*Plant Archives* Volume 20 No. 2, 2020 pp. 4855-4863 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

# GROWTH AND PRODUCTION OF POTATO PLANTS INFLUENCED BY BIO-STIMULANTS AND SOILLESS CULTURE SYSTEMS

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## Abstract

In order to study the effects of three commercial biostimulants (CTA stymulant-4, Calfruit and Beet extracts) in growth characteristics and production of potato plants grown in three different soilless systems (Pot, column and aeroponic cultures system), Two factorial experiments were conducted during fall seasons of 2017-2018 and 2018-2019 in an anti-aphid nylon greenhouse. The treatments were distributed randomly with 3 replicates and 6 plants per replicate. Growth properties such as plant height, number of main stems, number of leaves, leaf area and chlorophyll content were determined based on greenhouse experiments after 75 days. In addition, tuber yield and tuber quality included weight, size, length, total soluble solid (TSS), starch and total sugar contents of tuber were determined based on laboratory analysis after 110 days. The obtained results showed that the commercial bio-stimulants caused a significant improvement in the growth properties of potato plants as well as quantity and quality characteristics of potato tubers. The maximum values of growth properties, tuber yield and quality were potato plants supplied foliarly with beet extract, followed by CAF and CAT compared to non-treated plants (control). Compared to control, the percentage of increment reached to 18.53%, 30.42%, 14.57%, 30% and 29.97% for plant height, number of main stems, number of leaves, leaf area and chlorophyll content, respectively, of plant supplied foliarly with beet bio-stimulant. On average, tuber yield, weight, length, TSS, starch and total sugar contents of tuber were higher by 72.74%, 40.28%, 46.01%, 34.48%, 14.82% and 16.21%, respectively as compared to control. There were significant interactions between soilless culture systems and commercial bio-stimulants for potato growth properties as well as quantity and quality of tubers. In pot system, the maximum growth properties, tuber yield and tuber quality characteristics of potato plants supplied foliarly with beet extract (BET treatment), followed by CAF and CTA bio stimulants compared to untreated control. Furthermore, previous characteristics of potato plants grown in column and aeroponic systems and treated with CTA and CAF biostimulants were lower than those grown in pot system and treated with beet extract as well as were higher than control. Generally, the best vegetative growth, tuber weight, tuber length and tuber yield additionally tuber TSS, starch and sugar contents of potato plants grown in pot system and supplied foliarly with beet biostimulant.

***Key word:*** *Potato (Solanum tuberosum* L.*)*, Morphological characteristics, Tuber yield and quality, Bio-stimulants, Soilless culture systems.

## Introduction

Potato (*Solanum tuberosum* L.) is considered one of most important cash crop belong to *Solanaceae* family, originated in the Andes near the border between Bolivia and Peru, South America (Tunio *et al.,* 2020). This crop occupied the third placed globally after rice and wheat in terms of human consumption (Walker *et al*., 1999). The consumption of potato increased annually and total crop production arrived to 374 million metric tons in worldwide (Tessema and Dagne, 2018). In addition, around billion people worldwide eat potato. China is considered the world's biggest consumer of potatoes (CIP, 2017). Potato is a vital crop in terms of food security in the face of population growth and increased hunger rates (Tessema and Dagne, 2018). Therefore, potatoes could contribute around 50% of the increased food production it will need to meet population demand in the coming 20 years (CIP, 2017). Potato growth and production in traditional method affecting by several factors as climate condition, soil fertility, organic and inorganic fertilizers, soil salinity, soil-borne diseases, water quality and pests (Abdeldaym *et al*., 2018; Abuarab *et al*., 2019; Abdeldaym *et al*., 2019; Tunio *et al*., 2020). To increase potato quality and production, it is necessary for applying an alternative strategy to improve the potato cultivation.

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Soilless culture systems have become an important technology especially in the countries suffering from fresh water shortage and arable lands reduction. Utilization of this technique offers the potential to improve vegetable crop production and fruit quality compared to conventional methods (Chang and Lee, 2016; Abdelaziz and Abdeldaym, 2018). Furthermore, plant culture systems are altering from open to closed systems to improve the efficiency of water and nutrient use and to reduce the quantity of waste emission to the environment (Goto *et al*., 1996). Developed countries have imposed regulation demanding a transition from open to closed hydroponic systems (Bohme, 1995).

Currently, the propagation of seed potato is hydroponically done, mainly in using NFT (Chang *et al*., 2012) and aeroponic (Mbiyu *et al*., 2012) growing systems. These systems not only supplied adequate nutrient to plants but also allow to harvesting the mini-tubers, provide high seed quantity and quality. Whereas, several literatures mentioned the efficiency of hydroponic systems in seed potato production. However, little information on hydroponic set up, substrate and nutrient solution composition for potato tuber production in commercial scale (Novella *et al*., 2008; Tunio *et al*., 2020). Quantity and quality of potato are influenced by availability of nutrients and water in growing media (Chang and Lee, 2016).

Bio-stimulants are among the natural arrangements that treated as an additive to fertilizers and support the uptake of nutrients, promote plant growth and increase tolerance to biotic and abiotic stresses (Drobek *et al*., 2019). These stimulants can be effectively used in both agri- and horticultural crops. The main components used in such preparations are humic and fulvic acids, protein hydrolysates, compounds containing nitrogen, seaweed extracts, beneficial fungi and bacteria (Du-Jardin, 2015). Bio-stimulant composition may be based on single- or multi-component, but the synergic action of numerous diverse components has been observed. The purpose of this research work is to study influence of three bio-stimulants and three potato growing systems (aeroponic, pots and hydroponics) on the quantity and quality of potato tubers under Egyptian condition.

## Material and Methods

Two factorial experiments using randomized complete block design with three replications were conducted during fall seasons of 2017-2018 and 2018-2019 in an anti-aphid nylon greenhouse belongs to the Faculty of Agriculture Farm, Cairo University, Giza, Egypt (lat. 31°12'30'N, long. 30°07'01'E, altitude 139 m above sea level). The involving factors in this experiment included three commercial stimulants applied fo-liarly (Beet (BET), Calfruit (CAF), CTA Stymulant$^{-4}$ (CTA) extractions) and water used as control (CON) as well as three soilless systems (column Culture (COL), Pot culture (POT) and Aeroponic culture (AER)). The commercial bio-stimulants were obtained from Meristem Company. The description of used soilless systems and chemical compositions of applied commercial stimulants are showed in table 1 and 2; respectively. Seed of potato tubers (*Solanum tuberosum* L., *cv*. Sponta) were obtained from Daltex company-(Kafr El-Zayat, ELGharbia governorate, Egypt) and tubers were transplanted on October of 2017 and 2018 in three soilless systems at space of 30 cm × 25 cm among the plants, resulting in a plant density of 12 plants per square meter. the applied nutrient solution containing N, P, K, Ca, Mg, S, Fe, B, Cu, Mn, Zn and Mo (182, 41, 300, 200, 48, 158, 3, 1, 0.3, 1.3, 0.3 and 0.07 ppm, respectively) and this solution was continuously re-circulated four times per day and replaced every three weeks by changing the amount of N, P and Ca to 100, 141, 180 ppm after stolon initiation and to 60, 180, 160 ppm after tuber initiation, respectively. Also, the Electrical Conductivity (EC) was 2 ± 0.2 $dS \cdot m^{-1}$. The nutrient solution in tanks was replaced weekly and 2 $mol \cdot L^{-1}$ $H_3PO_4$ was used to maintain a pH of 5.8±0.2, which was checked daily (Mobini *et al.,* 2015).

### Plant growth and tuber production

After 75 days, five plants were selected randomly for determination vegetative growth parameters *i.e.* plant height, number of leaves /plant, number of main stems/ plant, chlorophyll content of leaves (using SPAD apparatus) and Leaf area /plant. Tubers of potato plant were harvest from each treatment after 110 day from planting date for determination total yield/ plants and its components (number of tuber/plant, tuber weight, tuber length, tuber diameter, tuber size and number of tuber).

### Tuber chemical properties

Starch content was determined according to formula. Starch% = 17.546 +199.07 (specific gravity - 1.0988), where specific gravity = tuber fresh weight/tuber volume (Shehata *et al*., 2018). Total Soluble Solid percentage, was determined by using digital refract meter (Abbe Leica model), according to the method described by A.O.A.C., (2000). Total sugars were determined in tuber by using the method described by A.O.A.C., (2005).

### Statistical analysis

The experimental design was two way randomized (the man factor: three soilless culture systems and sub factors: the commercial bio-stimulants) with 3 replicates. Combined analysis of variance were performed to determine any statistically significant differences. The

**Table 1:** View shows potato growth in different soilless culture systems.

| Soilless culture systems | Description | Image |
|---|---|---|
| **Column culture system** | The plants were grown vertically in upright cylindrical columns in four plastic gallons made of plastic (20 cm wide, 25 cm length and 40 cm height) ,two plantlet per gallon filled about 20 liters with mixture of substrates as perlite: peat moss (1:1v/v) and arrange and then placed in a greenhouse). |  |
| **Pot culture system** | The plants were grown plastic pots made of polystyrene (20cm diameter, and 30cm height). One plantlet per pot filled about 10 liters with mixture of substrates as perlite: peat moss (1:1v/v) and then placed in a greenhouse. |  |
| **Aeroponic culture system** | This system consist of box made of wood (1m wide, 2m length, 1m height, and 0.5m × 0.3m side windows every other meter, so that the operator can get access to the root system at harvest times). The top covering made of styrofoam is ceiling board should fit exactly over the rest of the structure. |  |

average data of two years were statistically analyzed using M-Stat program and the different letters in figures and tables indicate to significant variation according to the Duncan test ($P \leq 0.05$, Snedcor and Cokran, 1991). Bars in columns and ± values in tables indicate to standard deviation.

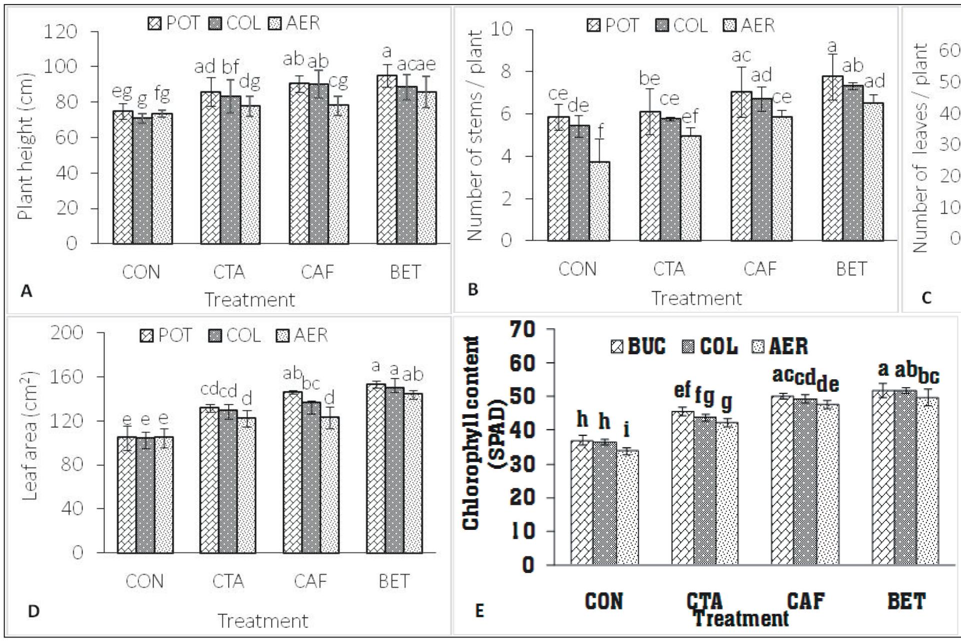
## Results and Discussion

### Changes in vegetative growth and morphological characteristics

Vegetative growth parameters, including plant height, number of main stems, number of leaves, leaf area and leaf chlorophyll content (SPAD), significantly affected by soilless culture systems (Table 3), treatment (Bio-stimulants, Table 4) and the interaction of bio-stimulants × soilless systems (Fig. 1). Growth parameters of potato plants grown in pot culture were slightly similar to column culture and higher than those grown in aeroponic system.

**Table 2:** Chemical composition of applied bio-stimulants.

| CTA stymulant$^{-4}$ | Calfruit | Beet |
|---|---|---|
| Seaweed extracts 20.5% (w/v) | Calfruit extract | Beat extracts |
| Cytokinins 120 mg/l | Total organic matter 16% (w/v) | Organic matter 40% (w/w) |
| Auxin 4 mg/l | Folic acid 15.16% (w/v) | Humic extracts 24% (w/w) |
| N 6.5% (w/v) | Free amino acids 0.3% (w/v) | Free amino acids 6% (w/w) |
| Fe (DPTA) 1.2% (w/v) | N 8.5% (w/v) | N 1.5% (w/w) |
| Zn (DPTA) 0.6% (w/v) | ($P_2O_5$) 0.17% (w/v) | P 0.7% (w/w) |
| Mn (DPTA) 0.6% (w/v) | ($K_2O$) 3.5% (w/v) | K 8% (w/w) |
| Mg (DPTA) 0.2% (w/v) | (MgO) 0.4% (w/v) | |
| | Ca 15.1% (w/v) | |




Columns followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. CON = control, CTA= CTA stymulant$^{-4}$, CAF= Calfruit bio-stimulant, BET= Beet bio-stimulant, POT = Pot system, COL= Column system and AER=Aeroponic system

**Fig. 1:** Vegetative growth characters of potato plants affected by interaction among bio-stimulants and soilless culture systems.

This reduction of vegetative growth parameters of potato plants grown in aerobic system could be attributed to lack of nutrient uptake in as well as blocked the mist by plant roots and exposure the plants and their roots and stolon's to sever drought stress (kawasaki *et al*., 2014).

Data in Table 2 shows the impact of bio-stimulants (treatment) on vegetative growth parameters of potato plants. Foliar application of bio-stimulates effect positively on potato growth properties. Plant height, number of main stems and number of leaves due to treatment with BET and CAL were similar and greater than for CTA and the CON (Table 4). Whereas, the maximum value of leaf area and SPAD was observed in potato plants treated foliarly beet extracts than all the other treatments. While the lowest values was recorded in control (CON). Improvement in growth parameters due to bio-stimulants application could be attributed to the vital role of humic acid, free amino acids and essential elements (Table 2). Beneficial effects of free amino acids on growth may be due to enhancement of the cell ultrastructure, particularly plastids in mesophyll tissue, which amended photosynthetic efficiency leading to production of more assimilates needed for formation of new cells (Kandil *et al*., 2013). Furthermore, humic acid stimulation of root growth, increased explosion of root hairs, production of smaller but more ramified secondary roots and enhanced nutrient uptake (Canellas *et al*., 2002).

**Table 3:** Effect of various soilless culture systems on some vegetative growth characters of potato plants.

| Growing systems | Plant height (cm) | Number of main stems/plant | Number of leaves/plant | Leaf area (cm$^2$) | SPAD |
|---|---|---|---|---|---|
| **POT** | 86.59±5.96$^{a}$ | 6.70±0.99$^{a}$ | 48.72±6.00$^{a}$ | 133.70±4.82$^{a}$ | 46.45±1.41$^{a}$ |
| **COL** | 83.13±6.78$^{ab}$ | 6.31±0.34$^{a}$ | 46.62±5.76$^{ab}$ | 129.83±5.69$^{a}$ | 45.54±0.98$^{a}$ |
| **AER** | 78.72±5.45$^{b}$ | 5.25±0.58$^{b}$ | 43.26±2.51$^{b}$ | 123.31±7.55$^{b}$ | 43.59±1.53$^{b}$ |

Values followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. POT = Pot system, COL= Column system and AER= Aeroponic system.

**Table 4:** Effect of different bio-stimulants on some vegetative growth characters of potato plants.

| Treat-ment | Plant height (cm) | Number of stems/plant | Number of leaves/plant | Leaf area (cm$^2$) | SPAD |
|---|---|---|---|---|---|
| **CON** | 73.11±3.04c | 5.01±0.74b | 42.40±6.07b | 104.27±8.70d | 35.97±1.20d |
| **CTA** | 82.24±7.65b | 5.61±0.53b | 44.20±3.04ab | 127.45±5.73c | 44.21±1.13c |
| **CAF** | 86.18±6.01ab | 6.54±0.70a | 48.57±6.28a | 135.17±4.28b | 49.23±1.08b |
| **BET** | 89.74±7.54a | 7.20±0.56a | 49.63±3.63a | 148.90±5.37a | 51.37±1.82a |

Values followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. CON = control, CTA= CTA stymulant$^{-4}$, CAF= Calfruit bio-stimulant, BET= Beet bio-stimulant.

There were significant interaction between soilless culture systems and different applied bio-stimulants for vegetative growth parameters ($P<0.05$). The maximum vegetative growth were observed with potato plants grown in pot system and supplied

**Table 5:** Effect of various soilless culture systems on tuber yield and its components of potato plants.

| Growing systems | Number of tubers/plant | Tuber weight (g) | Tuber Yield (g/plant) |
|---|---|---|---|
| **POT** | 16.99±0.78a | 51.93±2.86a | 882.29±16.30a |
| **COL** | 14.60±0.61b | 47.80±2.95b | 697.88±22.95b |
| **AER** | 12.60±0.57c | 36.95±1.11c | 465.57±10.63c |

Values followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. POT = Pot system, COL= Column system and AER= Aeroponic system.

foliarly with beet followed by plants grown column and aeroponic culture systems supplied by CAF and CTA compared to untreated plants. In the pot culture system, potato plants supplied foliarly with beet extract recorded a highest values of plant height (Fig. 1A), number of stems (Fig. 1B), number of leaves (Fig. 1C), leaf area (Fig. 1D) and leaf chlorophyll content (Fig. 1E) than all of the other treatments.

Plant height of potato plants supplied foliarly with beet bio-stimulant was increased by 21.04% in POT and 14.83% in COL and 8.17% in AER system (Fig. 1A). Whereas, the number of stems was higher by 24.58%, 25.78 and 42.7% for POT, COL and AER systems, respectively as compared to untreated control. Similar results noted in number of leaves (Fig. 1C), leaf area (Fig. 1D) and leaf chlorophyll content. The average of number of leaves, leaf area and leaf chlorophyll content was greater by 19.64%, 31.75% and 28.59% in POT, 14.83%, 30.76% and 29.47 in COL and 8.17%, 27.25 and 31.95 in AER, respectively as compared to untreated control. The best results of vegetative growth parameters were noted with potato plants grown in pot growing system and applied foliarly with beet extract. This improvement may be correlated to higher amount of free amino acid, humic acids and organic matters, essential elements of bio-stimulants (Table 2).

**Table 6:** Effect of bio-stimulants on tuber yield and its components of potato plants.

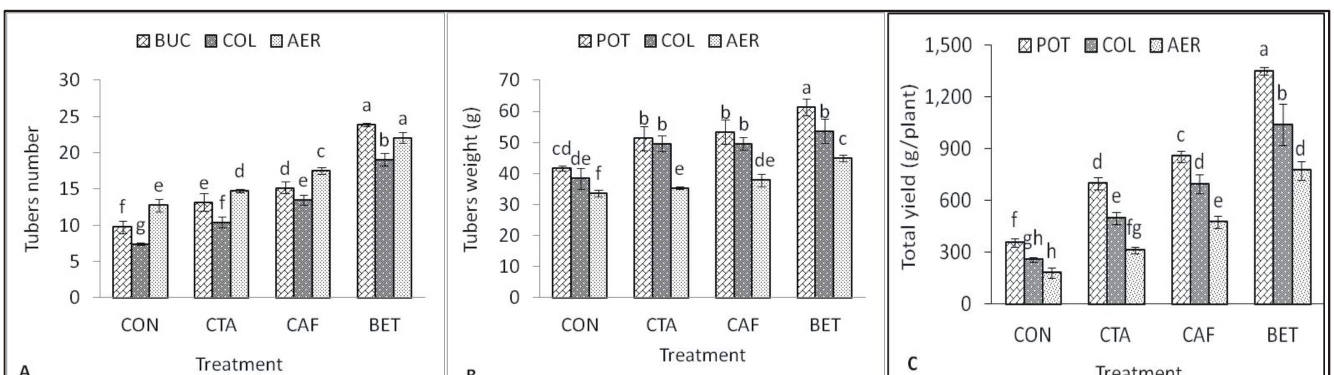
| Growing systems | Number of tubers/plant | Tuber weight (g) | Tuber Yield (g/plant) |
|---|---|---|---|
| **CON** | 9.98±0.62d | 36.58±1.79c | 365.06±9.91d |
| **CTA** | 12.78±0.75c | 45.44±2.85b | 580.72±13.34c |
| **CAF** | 15.38±0.63b | 46.91±2.65b | 721.48±17.05b |
| **BET** | 21.00±0.61a | 53.32±2.51a | 1119.72±26.22a |

Values followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. CON = control, CTA= CTA stymulant$^{-4}$, CAF= Calfruit bio-stimulant, BET= Beet bio-stimulant.

Total tuber yield of potato crop is more associated to number and weight of tuber (Mahmoud *et al*., 2020). The number, weight and total tuber yield of potato also affected by bio-stimulates soilless culture systems and all of their interactions. As shown in table 5. The maximum tuber number, weight and tuber yield were achieved by pot culture systems followed by column and aeroponic culture system. While, the lowest values of pervious parameters were recorded with aeroponic culture system.

The similar results were reported by Chang *et al*., (2012) who observed that the lower values of tuber number and weight were obtained from aeroponic culture system in comparison to hydroponic culture and deep-water culture. Furthermore, variances in tuber formation rate between soilless culture systems were reported by Tibbitts and Cao, (1994). According to their trials, tuberization was inhibited when roots and stolon's were exposed to continuous mist culture. In current study, Significant differences among soilless culture systems in tuber yield and its components could be associated to changes in nutrient solution, environment condition surrounded the root zone, plant growth and tuber formation rate, as Chang *et al*., (2012) reported.

In current study, tuber number and weight also significantly affected by treatment (Table 6) and by the




**Columns followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. CON = control, CTA= CTA stymulant$^{-4}$, CAF= Calfruit bio-stimulant, BET= Beet bio-stimulant, POT = Pot system, COL= Column system and AER= Aeroponic system**

**Fig. 2:** Tube yield and its components affected by interaction among bio-stimulants and soilless culture systems.

**Table 7.** Effect of various soilless culture systems on tuber quality.

| Soilless culture systems | Tuber length (cm) | Tuber diameter (cm) | Tuber size (cm3) | TSS (%) | Starch content (% fw) | Total sugars (% dw) |
|---|---|---|---|---|---|---|
| POT | 12.91±0.33a | 8.21±0.32a | 65.19±3.38a | 5.45±0.24a | 14.12±0.94a | 18.94±0.35a |
| COL | 11.15±0.37b | 7.08±0.34b | 55.79±4.62b | 4.86±0.19b | 13.95±0.88a | 17.92±0.21b |
| AER | 9.60±0.17c | 5.60±0.33c | 44.42±2.47c | 4.70±0.26b | 13.17±0.87b | 15.06±0.28c |

Values followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. POT = Pot system, COL= Column system and AER= Aeroponic system.

interaction of Treatment × soilless culture systems (Fig. 2). In general, foliar application with bio-stimulants improved tuber number, weight and total tuber yield. The maximum tuber number and yield were recorded with beet extract followed by CTA and Calfruit. While, the minimum values were recorded in control treatment (CON, Table 6). The similar results were reported by Shehata *et al*., (2017) who reported the biostimulants based on humic and amino acids significantly increased total yield and bulb weight compared to the control, during two growing seasons (2014/2015). The positive effect of free amino acids, humic acids and nutrient in biostimulants could be due to improved leaf photosynthesis and dry matter accumulation (Kandil *et al.*, 2013; El-Sayed *et al*., 2015).

Tuber yield and its component (number and weight) were affected by the interaction of Treatment × growing systems (Fig.) Maximum values of tuber number (Fig. 2A), tuber weight (Fig. 2B) and total tuber yield (Fig. 2C), were recorded with plants grown in pot culture system and supplied foliarly with beet bio-stimulant, while the minimum values were observed in untreated plant in aeroponic system. On average, the tubers number, tuber weight, total tuber yield of plant supplied with beet bio-stimulants were increased by 55.25%, 32.02% and 72.12% in pot system, 61.163, 28.35% and 72.17% in column culture system and 42.28%, 25.14% and 56.86% in aeroponic culture systems, respectively as compared to untreated plants (Fig. 2). Furthermore, the increase of number, tuber weight, total tuber yield of plant supplied with CAF bio-stimulants were higher by 35.55%, 21.79% and 57.92% in pot culture system, 45.11%, 22.48% and 57.45% in column culture system and 27.14%, 11.13% and 35.249% in aeroponic culture systems, respectively as compared to untreated plants. Reduction of tuber number, weight and tuber yield of potato plants grown in aeroponic culture system although supplied foliarly with by different biostimulants was clearly observed during exportation. These results were in agreement with some scientific investigators who stated that reduction in total tuber yield and its components in aeroponic systems is linked to delay the tuber formation and tuberization due to extending vegetative growth (Ritter *et al*., 2001; Farran and Mingo-Castel, 2006). This delayed was due to a relatively lack of nutrient supplement or/ and lack of mechanical stress such as intermittent misting in stolon environment as pointed out by Wheeler, (2006). Tuber formation was occurred when plants were exposed to a severe stress, as when irrigation was periodically stopped and plants wilted (Chang *et al*., 2012). It is likely that the occurred in pot and column culture systems in this study could be attributed the exposure the potato to periodical stress that induced the earlier tuberization process.

**Changes in potato tuber quality**

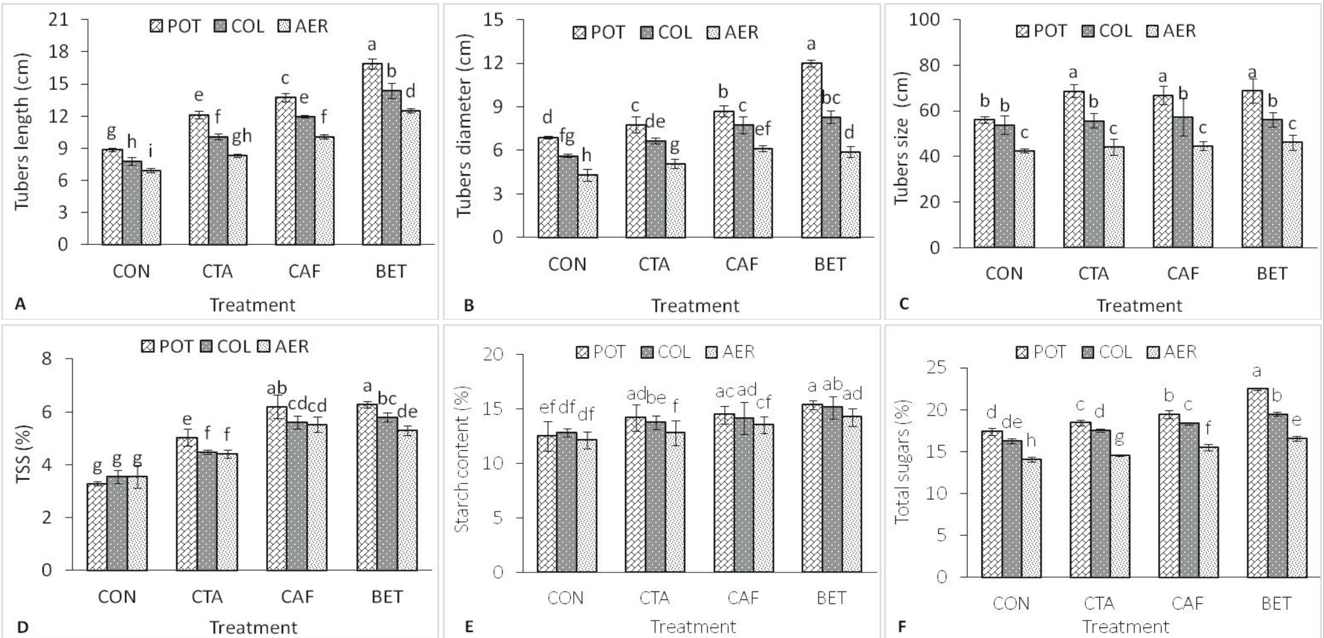
Tuber quality parameters also affected by soilless culture systems, treatment and all of their interactions (Table 7, 8 and Fig. 3). The maximum tuber quality tuber included, tuber length, tuber diameter, tuber size, TSS, starch and total sugars content, were recorded with potato plants grown in pot culture system followed by column and aeroponic culture systems. While, the lowest values of pervious parameters were noted in aeroponic culture system (Table 7).

Foliar application of bio-stimulates (treatments) significantly enhanced the tuber quality parameters (Table 8, $P \leq 0.05$). The highest values of tuber length, tuber diameter, TSS, starch and total sugars content were

**Table 8.** Effect of bio-stimulants on tuber quality of potato plants.

| Treatments | Tuber length (cm) | Tuber diameter (cm) | Tuber size (cm3) | TSS (%) | Starch content (% fw) | Total sugars (% dw) |
|---|---|---|---|---|---|---|
| CON | 7.98±0.23d | 5.61±0.21d | 50.90±2.10b | 3.80±0.25c | 12.70±0.81c | 15.77±0.33d |
| CTA | 10.18±0.25c | 6.50±0.36c | 56.24±3.18a | 4.64±0.18b | 13.35±0.99bc | 16.85±0.22c |
| CAF | 11.93±0.23b | 7.53±0.39b | 56.28±4.80a | 5.78±0.32a | 14.04±1.04b | 17.79±0.34b |
| BET | 14.78±0.45a | 8.22±0.35a | 57.11±3.88a | 5.80±0.16a | 14.91±0.74a | 18.82±0.22a |

Values followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. CON = control, CTA= CTA stymulant[4], CAF= Calfruit bio-stimulant, BET= Beet bio-stimulant.



Columns followed by different letters indicate significant differences at the 0.05 probability level according to Duncan Test. CON = control, CTA= CTA stymulant[-4], CAF= Calfruit bio-stimulant, BET= Beet bio-stimulant, POT = Pot system, COL= Column system and AER= Aeroponic system.

**Fig. 3:** Tube quality affected by interaction among bio-stimulants and soilless culture systems.

obtained by beet extract application than all the other treatment. While, the lowest values were in untreated plants. Whereas, the tuber size of potato plants supplied foliarly with bio-stimulants were similar and greater than untreated plants (Table 8).

In addition, there were significant interaction between soilless culture systems and different bio-stimulants for the tuber quality parameters ($P \leq 0.05$), except tuber size (Fig. 3C). Under different soilless culture systems, foliar application of bio-stimulants with significantly improved all tuber quality parameters compared to control plants (Fig. 3). The highest values of tuber quality parameters were achieved by foliar application of beet bio-stimulant for plants grown in pots culture system followed by column culture system with CAF extract and CTA with aeroponic culture system (Fig. 3A and B).

Compared to untreated plants, the tuber length and diameter of potato plants (Fig. 3A and B) supplied with beet extract significantly increased by 47.66% and 42.42% in pot culture system, 45.79% and 32.29% in column culture system and 44.56% and 27.12%; respectively. On the other side, the size of tuber produced from different soilless culture system and treated with BET, CAF and CTA bio-stimulants were similar and greater than the control plants (Fig. 3C).

The similar trends were observed with the chemical composition of potato tuber in terms TSS, starch and total sugars contents. The maximum tuber TSS (Fig. 3D), starch (Fig. 3E) and total sugar contents (Fig. 3F) were obtained by potato plants grown in post culture system and treated foliarly with beat bio-stimulant compared to the other treatments. While, the minimum values were observed in control (Fig. 3).

With beet bio-stimulant supplementation, the tuber TSS, starch and total sugar contents were increased by 47.78%, 18.74% and 22.53% for potato tuber produced from pot system, 38.63%, 15.28% and 16.37% for potato tuber produced from column system and 34.8%, 10.12% and 11.9% for potato tuber produced from aeroponic culture system; respectively as compared to control.

Likewise, TSS, starch and total sugar contents of potato tuber produced from column and aeroponic culture systems and supplied with CAF and CTA were greater than untreated plants. In column culture system, the tuber TSS, starch and total sugar contents were higher by 38.6%, 15.3% and 16.4% for tuber potato of plants treated foliarly with BET extract, 36.5 %, 9.4 % and 11.4% for tuber potato of plants treated foliarly with CAF extract and 20.5%, 6.6% and 7.2% for tuber potato of plants treated foliarly with CTA; respectively as compared to control.

Overall, in soilless culture systems, application of bio-stimulants containing organic matter, humic acid, free amino acids, plant hormones and essential elements that improved quality of potato plants. This improvement is could attribute to accumulation of protein, sugars and carbohydrate in potato tubers, as reported by several researchers (Shehata *et al*., 2017; Zarzecka *et al*., 2018 Merghany; Merghany *et al*., 2019).

## Conclusion

The current study indicated that the interaction among soilless cultures systems and biostimulants significantly improved the vegetative growth properties as well as quantity and quality characteristics of potato tuber. The best potato vegetative growth, tuber yield and tuber quality parameters of potato plants supplied foliarly with beet extract and grown in different culture systems. Meanwhile, foliar application with bio-stimulants, especially beet extract, were effective in enhancing plant height, leaf area, chlorophyll, number of stem and leaves and total tuber yield than CTA stymulant$^{-4}$ and Calfruit bio-stimulants. Furthermore, application of bio-stimulants improved tuber quality, included tuber length, diameter, weight, number and chemical properties such as TSS, starch and sugars contents. Overall, foliar supplementation of bio-stimulants with nutrient solutions in soilless culture is considered appropriate strategy for producing high tuber yield and quality.

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