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MODULATION OF THE GROWTH PERFORMANCE AND NUTRIENTS OF SWEET POTATO UPON FOLIAR APPLICATION OF FULVIC ACID

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Abstract

Fulvic acid (FA) can stimulate the growth of varying plants. Thus, this study investigated the effects of foliar application of FA on the growth of sweet potato (*Ipomoea batatas* L.) in field and greenhouse conditions. Sweet potatoes grown for 30 days were sprayed with 100 mL of different concentrations of FA solutions per plant, including 0.05% (F0.05), 0.1% (F0.1) and 0.15% (F0.15), and tap water (control). Foliar application of FA increased the vine length, vine girth, leaf area per plant, leaf nutrients, tuber per plant, tuber ash, polyphenols, carotene and ascorbic acid contents of sweet potatoes. Results indicated that foliar application of FA may be a practical method for improving the yield of sweet potato in both field and greenhouse conditions.

Key words: Fulvic acid; Foliar; Growth; Sweet potato.

Introduction

Fulvic acid (FA) is a natural organic compound primarily derived from trees and forests (Mao, 2019). It has strong adsorption and ion exchange capacity (Zhang, 2018). At present, the research on the application of FA in agriculture has achieved certain results, e.g. Xianju yellow chicken (Feng *et al.,* 2022), red swamp crayfish (Zhang, 2018), broilers (Mao, 2019), coffee (Justi *et al.,* 2019), tomato (Suh *et al.,* 2014), lettuce (Chen *et al.,* 2022), Damask Rose (Ali Esmat *et al.,* 2022) and forage legume (Capstaff Nicola *et al.,* 2020).

Sweet potato (*Ipomoea batatas* L.) is an annual or perennial herb of *Convolvulaceae ipomoea*. It is resistant to barrenness and drought and is widely planted (Shi *et al.,* 2022). China has the largest planting area of sweet potato in the world (He & Qin, 2020). With the continuous improvement of living standards, the demand of people for sweet potato is increasing, and its high nutritional and health care functions are favoured by consumers (Hossain *et al.,* 2022). Sweet potato is rich in a variety of nutrients needed by the human body. The root tuber is rich in soluble sugar, vitamins, starch, anthocyanins and carotene (Siqinbatu *et al.,* 2013). Sweet potato has also anti-tumour, hypoglycaemic and other health benefits. The huge market demand has led to high requirements on the yield and quality of sweet potatoes (Agbede, 2010). In recent years, a number of chemical compounds and natural substances such as nitrogen fertilizers (Yao *et al.,* 2020), phosphorus fertilizers (Kareem *et al.,* 2020), potassium and zinc fertilizers (Singh *et al.,* 2017), sheep manure and mushroom residue (Li *et al.,* 2022), oyster mushroom baglog compost (Prabowo *et al.,* 2020) and rice straw waste compost (Rahmawati & Basqoro, 2022), have been used to improve the growth performance of sweet potatoes.

Foliar application has been successful in many crops. Okunlola *et al.,* (2022) reported that foliar application of hydrogen peroxide improved growth, inorganic ion and osmolyte accumulation of soybean (*Glycine max*) cultivars under drought stress. Abdul-Hafeez & Ibrahim (2022) observed that foliar application of chitosan at 40 ppm followed by d D, L β aminobutyric acid at 40 ppm exhibited a significant increase in oil yield per fed comparing to the control. Hafeez *et al.,* (2022). found that foliar application of moringa leaf extract (MLE) enhanced antioxidant system, growth, and biomass related attributes in safflower plants. Alves *et al.,* (2022) discovered that exogenous foliar ascorbic acid applications enhanced salt-stress tolerance in peanut plants through increase in the activity of major antioxidant enzymes. Bijanzadeh *et al.,* (2022) reported that foliar application of sodium silicate mitigated drought stressed leaf structure in corn (*Zea mays* L.).

Thus, treatment with FA may affect the yield and quality of sweet potatoes. In addition, data regarding the effect of treatment with FA on the yield and quality of sweet potatoes are limited. Therefore, in this experiment, different concentrations of FA solution were sprayed on the leaves of sweet potato, and their effects on the yield and quality of sweet potatoes were evaluated to provide a theoretical basis for their development and production.

Materials and Methods

Materials: FA with a purity of > 99% was purchased from Shanxi Jintai Biological Co., Ltd. (Shanxi, China). Detoxified sweet potato seedlings were purchased from a local farmers' market. All other chemicals were of reagent grade.

Field experiment: The cultivation test site is Haizhou, Lianyungang, China. The soil type is clay, and the soil physical and chemical properties are presented in Table 1. The experimental period started on May 10 and ended on October 10 in 2022. The data on climatic conditions of the experimental location are presented in Table 2. The cultivation test was performed in three field plots, and each field plot was divided into four groups: the control group was sprayed with 100 mL of tap water; the three treatment groups were sprayed with 100 mL of 0.05% (FA0.05), 0.1% (FA0.1) and 0.15% (FA0.15) FA solutions. Before ridge raising in the experimental area, 15 kg of N, 10 kg of P_2O_5 and 7.5 kg of K_2O were applied as base fertilisers per 667 m^2. The ridge spacing was 120 cm, and the plant spacing was 25 cm. Sixty plants were planted in each ridge, and on June 30 after transplanting, each sweet potato was sprayed with 100 mL of tap water or different concentrations of FA solutions.

Table 1. Soil physical and chemical properties (0–20 cm depth).

Property	Loam
Clay (%)	93.16 ± 3.15
Sand (%)	5.17 ± 0.21
Bulk density (Mg m^{-3})	1.46 ± 0.03
pH	7.02 ± 0.21
Organic matter (%)	1.78 ± 0.06
Total N (%)	0.23 ± 0.03
Total P (%)	0.47 ± 0.02
Total K (%)	0.13 ± 0.03

Greenhouse experiment: This study was performed using a completely randomized design with four treatments and three replications the same as those of the field experiment in a greenhouse from May 10 to October 10 in 2022. The specific cultivation and fertilization methods are the same as those of the field experiment. The pots were watered once a month, and the amount of watering is consistent with the corresponding monthly precipitation. The plants were grown at air temperature 25-30°C, natural light intensity, 80-90% relative moisture, and natural photoperiod.

Leaf analysis: After 5 months of cultivation, sweet potato leaves were collected from six plants per ridge for chemical analysis. The leaf samples were oven dried at 90°C for 24 h and ground using an ultrafine pulveriser. Leaf N was determined by using the micro-Kjeldahl method. Leaf samples were ashed at 600°C for 6 h in an ash furnace and extracted by using a nitric-perchloric-sulphuric acid mixture for the determination of P, K, Ca and Mg. P was determined colorimetrically by using the vanadomolybdate method. K was determined by using a flame photometer. Ca and Mg were determined by using the ethylene diamine tetra acetic acid titration method (Anon., 2005).

Crop growth and yield: Twelve plants were selected randomly per ridge for the determination of vine length, vine girth and leaf area after 5 months of cultivation. The vine length was measured by using a meter ruler. The vine girth was measured by using a Vernier caliper. Moreover, the leaf area was measured by using the graphical method. Tuber yield was weighted by using a top loading balance.

Tuber analysis: The moisture, carbohydrate, protein, lipid, starch and ash contents in sweet potato tubers were assayed in accordance with standard methods (Anon., 2005). Polyphenols, carotene and ascorbic acid contents in sweet potato tubers were assayed using enzyme-linked immunosorbent assay kits (Nanjing Jiancheng Biology Company Research Institute, Jiangsu, China) following the manufacturer's instructions.

Statistical analysis: The data are expressed as mean ± SD (n = 3). Microsoft Excel 2010 was used for data processing and graphing, and DPSv7.05 was used for analysis of variance. In addition, Duncan's new multiple-range method was used for significance test.

Results

Effects of FA on horticultural features and yield of sweet potato: Effects of FA on the vine length, vine girth, leaf area per plant and yield of sweet potato are presented in Table 3. Spray treatment with FA increased the vine length, vine girth and leaf area per plant compared with the control group ($p<0.05$) and showed a dose-dependent effect under field and greenhouse conditions. It also improved sweet potato yield compared with the control group ($p<0.05$). However, a high dose of FA (FA0.15) decreased sweet potato yield under field and greenhouse conditions.

Effects of FA on leaf nutrients: Effects of FA on leaf and tuber nutrients are presented in Table 4. Spray treatment with FA increased N, P, K, Ca and Mg contents in the leaves of sweet potato compared with the control group ($p<0.05$) and showed a dose-dependent effect under field and greenhouse conditions.

Effects of FA on tuber nutrients: Effects of FA on tuber nutrients are shown in Table 5. No differences in moisture, carbohydrate, protein, lipid and starch contents in the tubers were found amongst all groups ($p>0.05$) under field and greenhouse conditions. However, spray treatment with FA increased ash, polyphenols, carotene and ascorbic acid contents in tubers compared with the control group ($p<0.05$) and showed a dose-dependent effect under field and greenhouse conditions.

Discussion

The leaf is the main organ of sweet potato for photosynthesis, and it is the basis for the formation of sweet potato yield. If the leaf area has a long duration and high photosynthetic rate, then it can synthesise more photosynthetic products. However, whether the photosynthetic products produced in sweet potato leaves can be transported to tuberous roots in a timely manner is closely related to the transport capacity of stems. If the stem has a strong transport ability, then the photosynthetic products produced by the leaf can be transported to the tuberous roots in time, thereby increasing the yield. However, if the photosynthetic products are not transported smoothly from the stem to the tuberous roots, then the photosynthetic products will accumulate in the shoots, which may hinder the improvement of production (He & Qin, 2020). In this study, spray treatment with FA increased the vine length, vine girth, leaf area per plant and sweet potato yield compared with the control group under field and greenhouse conditions. Similarly, FA stimulated the growth of coffee (Justi *et al.,* 2019), tomato (Suh *et al.,* 2014), lettuce (Chen *et al.,* 2022), Damask Rose (Ali Esmat *et al.,* 2022) and forage legume (Capstaff Nicola *et al.,* 2020). The yield reduction at FA0.15 may reflect phytotoxicity or nutrient imbalance at high concentrations, warranting further investigation.

Table 2. Average temperatures and monthly rainfall of the study location during the field experimental period in year 2022.

Month	Monthly average minimum temperature (°C)	Monthly average maximum temperature (°C)	Monthly rainfall (mm)
May	14	27	2.4
June	32	21	122.9
July	31	24	25.6
August	32	24	306.5
September	27	17	0
October	21	10	87.1

Table 3. Effects of fulvic acid (FA) on vine length, vine girth, leaf area per plant and yield of sweet potato in the field and greenhouse conditions.

Parameters	FA0	FA0.05	FA0.1	FA0.15
		Field		
Vine length (cm)	1.31 ± 0.05^{a}	1.62 ± 0.07^{b}	1.95 ± 0.08^{c}	2.32 ± 0.14^{d}
Vine girth (cm)	2.03 ± 0.02^{a}	2.35 ± 0.04^{b}	2.73 ± 0.05^{c}	3.15 ± 0.04^{d}
Leaf area per plant (m^2)	1.13 ± 0.05^{a}	1.37 ± 0.06^{b}	1.77 ± 0.05^{c}	1.95 ± 0.07^{d}
Tuber weight (kg)	1.27 ± 0.03^{a}	1.46 ± 0.05^{b}	1.63 ± 0.06^{c}	1.44 ± 0.05^{b}
		Greenhouse		
Vine length (cm)	1.52 ± 0.06^{a}	1.93 ± 0.09^{b}	2.26 ± 0.11^{c}	2.57 ± 0.08^{d}
Vine girth (cm)	2.25 ± 0.03^{a}	2.57 ± 0.06^{b}	2.95 ± 0.07^{c}	2.26 ± 0.08^{d}
Leaf area per plant (m^2)	1.36 ± 0.06^{a}	1.58 ± 0.07^{b}	1.94 ± 0.08^{c}	2.27 ± 0.09^{d}
Tuber weight (kg)	1.46 ± 0.04^{a}	1.68 ± 0.06^{b}	1.87 ± 0.07^{c}	1.63 ± 0.06^{b}

The different superscript letters indicate significant differences for each row ($p<0.05$). Values are the mean ± SD

Table 4. Effects of fulvic acid (FA) on leaf nutrients of sweet potato in the field and greenhouse conditions.

Parameters	FA0	FA0.05	FA0.1	FA0.15
		Field		
N (g/100g)	2.18 ± 0.11^{a}	2.43 ± 0.13^{b}	3.14 ± 0.16^{c}	3.66 ± 0.17^{d}
P (g/100g)	0.23 ± 0.01^{a}	0.29 ± 0.02^{b}	0.32 ± 0.02^{c}	0.37 ± 0.03^{d}
K (g/100g)	1.25 ± 0.04^{a}	1.46 ± 0.05^{b}	1.74 ± 0.06^{c}	1.93 ± 0.08^{d}
Ca (g/100g)	1.31 ± 0.05^{a}	1.58 ± 0.06^{b}	1.92 ± 0.08^{c}	2.41 ± 0.11^{d}
Mg (g/100g)	1.25 ± 0.04^{a}	1.46 ± 0.05^{b}	1.74 ± 0.06^{c}	1.93 ± 0.08^{d}
		Greenhouse		
N (g/100g)	2.06 ± 0.10^{a}	2.31 ± 0.12^{b}	3.01 ± 0.14^{c}	3.52 ± 0.15^{d}
P (g/100g)	0.21 ± 0.01^{a}	0.27 ± 0.01^{b}	0.31 ± 0.02^{c}	0.35 ± 0.02^{d}
K (g/100g)	1.13 ± 0.03^{a}	1.34 ± 0.04^{b}	1.69 ± 0.06^{c}	1.86 ± 0.07^{d}
Ca (g/100g)	1.28 ± 0.04^{a}	1.46 ± 0.05^{b}	1.79 ± 0.07^{c}	2.16 ± 0.09^{d}
Mg (g/100g)	1.17 ± 0.03^{a}	1.38 ± 0.04^{b}	1.68 ± 0.04^{c}	1.85 ± 0.07^{d}

The different superscript letters indicate significant differences for each row ($p<0.05$). Values are the mean ± SD

Table 5. Effects of fulvic acid (FA) on tuber nutrients of sweet potato in the field and greenhouse conditions.

Parameters	FA0	FA0.05	FA0.1	FA0.15
		Field		
Moisture (g/100g)	62.18 ± 2.16^{a}	62.14 ± 2.14^{a}	62.03 ± 2.11^{a}	62.07 ± 2.13^{a}
Carbohydrate (g/100g)	29.62 ± 0.13^{a}	30.07 ± 0.14^{a}	29.79 ± 0.12^{a}	30.11 ± 0.15^{a}
Protein (g/100g)	2.06 ± 0.01^{a}	2.04 ± 0.01^{a}	2.08 ± 0.02^{a}	2.07 ± 0.01^{a}
Lipid (g/100g)	0.14 ± 0.01^{a}	0.13 ± 0.01^{a}	0.15 ± 0.01^{a}	0.14 ± 0.01^{a}
Starch (g/100g)	15.27 ± 0.55^{a}	15.23 ± 0.56^{a}	15.31 ± 0.57^{a}	15.29 ± 0.56^{a}
Ash (g/100g)	1.83 ± 0.01^{a}	2.04 ± 0.02^{b}	2.29 ± 0.03^{c}	2.51 ± 0.02^{d}
Polyphenols (mg/100g)	51.03 ± 2.24^{a}	56.25 ± 2.37^{b}	60.14 ± 2.39^{c}	64.29 ± 2.51^{d}
Carotene (mg/100g)	2.06 ± 0.01^{a}	2.51 ± 0.01^{b}	3.28 ± 0.02^{c}	3.62 ± 0.02^{d}
Ascorbic acid (mg/100g)	13.15 ± 0.05^{a}	16.37 ± 0.06^{b}	19.38 ± 0.07^{c}	24.32 ± 0.08^{d}
		Greenhouse		
Moisture (g/100g)	61.93 ± 2.14^{a}	61.95 ± 2.15^{a}	61.93 ± 2.13^{a}	61.96 ± 2.11^{a}
Carbohydrate (g/100g)	29.97 ± 0.11^{a}	30.03 ± 0.12^{a}	30.03 ± 0.14^{a}	30.06 ± 0.12^{a}
Protein (g/100g)	2.07 ± 0.02^{a}	2.05 ± 0.02^{a}	2.06 ± 0.01^{a}	2.03 ± 0.02^{a}
Lipid (g/100g)	0.13 ± 0.01^{a}	0.12 ± 0.01^{a}	0.14 ± 0.01^{a}	0.13 ± 0.01^{a}
Starch (g/100g)	15.31 ± 0.52^{a}	15.29 ± 0.61^{a}	15.33 ± 0.54^{a}	15.30 ± 0.55^{a}
Ash (g/100g)	1.78 ± 0.01^{a}	1.95 ± 0.03^{b}	2.17 ± 0.02^{c}	2.42 ± 0.03^{d}
Polyphenols (mg/100g)	47.25 ± 2.12^{a}	52.47 ± 2.18^{b}	57.71 ± 2.27^{c}	61.62 ± 2.27^{d}
Carotene (mg/100g)	1.86 ± 0.02^{a}	2.36 ± 0.02^{b}	3.01 ± 0.03^{c}	3.46 ± 0.04^{d}
Ascorbic acid (mg/100g)	11.36 ± 0.04^{a}	13.49 ± 0.08^{b}	16.25 ± 0.05^{c}	21.72 ± 0.06^{d}

FA has strong adsorption capacity and ion exchange capacity (Zhang, 2018). FA can save fertilizer use and increase efficiency, promote crop growth and improve the quality of soil and agricultural products, crop stress resistance and yield (Justi *et al.,* 2019). FA stimulates the growth of plant roots and their nutrient absorption, regulating the transformation of nutrients in soil and fertilizers and affecting soil microbial and enzymatic activities (Suh *et al.,* 2014). In this study, spray treatment with FA increased FA content in tuber and soil, thereby N, P, K, Ca and Mg contents in the leaves of sweet potato under field and greenhouse conditions. Similarly, foliar application of FA increased N, P, K, Mg, Fe, and Zn contents in rose leaves (Ali *et al.,* 2022), P, Ca, Mg, Fe, and Mn contents in the shoots of *Scrophularia nodosa* (Ernst *et al.,* 1987), and N, P, and K in the leaves and flowers of yarrow (*Achillea millefolium* L.) (Bayat, *et al.,* 2021).

Ash content in plant reflects mineral content in plants. Polyphenols, carotene and ascorbic acid have potent antioxidant activities and important biological effects (Agnieszka & Elżbieta, 2023; Durgadas *et al.,* 2018; Wang *et al.,* 2023). Thus, ash, polyphenols, carotene and ascorbic acid contents are important indicators for food resources. The increased FA content in tubers improved the adsorption of minerals, thereby increasing ash content in sweet potato tubers. FA has potent antioxidant activity and can inhibit the oxidation of polyphenols, carotene and ascorbic acid, thereby increased polyphenols, carotene and ascorbic acid contents in tubers (Sultan *et al.,* 2019). Similarly, foliar application of FA increased carotenoids in rose leaves (Ali *et al.,* 2022), and chlorophyll a, b, total chlorophyll, and carotenoid contents in the leaves and flowers of yarrow (*Achillea millefolium* L.) (Bayat *et al.,* 2021).

In conclusion, spray treatment with FA increased the vine length, vine girth, leaf area plant, leaf nutrients, tuber per plant, tuber ash, polyphenols, carotene and ascorbic acid contents of sweet potatoes under field and greenhouse conditions. Thus, spray treatment with FA improved sweet potato tuber yield and quality and may be of crop industrial relevance. However, other parameters and mechanism should be investigated in the future.

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