 r	12.88 lm	11.11 m	3.61 mn	3.69 l	3.62 ghi	3.00 mn	19.88 s	19.57 r
		Sa. acid	176.64 n	189.07 l	15.58 j	14.88 i	4.08 jk	4.64 g	3.82 cdefg	3.20 jk	23.25 n	23.64 m
		As. acid	195.49 k	207.21 h	19.12 f	16.97 fg	4.35 ij	5.23 f	4.39 a	3.24 j	24.35 m	26.38 i
	72 kg K ₂ O/fed.	Control	166.58 q	179.98 n	15.26 j	13.40 kl	3.98 kl	4.36 h	3.84 cdefg	3.07 klm	20.95 q	22.35 o
		Sa. acid	203.32 j	213.27 g	18.61 fg	17.13 efg	4.91 efg	5.21 f	3.79 defg	3.28 ij	25.80 k	26.49 i
		As. acid	212.57 g	229.25 e	20.40 cd	20.01 cd	5.02 de	5.44 de	4.06 bc	3.67 efg	27.22 h	30.09 f
	Control	Control	135.63 u	146.58 s	11.25 n	10.22 n	3.50 no	3.38 m	3.21 k	3.02 lmn	20.36 r	17.97 s
		Sa. acid	171.67 o	184.18 m	15.08 j	13.77 jk	3.78 lm	3.76 kl	3.99 cd	3.65 fg	23.34 n	22.95 n
		As. acid	186.54 m	201.97 i	16.92 hi	17.31 ef	3.99 kl	3.89 jk	4.24 ab	4.45 a	25.20 l	27.45 h
1000 ppm	48 kg K ₂ O/fed.	Control	167.23 q	164.27 q	13.52 kl	13.27 kl	4.60 hi	4.70 g	2.93 l	2.82 o	22.94 o	21.71 p
		Sa. acid	210.51 h	228.73 e	19.26 ef	17.62 e	4.96 def	5.61 cde	3.88 cdef	3.14 jklm	26.61 j	27.30 h
		As. acid	222.64 f	236.93 cd	20.53 cd	19.42 d	5.20 cd	5.69 c	3.94 cde	3.41 hi	29.96 e	31.05 c
72 kg K ₂ O/fed.	Control	202.69 j	188.11 l	16.97 hi	16.59 gh	5.03 cde	5.48 de	3.37 jk	3.02 lmn	25.04 l	25.19 k	
	Sa. acid	246.60 c	238.03 c	21.58 b	21.84 b	5.73 ab	5.76 bc	3.76 defgh	3.79 ef	30.28 d	30.93 cd	
	As. acid	258.35 a	254.11 a	23.44 a	25.18 a	5.92 a	5.98 a	3.96 cde	4.21 bc	34.29 a	33.99 a	
Control	Control	163.26 r	176.61 o	13.91 k	13.03 l	3.73 lmn	3.98 ij	3.73 efgh	3.27 ij	21.71 p	21.81 p	
	Sa. acid	186.11 m	198.59 j	16.64 i	17.55 ef	4.56 hi	4.15 i	3.64 fg	4.23 bc	26.91 i	26.27 i	
	As. acid	206.26 i	212.10 g	18.39 g	19.55 cd	4.69 fgh	4.73 g	3.91 cde	4.13 c	28.06 g	30.41 ef	
2000 ppm	48 kg K ₂ O/fed.	Control	193.27 l	199.62 j	16.44 i	15.15 i	4.65 gh	4.76 g	3.53 hij	3.18 jkl	23.47 n	24.75 l
		Sa. acid	212.04 gh	223.30 f	19.92 de	20.07 c	5.29 c	5.62 cd	3.76 defgh	3.56 gh	28.92 f	29.58 g
		As. acid	230.02 e	237.21 cd	20.33 d	21.43 b	5.57 b	5.74 c	3.65 fg	3.73 efg	31.74 c	31.91 b
72 kg K ₂ O/fed.	Control	203.79 j	191.66 k	17.37 h	16.31 h	5.07 cde	5.43 e	3.42 ijk	3.00 mn	30.02 de	25.67 j	
	Sa. acid	243.53 d	235.21 d	21.06 bc	21.80 b	5.77 ab	5.70 c	3.65 fg	3.82 de	33.65 b	30.65 de	
	As. acid	256.27 b	250.75 b	22.95 a	24.83 a	5.82 ab	5.94 ab	3.94 cde	4.18 bc	25.26 l	33.71 a	

Means with the same letters are not significantly differed at 5% according to Duncan's multiple range test.

Ca. = Calcium & Po. = Potassium & An. = Antioxidants & Sa. acid = Salicylic Acid & As. acid = Ascorbic Acid.

Salicylic acid and Ascorbic acid were applied at 200 ppm.

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تأثير الكالسيوم والبوتاسيوم وبعض مضادات الأكسدة على النمو والمحصول والقدرة التخزينية في البطاطا:

1- النمو الخضري والمحصول وصفات الجذور الدرنية.

سمير كامل الصيفي¹ ، محمود عبد المحسن حسن¹ ، سوسن محمد حسن سرج¹ ، أسامة محمد سيف الدين² ومحمد احمد محمد علي¹.

1- قسم البساتين - كلية الزراعة بالأسماعيلية- جامعة قناة السويس.

2- قسم بحوث الخضراوات - معهد بحوث البساتين - مركز البحوث الزراعية - الجيزة.

أجريت تجربتان حقليتان في مزرعة البرامون للبحث الزراعي التابعة لمحطة بحوث البساتين بالمنصورة خلال موسمى الزراعة الصيفي (2011 ، 2012) على نباتات البطاطا صنف بيوريجارد بهدف دراسة تأثير الرش الورقي بالكالسيوم بمعدل (صفر ، 1000 ، 2000 جزء في المليون) على صورة سترات كالسيوم 21 % ، التسميد الأرضي البوتاسي بمعدل (صفر ، 48 ، 72 كجم أكسيد بوتاسيوم/فدان) على صورة سلفات بوتاسيوم 48 % ، بالإضافة إلى الرش الورقي بمضادات الأكسدة بمعدل (صفر ، حامض الأسكوربيك بمعدل 200 جزء في المليون ، حامض الساليسيليك بمعدل 200 جزء في المليون) على كل من النمو النباتي والمحصول ومكوناته وصفات الجذر الدرني. أوضحت النتائج المتحصل عليها أن الرش الورقي بالكالسيوم بمعدل 2000 جزء في المليون منفرداً أو 1000 جزء في المليون عند إضافته مع التسميد الأرضي البوتاسي بمعدل 72 كجم أكسيد بوتاسيوم/فدان مع الرش الورقي بحامض الأسكوربيك أو حامض الساليسيليك كل بمعدل 200 جزء في المليون كمضادات أكسدة أدى إلى زيادة معنوية في كل صفات النمو الخضري والمحصول الكلي ومكوناته وخصائص الجذور الدرنية مقارنة بالكنترول. لوحظت التفاعلات الموجبة بين الرش الورقي بالكالسيوم ومستويات التسميد الأرضي البوتاسي والرش الورقي بمضادات الأكسدة. وجد أن أفضل نتيجة تم الحصول عليها هي الرش الورقي للبطاطا بالكالسيوم بمعدل 2000 جزء في المليون منفرداً أو 1000 جزء في المليون عند إضافته مع التسميد الأرضي البوتاسي بمعدل 72 كجم أكسيد بوتاسيوم/فدان مع الرش الورقي بحامض الأسكوربيك أو حامض الساليسيليك كل بمعدل 200 جزء في المليون كمضادات أكسدة.