Journal of Plant Production

Journal homepage & Available online at: www.jpp.journals.ekb.eg

Enhancing the Aesthetic and Health Standards of Croton Plants (*Codiaeum variegatum*) through Integrated Fertilization with Natural Stimulants and Mineral Nutrients

Hekmat Y. Massoud[1]; Boushra A. Mohamed[2]; Fatma R. Ibrahim[1*] and M.A. M. M. El-Erian[2]

[1] Vegetable and Floriculture Department, Faculty of Agriculture, Mansoura University, Egypt
[2] Horticultural Research Institute, Agriculture Research Centre, Giza, Egypt

ABSTRACT

The study aimed to pinpoint the most efficacious natural stimulant in conjunction with mineral fertilization (N, P, K) and provide actionable guidelines for enhancing the health and overall ornamental excellence of croton plants. The experiment involved eighteen treatments, encompassed all possible combinations of two levels of NPK fertilization **(**0.0 and 2.0 g pot^{-1}) and some different foliar applications of stimulants **[**Control, yeast extract (5.0 and 10.0 g L^{-1})**,** seaweed extract (1.0 and 2.0 cm^3 L^{-1}), garlic extract (5.0 and 10.0 cm^3 L^{-1}**)** as well as black tea extract (5.0 and 10.0 cm^3 L^{-1})]. The obtained results indicate that mineral fertilization recorded highest values of plant height (cm), No. of leaves plant^{-1}, leaf area (cm^2 plant^{-1}), concentration of N, P, K as well as chlorophyll a & b compared to the control group. However leaf total phenol content, carotene and anthocyanin pigments were decreased. The black tea extract at rate of 10.0 cm^3 L^{-1} was the superior natural stimulant for obtaining the maximum values of all aforementioned traits expect the chlorophyll a & b. Generally, the combination of NPK fertilization and black tea extract at 10.0 cm^3 L^{-1} resulted in the best performance. It could be recommended that growers can potentially enhance the health and ornamental excellence of croton plants, leading to more vibrant and attractive ornamental displays**.**

Keywords: Yeast, seaweed, garlic, black tea, croton

INTRODUCTION

Croton (*Codiaeum variegatum* L.) is a widely cultivated ornamental plant known for its vibrant and multicolored foliage, making it a popular choice for indoor and outdoor landscaping (Djangaopa *et al.* 2020). Beyond its ornamental value, croton also plays a crucial role in improving air quality as it has been found to remove harmful indoor air pollutants (Kanedi *et al.* 2021). Like many cultivated plants, croton's optimal growth and quality depend on the availability of essential nutrients (Nio *et al.* 2023). Nitrogen (N), phosphorus (P), and potassium (K) are essential nutrients for croton plants. Nitrogen is crucial for the overall growth and development of the plant, as it plays a key role in photosynthesis and the formation of proteins (Barker and Bryson, 2016). Phosphorus is essential for root development and overall energy transfer within the plant (Malhotra *et al.* 2016). Potassium is important for croton plant overall health and vigor, as it helps regulate water uptake, enhances disease resistance, and promotes the plant's tolerance to environmental stress (Mengel, 2016). Properly balanced NPK fertilization is critical for the optimal growth and vibrant appearance of croton plants (Constanta and Simona, 2015).

The incorporation of natural stimulants into ornamental fertilization programs offers a promising avenue for elevating overall quality (Nofal *et al.* 2021). These stimulants bring a range of benefits, as they not only enhance nutrient uptake efficiency but also development, and contribute the enhancement of foliage quality (Kisvarga *et al.* 2022).

Yeast extract, when incorporated into ornamental plant fertilization programs, can promote healthier, more vibrant, and aesthetically pleasing foliage, making it a valuable asset in ornamental horticulture (El-Shawa *et al.* 2020; Zaman *et al.* 2022).

Seaweed extract provides ornamental plants with a holistic nutritional boost, enhancing their overall health, promoting robust growth, and aiding in stress resistance (Rizk and Elngar, 2020; Alhasan *et al.* 2021).

Garlic extract contains essential nutrients such as sulfur, phosphorus, and potassium, which promote overall plant health and vigor (Abbasifar *et al.* 2020; Attia *et al.* 2020). The presence of antioxidants in garlic extract also contributes to stress tolerance and helps ornamental plants thrive in adverse environmental conditions (Singh *et al.* 2022).

Tea extract contains a range of phytochemicals, including catechins, flavonoids, and polyphenols, which act as antioxidants, protecting plants from oxidative stress and enhancing their overall resilience (Li *et al.* 2013). Additionally, tea extract contains natural plant growth regulators, such as auxins, which can stimulate root development and encourage robust foliage growth (Senanayake *et al.* 2013).

This investigation aimed to pinpoint the most efficacious natural stimulant in conjunction with mineral fertilization (N, P, K). Croton (*Codiaeum variegatum*) plant health and their overall ornamental excellence were also evaluated.

*** Corresponding author.**
E-mail address: floyisa@mans.edu.eg
DOI: 10.21608/jpp.2023.246928.1283

MATERIALS AND METHODS

Experimental location and implementation period

This research work took place at Al-Mansoura Agricultural Research Station, which is part of the Agricultural Research Center, Egypt (31.0500°N latitude and 31.3833°E longitude). The study was conducted under greenhouse conditions and spanned from the 15th of October to the 15th of August, during the seasons of 2021/2022 and 2022/2023 (A period of 10 months for each season).

Plant material

The cultivar of Croton (*Codiaeum variegatum* L.) used in this study was Petra c.v., which was sourced from commercial nursery. The Petra cultivar is characterized by its broad leaves featuring red veins and margins (Bakheet *et al.* 2018).

Studied substances

1.N, P, K fertilizer:

A commercial compound known as Eco Fol, with an NPK fertilizer ratio of 20-20-20, was utilized in this study. A solution was prepared by dissolving 2.0 grams of Eco Fol in one liter of tap water and used as a soil drench.

2. Extracts of the studied stimulants:

Yeast extract

Preparation of yeast solution of (5 and 10 g L^{-1}) was carried out according to El-Ghamriny *et al.* (1999), while Analysis of yeast extract was done as described by Walinga *et al.* (2013); Vieira *et al.* (2016), and the data were presented in Table A.

Table A. Chemical components of yeast extract

Macro elements (%)		Micro elements (mg kg^{-1})		Vitamins(mg $100g^{-1}$)		Amino acids (%)		Others(%)	
N	7.00	Cu	5.5	Vit B1	24.0	Arginine	1.52	Crude fiber	4.20
P	0.75	Zn	80	Vit B2	20.4	Lysine	1.20	Crude protein	3.00
K	1.15	Fe	103	Vit B6	20.2	Glutamic	4.00	Carbohydrate	20.0
Mg	0.25	Mn	45	Thimain	24.0	Alanine	1.70	Crude fat	4.00

Seaweed extract

The commercial product Eco Alga was the source of seaweed fertilizer, as it was purchased from the Egyptian commercial market. The company brochure lists the components of Eco Alga, a commercial seaweed extract product, which include stimulating elements like cytokinins (0.02%), IAA (0.03 %), ABA (0.01%), protein (5%), carbohydrate (22%), potassium (2.5%), alginic acid (1.5%), and mannitol (0.5%). Eco Alga was in a liquid form, and two different concentrations (1.0 and 2.0 cm^3 L^{-1}) were prepared for utilization in this research study as a foliar application.

Garlic extract

Garlic extract was prepared as described by El-Sherpiny *et al.* (2022). The resulting garlic extract, based on dry mass, contained 3.2 % of nitrogen (N), 1.5% of phosphorus (P), 5.3 % of potassium (K), 0.35 % of calcium (Ca), and 0.09% of iron (Fe). All nutrient elements were determined *via* the standard methods described by Walinga *et al.* (2013). Two different concentrations of garlic extract (5.0 and 10.0 cm^3 L^{-1}) were used as a foliar application in this investigation.

Black tea extract

Ethanol was used as a solvent to extract compounds from black tea leaves as described by Gramza *et al.* (2005) and Bhebhe *et al.* (2016).. The components of the extracted material were assessed following the standard methods established by Walinga *et al.* (2013). Two concentrations, specifically 5.0 and 10.0 cm^3 L^{-1}, to be used in this study as foliar application. Table B shows the black tea extract components.

Table B. Chemical components of black tea extract

Macro elements (%)		Other components (%)			
N	6.50	Catechins	20.5	Flavonoids	12.0
P	0.85	Theaflavins	15.2	Anthocyanin (mg $100g^{-1}$)	2.40
K	1.30	Caffeine	3.00	//	//
Mg	0.30	Polyphenols	25.9	//	//

Experimental design and treatments:

The experiment involved eighteen treatments, which encompassed all possible combinations of two levels of NPK fertilization and some different foliar applications (9 treatments). These treatments were organized in a split-plot design, with the NPK fertilization levels serving as the main factor, and the foliar application of bio-stimulants as the sub main factor. Each treatment was replicated nine times, resulting in a total of 162 pots used for each season of the study. The various treatments under investigation were represented by the following symbol;

T_1: Without NPK
T_2: With NPK at rate of 2.0 g pot^{-1}
F_1: Without foliar applications
F_2: Yeast extract at rate of 5.0 g L^{-1}
F_3: Yeast extract at rate of 10.0 g L^{-1}
F_4: Seaweed extract at rate of 1.0 cm^3 L^{-1}
F_5: Seaweed extract at rate of 2.0 cm^3 L^{-1}
F_6: Garlic extract at rate of 5.0 cm^3 L^{-1}
F_7: Garlic extract at rate of 10.0 cm^3 L^{-1}
F_8: Black tea extract at rate of 5.0 cm^3 L^{-1}
F_9: Black tea extract at rate of 10.0 cm^3 L^{-1}

Experimental set up:

Croton plants 20 cm height were brought from a commercial nursery and subsequently transplanted into their final plastic pots (20 cm diameter and 18 cm depth) filled with a mixture of sand and clay (1:1 v/v). Some characteristics of the experimental medium are presented in Table (C), as the analysis was done according to Dewis and Freitas, (1970). The NPK fertilization treatments were applied at a rate of 2.0 g pot^{-1} as a soil drench, divided into ten equal doses with each dose consisting of 100 ml. The initial dose was applied 20 days after transplanting, and subsequent doses were applied at 30 days intervals. The foliar application of each bio-stimulant was performed 10 times during the experiment (each every month) using a plastic atomizer, starting 20 days from transplanting. Irrigation was performed on a weekly basis during the winter months from October to February. In contrast, from March to August during the summer months. The irrigation frequency was increased to twice a week.

Table C. Characteristics of the experimental medium

Characteristics	Values
Available N, mg kg^{-1}	38.9
Available P, mg kg^{-1}	10.25
Available K, mg kg^{-1}	200.3
WHC,%	38
O.M,%	1.03
CEC, cmol kg^{-1}	32.2
EC, dSm^{-1}	2.20
pH	8.00
Sand,%	48,%
Silt,%	10,%
Clay,%	42,%
Texture class is sandy clay	

Measurements:

1. Growth characteristics

Plant height (cm), No. of leaves plant^{-1}, leaf area (cm^2 plant^{-1}), were recorded at the 15st of August of each season.

2. Leaf chemical constituents

N, P, K concentrations were determined in the leaves as described by Walinga *et al.* (2013). The total phenol content in the fresh leaves was determined following the method described by Sengul *et al.* (2009) at the 15st of August. In addition, chlorophylls *i.e.,* chlorophyll a & b (mg g^{-1} F.W), carotenoids *i.e.,* carotene (mg g^{-1} F.W) and flavonoids *i.e.,* anthocyanin pigment (mg 100g^{-1}) were determined in the leaves according to the standard methods described by Schoefs, (2005).

Statistical analysis

The statistical analysis of the data was conducted using CoStat (Version 6.303, CoHort, USA, 1998-2004). To compare means, the least significant difference (LSD) test was applied at a significance level of 0.05, following the procedure outlined by Gomez and Gomez (1984). To compare the means among the treatments, Duncan's test was employed (Duncan, 1955).

RESULTS AND DISCUSSION

1. Growth characteristics

Effect of mineral fertilization (NPK)

Table 1 indicates that mineral fertilization resulted in the highest values for various growth parameters studied, including plant height (51.89 and 52.70 cm for 1st and 2nd seasons, respectively), No. of leaves plant^{-1} (45.26 and 47.48 for 1st and 2nd seasons, respectively) and leaf area (143.63 and 145.59 cm^2 plant^{-1} for 1st and 2nd seasons, respectively) compared to the control.

Effect of bio stimulants

Data of Table 1 illustrate that the black tea extract at rate of 10.0 cm L^{-1} (F_9 treatment) was the superior natural stimulant for obtaining the maximum values of plant height (50.25 and 51.58 cm), No. of leaves plant^{-1} (43.67 and 46.17) and leaf area (141.54 and 143.68 cm^2 plant^{-1}) for 1st and 2nd seasons, respectively. This treatment followed by the F_8 treatment, which consisted of plants sprayed with the black tea extract at rate of 5.0 cm L^{-1}, while the control treatment (F_1 treatment) possessed the lowest values.

On the other hand, it is worth noting that the best stimulant for obtaining the best growth performance, as shown in Table (1) was black tea extract followed by yeast extract then garlic extract and lately seaweed extract. Also, it was noticed that the values of all aforementioned traits increased as the concentration of the bio-stimulant extract increased compared to its lower concentration and the control treatment. The same pattern remained consistent throughout both seasons under study.

Table 1. Effect of mineral fertilization (NPK) and bio stimulant extracts on growth criteria (No. of leaves, plant height (cm) and leaf area (cm) of croton plant during two successive seasons (2021/2022 and 2022/2023).

Treatments	Plant height, cm		No. of leaves plant^{-1}		Leaf area cm^2 plant^{-1}	
	1stSeason	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Main factor: Mineral fertilization (NPK)						
T_1	42.04b	42.98b	34.93b	36.52b	111.24b	112.72b
T_2	51.89a	52.70a	45.26a	47.48a	143.63a	145.59a
LSD at 5%	3.11	3.52	1.67	0.42	4.31	2.95
Sub main factor: Foliar application of bio stimulants						
F_1	39.58g	41.42g	34.00h	35.67g	112.70i	113.87i
F_2	48.50bc	48.75cd	41.17cd	43.17c	131.14d	133.02d
F_3	49.33ab	49.83bc	41.83c	44.83b	134.75c	136.69c
F_4	44.58f	45.58f	37.83g	39.50f	116.76h	118.13h
F_5	45.75ef	46.75ef	39.17f	40.17ef	120.37g	122.03g
F_6	46.58de	47.50de	39.83ef	41.33de	124.04f	125.72f
F_7	47.67cd	48.42cde	40.50de	42.17cd	127.62e	129.28e
F_8	50.42a	50.75ab	42.83b	45.00ab	137.99b	139.94b
F_9	50.25a	51.58a	43.67a	46.17a	141.54a	143.68a
LSD at 5%	1.47	1.72	0.77	1.20	1.99	2.11

Since, T1: Without NPK ; T2: With NPK ; F1: Without foliar applications ; F2: Yeast extract at rate of 5.0 g L-1 ; F3: Yeast extract at rate of 10.0 g L-1 ; F4: Seaweed extract at rate of 1.0 cm L-1 ; F5: Seaweed extract at rate of 2.0 cm L-1 ; F6: Garlic extract at rate of 5.0 cm L-1 ; F7: Garlic extract at rate of 10.0 cm L-1 ; F8: Black tea extract at rate of 5.0 cm L-1 ; F9: Black tea extract at rate of 10.0 cm L-1

Effect of the Interaction

The combined applications among the mineral fertilization (NPK) and bio-stimulant extracts significantly influenced growth performance of croton, including plant height (cm), No. of leaves plant^{-1} and leaf area (cm^2 plant^{-1}) (Figs 1, 2 and 3), particularly in the interaction between T_2 treatment (in the presence of N, P, K) and black tea extract at a concentration of 10 cmL^{-1} (F_9 treatment), which caused the highest values of all aforementioned traits. Conversely, the control treatment (T_1 x F_1) exhibited the lowest values .The identical pattern persisted consistently throughout both seasons under examination.

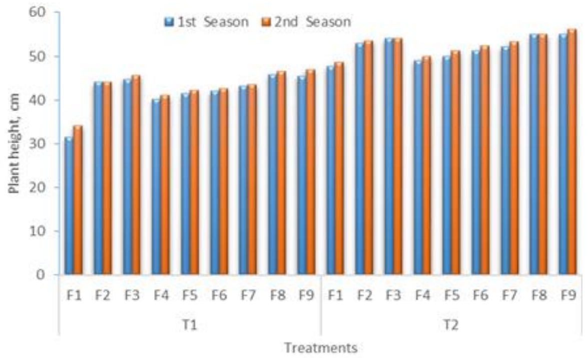

Fig. 1. Effect of mineral fertilization (NPK) and bio stimulant extracts on plant height of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

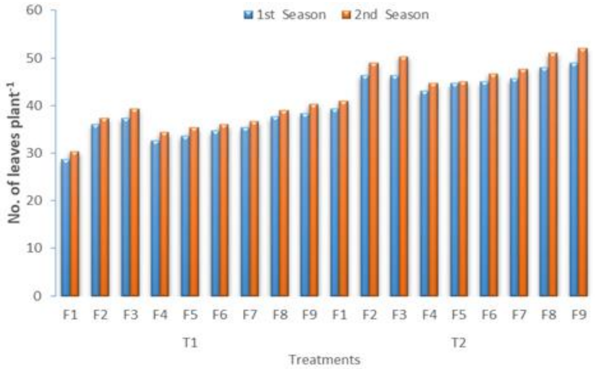

Fig. 2. Effect of mineral fertilization (NPK) and bio stimulant extracts on No. of leaves of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

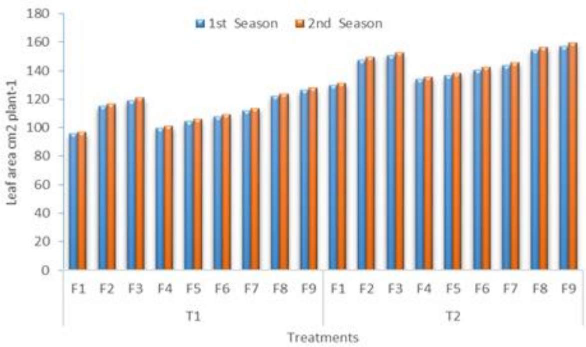

Fig. 3. Effect of mineral fertilization (NPK) and bio stimulant extracts on leaf area of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

The results regarding the individual effects of mineral fertilization (N, P, K) and bio-stimulants on croton plant growth can be explained based on the principles of plant physiology and the unique properties of these natural stimulants as follows;

Mineral fertilization provides essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are fundamental for plant growth. NPK fertilizers ensure that these nutrients are readily available in the soil. Nitrogen is vital for leafy growth, phosphorus supports root development and flowering, and potassium aids overall plant health and stress resistance (Farouk *et al.* 2023). Adequate nutrient supply, especially nitrogen, facilitates optimal photosynthesis. More leaves and larger leaf areas result in increased surface area for photosynthesis, enabling the plant to convert more sunlight into energy. This higher photosynthetic activity contributes to the observed increase in the number of leaves, plant height, and overall plant vigor (Ibrahim *et al.* 2023).

Black tea extract emerged as the superior bio-stimulant. This can be attributed to its rich composition, including various polyphenols and micronutrients, which promote plant growth and health. Polyphenols can act as antioxidants, protecting plant cells from damage, while micronutrients play crucial roles in enzymatic processes (Turkmen *et al.* 2007). The higher concentration likely provided a more significant supply of these beneficial compounds, resulting in superior growth. Yeast extract came after black tea extract due to its abundant reservoir of amino acids, notably B vitamins, and essential minerals (El-Shawa *et al.* 2020). Together, these constituents synergize to elevate plant growth, optimize nutrient absorption, and bolster resilience to stress factors. Amino acids facilitate crucial protein synthesis, while vitamins actively participate in metabolic functions, enhancing the overall robustness of plants (Khudair and Hajam, 2021). Garlic extract came in the third order after yeast and black tea extracts due to it is rich in natural sulfur compounds, including allicin, which can enhance plant resistance to pests and diseases (Abbasifar *et al.* 2020). Additionally, garlic extract contains essential nutrients such as sulfur, phosphorus, and potassium, which promote overall plant health and vigor (Attia *et al.* 2020). Seaweed extract came in the fourth order superior to control treatment due to it is packed with essential nutrients such as macro and micronutrients, amino acids, vitamins (including A, C, E, and B vitamins), and growth-promoting hormones like auxins and cytokinins (Rizk and Elngar, 2020).

The observed improvement in growth traits as the concentration of the bio-stimulant extract increased reflects a concentration-dependent response. Higher concentrations of these bio-stimulants extracts deliver more nutrients, growth-promoting compounds, and phytochemicals to the plants. Consequently, growth parameters, such as the number of leaves, plant height, and leaf area, showed a positive correlation with increasing extract concentration.

The effectiveness of bio-stimulants followed this order: Black tea extract > yeast extract > garlic extract > seaweed extract. This ranking is likely due to variations in their nutrient content, bioactive compounds, and stimulant properties. Black tea extract, with its diverse phytochemical profile, had the most pronounced positive impact on growth.

The observed synergistic effect between NPK fertilization (T_2 treatment) and black tea extract at a concentration of 10.0 cm L^{-1} (F_9 treatment) can be explained as follows:

NPK fertilization provides essential nutrients, while black tea extract contributes additional micronutrients and beneficial compounds. The combined effect results in optimal nutrient availability for plant uptake. Black tea extract, known for its antioxidant properties, can help mitigate stress and protect plant cells. In combination with NPK, this effect is likely amplified, leading to healthier and less-stressed plants. The synergy between the two treatments likely leads to a greater improvement in photosynthesis, root development, and overall growth than either treatment alone, resulting in the highest values for all growth traits. The consistent pattern observed across both seasons underscores the reliability of these effects, indicating that the synergy between NPK and black tea extract can be consistently reproduced over time. These findings align with principles of plant nutrition, physiology, and synergistic interactions in agriculture as mentioned by Abbasifar *et al.* (2020); Attia *et al.* (2020); El-Shawa *et al.* (2020); Khudair and Hajam, (2021); Farouk *et al.* 2023) and Kirkby, (2023).

Leaf chemical constituents

Effect of mineral fertilization (NPK)

Data presented in Table (2) exhibit divergent trends for the various parameters under investigation. Specifically, in terms of leaf nitrogen, phosphorus, potassium, mineral fertilization realized the highest values (2.85% and 2.90% for the 1st and 2nd seasons, respectively, for leaf nitrogen; 0.389% and 0.397% for the 1st and 2nd seasons, respectively, for leaf phosphorus; 2.58% and 2.61% for the 1st and 2nd seasons, respectively, for leaf potassium) compared to the control group (without NPK), which recorded the lowest values (2.42% and 2.47% for the 1st and 2nd seasons, respectively, for leaf nitrogen; 0.334% and 0.340% for the 1st and 2nd seasons, respectively, for leaf phosphorus; 2.12% and 2.15% for the 1st and 2nd seasons, respectively, for leaf potassium).

Conversely, as shown in the same Table, mineral fertilization led to the lowest values for leaf total phenol content (51.47 mg g^{-1} and 53.61 mg g^{-1} for the 1st and 2nd seasons, respectively) compared to the control group which caused the highest values (53.46 mg g^{-1} and 55.11 mg g^{-1} for the 1st and 2nd seasons, respectively).

Effect of bio stimulants

Data presented in Table (2) demonstrate that the most effective natural stimulant for achieving peak values in various parameters, including leaf nitrogen (2.82 and 2.87% for the 1st and 2nd seasons, respectively), leaf phosphorus (0.385 and 0.393% for the 1st and 2nd seasons, respectively), leaf potassium (2.54 and 2.58% for the 1st and 2nd seasons, respectively), and leaf total phenol content (55.39 and 57.84% for the 1st and 2nd seasons, respectively) was the black tea extract applied at a rate of 10.0 cm^3L^{-1} (designated as the **F_9** treatment). Conversely, the control treatment (**F_1** treatment) exhibited the lowest values for these parameters, with leaf nitrogen content at 2.43 and 2.49% for the 1st and 2nd seasons, leaf phosphorus at 0.335 and 0.340% for the 1st and 2nd seasons, leaf potassium at 2.14 and 2.16% for the 1st and 2nd seasons, and leaf total phenol content at 48.05 and 49.43% for the 1st and 2nd seasons.

Also, it is noteworthy that the most effective stimulant for achieving the highest values across all the mentioned traits, as depicted in Table 2, was the black tea extract, followed by the yeast extract, then the garlic extract, and finally the seaweed extract. Additionally, it was observed that the values for all the aforementioned traits exhibited an upward trend as the concentration of the bio-stimulant extract increased, in comparison to the lower concentration and control treatment.

Table 2. Effect of mineral fertilization (NPK) and bio stimulant extracts on leaf chemical constituents (nitrogen, phosphorus and potassium) of croton plant as well as leaf content of total phenol during two successive seasons (2021/2022-2022/2023).

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Total phenol (mg g^{-1})	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Main factor: Mineral fertilization (NPK)								
T_1	2.42b	2.47b	0.334b	0.340b	2.12b	2.15b	53.46a	55.11a
T_2	2.85a	2.90a	0.389a	0.397a	2.58a	2.61a	51.47b	53.61a
LSD at 5%	0.03	0.09	0.013	0.008	0.07	0.01	1.56	*N.S
Sub main factor: Foliar application of bio stimulants								
F_1	2.43f	2.49f	0.335h	0.340h	2.14h	2.16i	48.05e	49.43e
F_2	2.68bc	2.72bc	0.368d	0.375d	2.39cd	2.43d	54.36b	56.14b
F_3	2.74ab	2.80ab	0.374c	0.382c	2.45bc	2.50c	54.88ab	56.65ab
F_4	2.49ef	2.54ef	0.343g	0.350g	2.20gh	2.23h	49.53d	51.00d
F_5	2.55de	2.60de	0.351f	0.357f	2.25fg	2.29g	50.08d	51.64d
F_6	2.59d	2.64cd	0.357e	0.365e	2.30ef	2.34f	52.24c	53.92c
F_7	2.63cd	2.69cd	0.361e	0.368e	2.35de	2.39e	52.83c	54.70c
F_8	2.78a	2.84a	0.379b	0.387b	2.50ab	2.54b	54.87ab	57.84ab
F_9	2.82a	2.87a	0.385a	0.393a	2.54a	2.58a	55.39a	57.96a
LSD at 5%	0.09	0.09	0.004	0.005	0.08	0.04	0.78	0.72

**Since, T1: Without NPK ; T2: With NPK ; F1: Without foliar applications ; F2: Yeast extract at rate of 5.0 g L-1 ; F3: Yeast extract at rate of 10.0 g L-1 ; F4: Seaweed extract at rate of 1.0 cm L-1 ; F5: Seaweed extract at rate of 2.0 cm L-1 ; F6: Garlic extract at rate of 5.0 cm L-1 ; F7: Garlic extract at rate of 10.0 cm L-1 ; F8: Black tea extract at rate of 5.0 cm L-1 ; F9: Black tea extract at rate of 10.0 cm L-1 *N.S =Non-significant **

Effect of the interaction

In terms of leaf nitrogen, phosphorus, potassium, the data in Figs from 4 to 6 elucidate that the interaction between T_2 treatment (in the presence of N, P, K) and black tea extract at a concentration of 10 cmL^{-1} (F_9 treatment) realized the highest values of all aforementioned traits. Conversely, the control treatment (T_1 x F_1) exhibited the lowest values for both studied seasons.

Regarding the total phenol content (Fig. 7), it is evident that the values for plants subjected to NPK treatment, regardless of the applied stimulants, were consistently lower than those of their counterparts grown without NPK fertilizers.

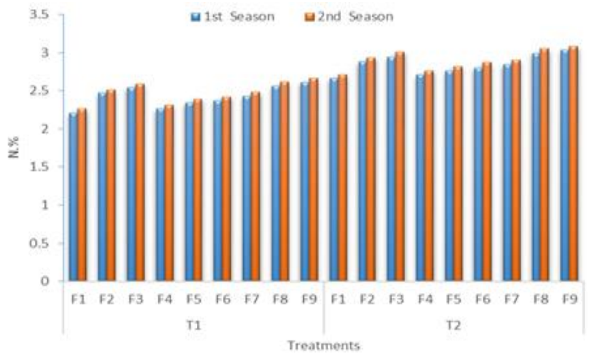

Fig. 4. Effect of mineral fertilization (NPK) and bio stimulant extracts on leaf chemical constituents (nitrogen) of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

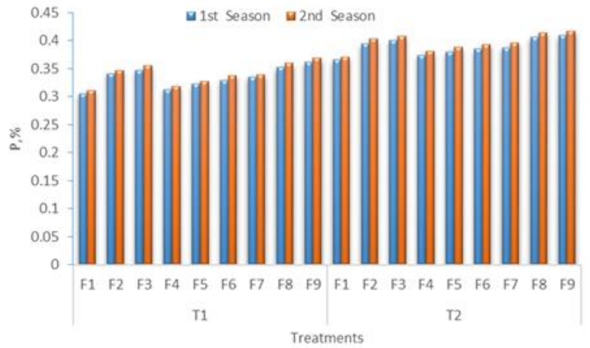

Fig. 5. Effect of mineral fertilization (NPK) and bio stimulant extracts on leaf chemical constituents (phosphorus) of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

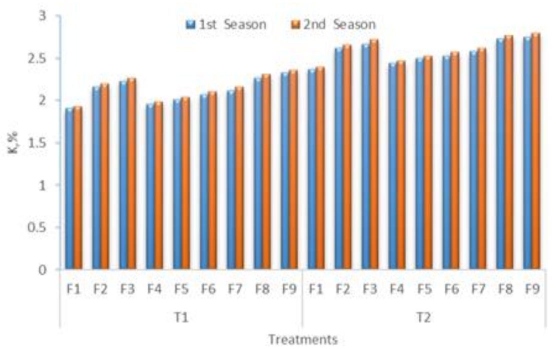

Fig. 6. Effect of mineral fertilization (NPK) and bio stimulant extracts on leaf chemical constituents (potassium) of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

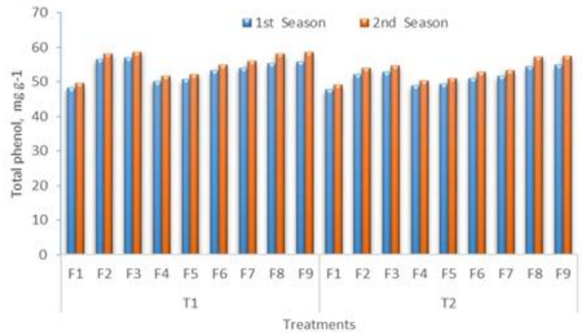

Fig. 7. Effect of mineral fertilization (NPK) and bio stimulant extracts on leaf total phenol of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

To put it differently, the highest total phenol content was observed in the interaction between the T_1 treatment (absence of N, P, K) and the application of black tea extract at a concentration of 10 cmL^{-1} (F_9 treatment), while the lowest total phenol content was consistently associated with the interaction between the T_2 treatment (presence of N, P, K) without foliar application (T_2 x F_1). The same trend was found for both studied seasons.

The observed patterns in leaf chemical constituents (nitrogen, phosphorus and potassium) of croton plant as well as leaf and total phenol can be scientifically explained as follows:

Effect of mineral fertilization (NPK):

Mineral fertilization with NPK had a significant impact on the chemical composition of croton leaves. This treatment led to increased levels of leaf nitrogen, phosphorus, and potassium. The higher values observed for these nutrients indicate that the application of NPK fertilizers positively influenced their uptake and accumulation in the leaves. This is consistent with the expectation that mineral fertilization provides essential nutrients that plants require for growth and development. Conversely, mineral fertilization resulted in lower values for leaf total phenol content. Total phenols are secondary metabolites that often act as defense compounds in plants. The reduction in total phenols may be attributed to the fact that when plants receive ample nutrients from mineral fertilization, they may allocate more resources to primary metabolic processes, such as nitrogen assimilation and photosynthesis, rather than investing in secondary metabolites like phenols (Pandey and Mahiwal, 2020; Arnao *et al.* 2022). When croton plants were subjected to NPK fertilization, regardless of the applied bio-stimulants, the total phenol content consistently decreased. This phenomenon can be attributed to several factors; NPK fertilization provides essential macronutrients (nitrogen, phosphorus, and potassium) in ample quantities. When these nutrients are readily available to the plants, they tend to prioritize primary metabolic processes, such as growth and photosynthesis, over secondary metabolite production like phenols. Adequate nutrient supply from

NPK fertilization can reduce stress on plants, as they do not need to invest resources in defense mechanisms like phenol production. Phenols often act as defense compounds in response to environmental stressors, pests, or diseases. In the absence of N, P, and K, the plants experienced nutrient stress. This stress condition likely triggered a higher production of total phenols as a defense response to compensate for the lack of essential nutrients (Kirkby, 2023).

Superiority of black tea extract compared to others:

As mentioned above, the black tea extract was the most effective stimulant in increasing leaf nitrogen, phosphorus, potassium, and total phenol content. This suggests that the black tea extract contains compounds or elements that enhance nutrient uptake and metabolic processes in the plant (Li *et al.* 2013; Senanayake *et al.* 2013). The sequencing of yeast extract following black tea extract can be attributed to its substantial reservoir of amino acids, particularly B vitamins, and essential minerals, as documented by El-Shawa *et al.* (2020). These components likely contributed to its effectiveness in promoting plant growth and development and this effect positively affected the leaf chemical constituents (nitrogen, phosphorus and potassium) of the croton plant as well as the total phenol. Garlic extract took the third position after yeast and black tea extracts, primarily due to its rich content of natural sulfur compounds, including allicin. This sulfur compound is known for enhancing a plant's resistance to pests and diseases, as discussed by Abbasifar *et al.* (2020). Furthermore, garlic extract contains essential nutrients such as sulfur, phosphorus, and potassium, which collectively contribute to overall plant health and vigor, as outlined by Attia *et al.* (2020). This effect positively affected the leaf chemical constituents (nitrogen, phosphorus and potassium) of the croton plant as well as the total phenol. Seaweed extract ranks fourth, surpassing the control treatment, owing to its rich composition of vital nutrients, including macro and micronutrients, amino acids, vitamins (including A, C, E, and B vitamins), and growth-promoting hormones like auxins and cytokinins. These properties, highlighted by Rizk and Elngar (2020), likely contribute to its positive impact on plant growth and health.

The observed rise in croton plant leaf chemical constituents (nitrogen, phosphorus, and potassium), as well as total phenol, with increasing concentration of the bio-stimulant extract indicates a concentration-dependent response. Elevated concentrations of these extracts result in a greater delivery of nutrients, growth-promoting compounds, and phytochemicals to the plants. Consequently, there is a demonstrated positive correlation between increasing extract concentration and the observed enhancements in these parameters.

The effectiveness of the bio-stimulants followed this sequence: Black tea extract > yeast extract > garlic extract > seaweed extract. This ranking is likely attributed to differences in their nutrient content, bioactive compounds, and stimulant properties. Notably, black tea extract, with its diverse phytochemical profile, exhibited the most pronounced positive impact on leaf chemical constituents (nitrogen, phosphorus, and potassium), as well as total phenol.

Effects of combined applications:

The interaction between mineral fertilization (T_2 treatment, with the presence of NPK) and the application of black tea extract at a concentration of 10 cm L^{-1} (F_9 treatment) resulted in the highest values for leaf nitrogen, phosphorus, potassium.This indicates a synergistic effect between the presence of essential nutrients from mineral fertilization and the stimulating properties of the black tea extract.

Conversely, the control treatment (T_1 x F_1) consistently exhibited the lowest values for all studied traits. This suggests that when NPK fertilizers are absent, the lack of nutrients, coupled with the absence of bio-stimulants, leads to reduced nutrient uptake and lower total phenol content.

T_1 (Absence of N, P, K) and black tea extract (F_9) Interaction: The highest total phenol content was consistently observed in the interaction between the T_1 treatment (absence of nitrogen, phosphorus, and potassium) and the application of black tea extract at a concentration of 10 cmL^{-1} (F_9 treatment). This can be explained by the following:

Black tea extract, known for its diverse phytochemical profile, might contain compounds that stimulate the production of phenols or enhance the plant's stress response. These bioactive compounds could have a synergistic effect with the nutrient stress, leading to an increase in total phenol content.

T_2 (Presence of N, P, K) without foliar application (T_2 x F_1) Interaction: Conversely, the lowest total phenol content was consistently associated with the interaction between the T_2 treatment (presence of N, P, K) without foliar application (T_2 x F_1). The reasons for this can be outlined as follows:

Nutrient Sufficiency: In the presence of N, P, and K from the soil and NPK fertilization, the plants likely had access to sufficient nutrients. As a result, they did not need to allocate resources to produce higher levels of phenols for defense purposes.

Absence of Bio-Stimulant: The lack of foliar application of bio-stimulant (F_1 treatment) meant that there was no additional stimulation for the plant to trigger increased phenol production. Bio-stimulants can sometimes induce a stress response in plants, leading to higher phenol levels, but in this case, the absence of bio-stimulants left the plants in a state of nutrient sufficiency without added stress.The obtained results are in harmony with those of Abbasifar *et al.* (2020); Attia *et al.* (2020); El-Shawa *et al.* (2020); Khudair and Hajam, (2021); Farouk *et al.* 2023) and Kirkby, (2023).

Plant pigments

Effect of mineral fertilization (NPK)

Data presented in Table (3) exhibit divergent trends for the various pigments under investigation. Specifically, in terms of chlorophyll pigments group *i.e.*, chlorophyll a & b, mineral fertilization realized the highest values (0.908 and 0.938 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for chlorophyll a; 0.524 and 0.546 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for chlorophyll b) compared to the control group (without NPK), which recorded the lowest values (0.866 and 0.892 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for chlorophyll a 0.504 and 0.525 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for chlorophyll b).

Conversely, as shown in the same Table, mineral fertilization led to the lowest values for carotene and anthocyanin pigments (0.352 and 0.370 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for carotene ; 3.70 and 3.77 mg $100g^{-1}$ for the 1st and 2nd seasons, respectively, for anthocyanin) compared to the control group which caused the highest values (0.371 and 0.390 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for carotene; 4.42 and 4.50 mg $100g^{-1}$ for the 1st and 2nd seasons, respectively, for anthocyanin). The same trend was found for both studied seasons.

Table 3. Effect of mineral fertilization (NPK) and bio stimulant extracts on plant pigments (chlorophyll a, chlorophyll b, carotene and anthocyanin) of croton plant during two successive seasons (2021/2022-2022/2023).

Treatments	Chlorophyll a		Chlorophyll b (mg g^{-1} F.W)		Carotene		Anthocyanin (mg $100g^{-1}$)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Main factor: Mineral fertilization (NPK)								
T_1	0.866b	0.892b	0.504b	0.525b	0.371a	0.390a	4.42a	4.50a
T_2	0.908a	0.938a	0.524a	0.546a	0.352b	0.370b	3.70b	3.77b
LSD at 5%	0.035	0.014	0.017	0.006	0.016	0.011	0.07	0.21
Sub main factor: Foliar application of bio stimulants								
F_1	0.976a	1.004a	0.558a	0.579a	0.312d	0.327f	2.51i	2.57g
F_2	0.834ef	0.873d	0.492de	0.516d	0.384a	0.401c	4.70d	4.79c
F_3	0.840e	0.857e	0.493d	0.509de	0.384a	0.405bc	4.85c	4.95b
F_4	0.949b	0.977b	0.543b	0.565b	0.332c	0.349e	3.07h	3.14f
F_5	0.940b	0.971b	0.539b	0.561b	0.338c	0.355e	3.20g	3.27f
F_6	0.894c	0.921c	0.515c	0.537c	0.361b	0.379d	3.94f	4.01e
F_7	0.882d	0.912c	0.511c	0.532c	0.366b	0.384d	4.13e	4.21d
F_8	0.837ef	0.863de	0.491de	0.512de	0.387a	0.408ab	4.96b	5.06b
F_9	0.827f	0.855e	0.487e	0.506e	0.392a	0.412a	5.13a	5.24a
LSD at 5%	0.010	0.014	0.006	0.008	0.012	0.006	0.06	0.14

**Since, T1: Without NPK ; T2: With NPK ; F1: Without foliar applications ; F2: Yeast extract at rate of 5.0 g L-1 ; F3: Yeast extract at rate of 10.0 g L-1 ; F4: Seaweed extract at rate of 1.0 cm L-1 ; F5: Seaweed extract at rate of 2.0 cm L-1 ; F6: Garlic extract at rate of 5.0 cm L-1 ; F7: Garlic extract at rate of 10.0 cm L-1 ; F8: Black tea extract at rate of 5.0 cm L-1 ; F9: Black tea extract at rate of 10.0 cm L-1 **

Effect of bio stimulants

Also, the data of Table (3) exhibit divergent trends for the various pigments under investigation. It was observed that the F_1 treatment (control) was the superior for achieving the maximum values of chlorophyll a (0.976 and 1.004 mg g^{-1} F.W for the 1st and 2nd seasons, respectively) and chlorophyll b (0.558 and 0.579 mg g^{-1} F.W for the 1st and 2nd seasons, respectively). While all studied stimulants caused the decline in the values of chlorophyll a & b compared to control treatment (F_1 treatment). It worth mentioning that the less values (0.827 and 0.855 mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for chlorophyll a; 487 and 0.506mg g^{-1} F.W for the 1st and 2nd seasons, respectively, for chlorophyll b) were realized under F_9 treatment, (black tea extract applied at a rate of 10.0 cm^3 L^{-1}).

Concerning carotene and anthocyanin, the most effective natural stimulant for achieving the maximum values of carotene (0.392 and 0.412 mg g^{-1} F.W for the 1st and 2nd seasons, respectively) and anthocyanin (5.13 and 5.24 mg $100g^{-1}$ for the 1st and 2nd seasons, respectively) was the black tea extract applied at a rate of 10.0 cm^3 L^{-1} (designated as the F_9 treatment). Conversely, the control treatment (F_1 treatment) exhibited the lowest values for these pigments, with carotene content at 0.312 and 0.327 mg g^{-1} F.W for the 1st and 2nd seasons and anthocyanin at 2.51 and 2.57 mg $100g^{-1}$ for the 1st and 2nd seasons. In other words, the black tea extract was the superior for obtaining the highest values of carotene and anthocyanin pigments, followed by the yeast extract, then the garlic extract, and finally the seaweed extract. Additionally, the values for these pigments exhibited an upward trend as the concentration of the bio-stimulant extract increased, in comparison to the lower concentration and control treatment.

In terms of carotene and anthocyanin, their trend looked just like the trend of growth criteria. However, it's important to note that chlorophyll pigments followed a distinctly different pattern, showing a trend that was entirely divergent from the growth criteria and quality. The same trend was observed in both of the seasons under study for all the pigments, including carotene and anthocyanin, as well as chlorophyll pigments.

Effect of the Interaction

In terms of chlorophyll a & b, the data in Figs. (8 and 9) indicate that the combined treatment of (T_2 x F_1) realized the highest values of these pigments. Conversely, the combined treatment of (T_1 x F_9) exhibited the lowest values for chlorophyll a & b. Also, the same Figs. (10 and 11) show that the maximum values of both carotene and anthocyanin pigments were recorded the combined treatment of (T_1 x F_9), while the lowest values were achieved with the combined treatment of (T_2 x F_1).

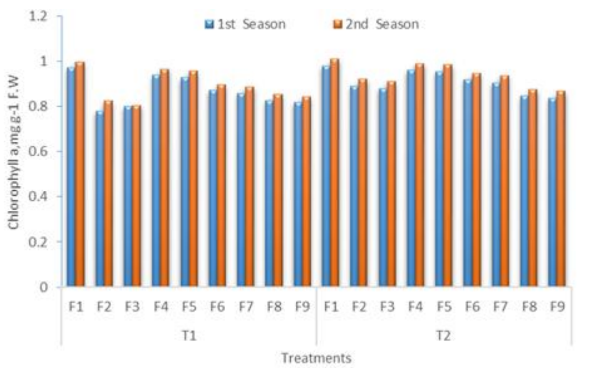

Fig. 8. Effect of mineral fertilization (NPK) and bio stimulant extracts on chlorophyll a in leaves of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

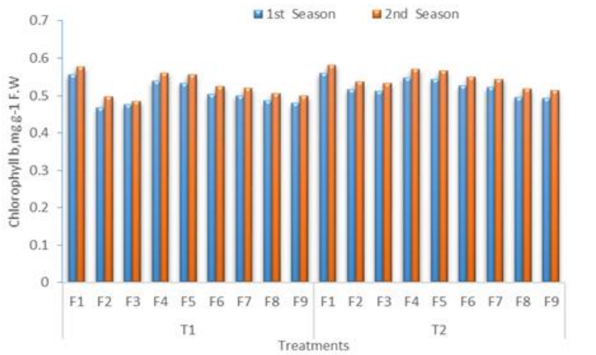

Fig. 9. Effect of mineral fertilization (NPK) and bio stimulant extracts on chlorophyll b in leaves of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

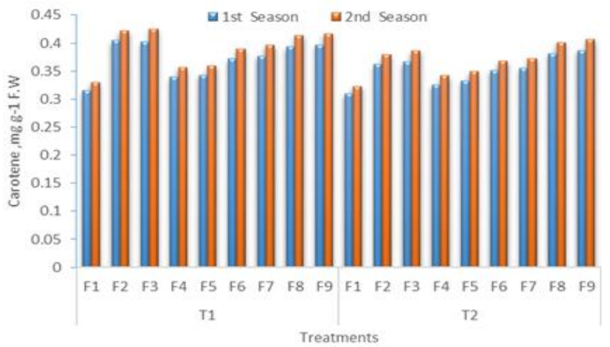

Fig. 10. Effect of mineral fertilization (NPK) and bio stimulant extracts on carotene in leaves of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

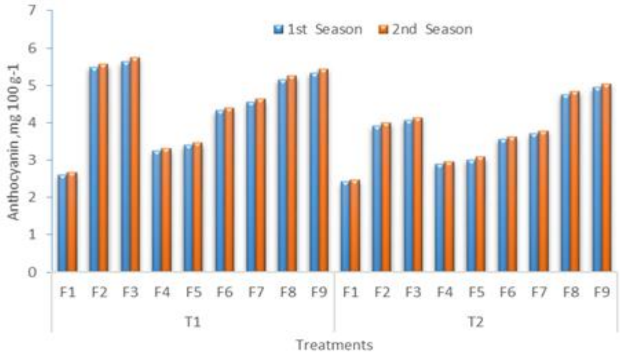

Fig. 11. Effect of mineral fertilization (NPK) and bio stimulant extracts on anthocyanin in leaves of croton plant during two successive seasons (2021/2022-2022/2023)

Since, T_1: Without NPK ; T_2: With NPK ; F_1: Without foliar applications ; F_2: Yeast extract at rate of 5.0 g L^{-1} ; F_3: Yeast extract at rate of 10.0 g L^{-1} ; F_4: Seaweed extract at rate of 1.0 cm L^{-1} ; F_5: Seaweed extract at rate of 2.0 cm L^{-1} ; F_6: Garlic extract at rate of 5.0 cm L^{-1} ; F_7: Garlic extract at rate of 10.0 cm L^{-1} ; F_8: Black tea extract at rate of 5.0 cm L^{-1} ; F_9: Black tea extract at rate of 10.0 cm L^{-1}

It is worth mentioning that it was noticed that the values of carotene and anthocyanin pigments for plants subjected to NPK treatment, regardless of the applied stimulants, were consistently lower than those of their counterparts grown without NPK fertilizers. On the contrary, the values of chlorophyll pigments for plants subjected to NPK treatment, regardless of the applied stimulants, were consistently higher than those of their counterparts grown without NPK fertilizers. The same trend was found for both studied seasons.

The different trends in pigment levels can be explained by the biochemical and physiological processes that these pigments are involved in and how the treatments affect them.as follows:

Effect of mineral fertilization (NPK):

These findings suggest that mineral fertilization had opposing effects on these different pigment groups. While it boosted the levels of chlorophyll pigments, it concurrently suppressed carotene and anthocyanin pigment levels. The variations in the response of these pigments to mineral fertilization might be attributed to their distinct roles in plant physiology and the specific influence of the fertilizer on the underlying biochemical processes. The divergent trends in the effects of treatments on different pigment groups, specifically chlorophyll pigments (chlorophyll a and b). carotene and anthocyanin pigments can be explained by the underlying biochemical and physiological processes associated with these pigments and how the treatments influence them.

Mineral fertilization typically increases the availability of essential nutrients, especially nitrogen (N), phosphorus (P), and potassium (K), which are crucial for photosynthesis and overall plant growth. Chlorophyll pigments play a central role in photosynthesis, where they capture light energy and convert it into chemical energy. An increase in available nutrients can enhance chlorophyll synthesis, resulting in higher chlorophyll levels. The availability of NPK nutrients likely supported the plant's photosynthetic processes, resulting in increased chlorophyll content (Davies, 2004; Pandey and Mahiwal, 2020; Arnao *et al.* 2022).

Carotenes and anthocyanin have different functions compared to chlorophylls. Carotenes are involved in photo protection, helping to dissipate excess light energy and protect the plant from photo oxidative damage. Anthocyanin are often produced in response to various stressors, including nutrient imbalances and environmental stress. The application of mineral fertilization may not have directly impacted the synthesis of carotenes and anthocyanin as it did with chlorophyll (Młodzińska, 2009). Instead, the increased nutrient availability might have influenced the plant's overall physiology, reducing the need for carotenes' photo protection and anthocyanin' stress response. Consequently, lower levels of carotene and anthocyanin were observed when mineral fertilization was applied. The differences in the response of these pigments to treatments can be attributed to their specific roles in plant function and the plant's ability to adapt to changes in its environment. Chlorophyll pigments are directly related to photosynthesis and growth, while carotenes and anthocyanin serve different functions, such as photo protection and stress response. Therefore, the treatments had varying effects on these pigments based on their unique roles and how they are influenced by changes in nutrient availability and environmental conditions (Kirkby, 2023).

Superiority of black tea extract compared to others:

Chlorophyll a and b are the primary pigments responsible for capturing light energy during photosynthesis. They are directly involved in the process of converting light into chemical energy. When a plant has ample nutrients and ideal growth conditions, it invests in producing more chlorophyll to maximize photosynthetic efficiency. The control treatment (F_1) likely provided optimal growth conditions, resulting in higher chlorophyll a and b levels. Conversely, the application of stimulants, although beneficial for other aspects of plant development, may have impacted the allocation of resources and photosynthetic processes, leading to lower chlorophyll levels compared to the control (Davies, 2004).

The increase in carotene and anthocyanin pigments as a result of the studied stimulants compared to the control treatment can be attributed to the way these stimulants influenced the plant's physiology and responses.

Carotenes, including beta-carotene, serve as photo protective pigments. When plants are exposed to stressors such as nutrient imbalances or environmental stress, they may increase the production of carotenes to help dissipate excess light energy and protect the plant from potential damage caused by photo oxidation. The stimulants might have induced a mild stress response, leading to higher carotene levels. Anthocyanin pigments are often produced as part of the plant's stress response mechanism. They can be triggered by various stressors, including nutrient imbalances or environmental factors like light intensity or temperature fluctuations. The application of stimulants might have introduced mild stress signals that led to an increase in anthocyanin production (Młodzińska, 2009). The application of stimulants could have altered the plant's resource allocation strategy. When plants perceive changes in their environment, they may prioritize the production of certain secondary metabolites like carotenes and anthocyanin to cope with the perceived stress. This allocation of resources to pigment production can result in higher pigment levels (Carvalho *et al.* 2011). While stimulants may provide some essential nutrients, they could also change the nutrient uptake and utilization patterns of the plant. This can result in nutrient imbalances that trigger the production of anthocyanin and carotenes as part of the plant's stress responses (Boo *et al.* 2012). Some stimulants may contain signaling molecules or compounds that interact with the plant's internal signaling pathways. These interactions can lead to the activation of genes responsible for the production of carotenes and anthocyanin. The observed trends in pigment levels aligning with the growth criteria and quality indicators suggest that these pigments play a role in plant health and adaptation, responding to changes in the plant's environment and resource availability (Chen *et al.* 2015).

In summary, the increase in carotene and anthocyanin pigments compared to the control treatment is likely due to a combination of factors, including stress induction, altered resource allocation, changes in nutrient availability, and the presence of signaling compounds in the stimulants. These pigments act as protective mechanisms and stress indicators, helping the plant adapt to changing environmental conditions and stressors.

Effects of combined applications:

Chlorophyll a & b:

Combined treatment (T_2 x F_1): This treatment combination, which involves the application of NPK (T_2) with the control (F_1), resulted in the highest values for chlorophyll a & b. This could be due to the synergistic effect of mineral fertilization (NPK) enhancing nutrient availability for chlorophyll synthesis when combined with a control foliar treatment (F_1).

Combined treatment (T_1 x F_9): On the contrary, the combination of no NPK (T_1) with black tea extract at a high rate (F_9) resulted in the lowest values for chlorophyll a & b. This could be due to potential nutrient imbalances induced by the high concentration of black tea extract, which may have limited chlorophyll synthesis.

Effect of NPK: It's noteworthy that regardless of the applied stimulants, the values of chlorophyll pigments were consistently higher for plants subjected to NPK treatment (T_2) compared to those grown without NPK fertilizers (T_1). This is likely because NPK fertilization provides essential nutrients that support chlorophyll production, enhancing the pigments' levels.

Carotene and Anthocyanin:

Combined Treatment (T_1 x F_9): This combination, without NPK (T_1) but with black tea extract at a high rate (F_9), resulted in the maximum values for both carotene and anthocyanin pigments. This suggests that the high concentration of black tea extract altered resource allocation, leading to increased pigment production.

Effect of NPK: It's interesting to note that the values of carotene and anthocyanin pigments were consistently lower for plants subjected to NPK treatment (T_2) regardless of the applied stimulants. This could be because NPK fertilization may have supported growth and photosynthesis to a point where the plant allocated fewer resources to secondary metabolites like carotene and anthocyanin.

These observations highlight the complex interactions between mineral fertilization (NPK) and various foliar stimulants on pigment production in plants. The results suggest that different combinations of treatments can lead to contrasting effects on pigment levels, reflecting the intricate balance of nutrient availability, stress responses, and resource allocation in plant physiology. The trends observed in both seasons indicate the consistency of these interactions. The obtained results are in harmony with those of Abbasifar *et al.* (2020); Attia *et al.* (2020); El-Shawa *et al.* (2020); Khudair and Hajam, (2021); Farouk *et al.* 2023) and Kirkby, (2023).

CONCLUSION

It could be concluded that NPK fertilization significantly improved various growth parameters studied as well as leaf concentration of chlorophylls, N,P,K, whereas reduced leaf total phenol content, carotene and anthocyanin pigments. Among the bio-stimulants, black tea extract at a concentration of 10.0 cm^3 L^{-1} demonstrated superior performance in promoting growth characteristics and increasing leaf nitrogen, phosphorus, potassium, total phenol content, carotene and anthocyanin pigments. Generally, the combination of NPK fertilization and black tea extract at 10.0 cm^3 L^{-1} resulted in the highest growth parameters, leaf chemical constituents and pigments' values.

REFERENCES

Abbasifar, A., Valizadehkaji, B., Karimi, M., & Bagheri, H. (2020). The first report: The effect of garlic extract on rooting of cuttings of some ornamental plants and fruit trees. Advances in Horticultural Science, 34(2), 191.

Alhasan, A. S., Aldahab, E. A., & Al-Ameri, D. T. (2021). Influence of different rates of seaweed extract on chlorophyll content, vegetative growth and flowering traits of gerbera (*Gerbera jamesonii* L.) grown under the shade net house conditions. In IOP Conference Series: Earth and Environmental Science .1(923), 012019.

Arnao, M. B., Hernández-Ruiz, J., & Cano, A. (2022). Role of melatonin and nitrogen metabolism in plants: Implications under nitrogen-excess or nitrogen-low. International Journal of Molecular Sciences, 23(23), 15217.

Attia, E. A., Gomaa, S. A. A., & Hegazi, M. A. (2020). Effect of some fertilization treatments and spraying garlic extract on growth and flowering of *Hedychium coronrium* plants. Menoufia Journal of Plant Production, 5(8), 385-398.

Bakheet, G. I., Soliman, S. S., Abdelkader, M. A. I., & Elashtokhy, M. M. A. (2018). Effects of different croton (*Codiaeum variegatum* L.) genotypes and growth regulators on callus induction, micro propagation and antibacterial activities. Zagazig J. of Agricultural Res. 45(1), 331-347.

Barker, A. V., & Bryson, G. M. (2016). Nitrogen. In *Handbook of plant nutrition* (pp. 37-66). CRC Press.

Bhebhe, M., Füller, T. N., Chipurura, B., & Muchuweti, M. (2016). Effect of solvent type on total phenolic content and free radical scavenging activity of black tea and herbal infusions. Food Analytical Methods, 9, 1060-1067.

Boo, H. O., Hwang, S. J., Bae, C. S., Park, S. H., Heo, B. G., & Gorinstein, S. (2012). Extraction and characterization of some natural plant pigments. Industrial Crops and Products, 40, 129-135.

Carvalho, R. F., Takaki, M., & Azevedo, R. A. (2011). Plant pigments: the many faces of light perception. Acta Physiologiae Plantarum, 33, 241-248.

Chen, C. (2015). Overview of plant pigments. Pigments In fruits and vegetables: genomics and dietetics, 1-7.

Constanta, A., & Simona, P. (2015). Influence of the fertilization on the maintaining of the quality of croton plants (*Codiaeum*) cultivated in pots. JOURNAL of Horticulture, Forestry and Biotechnology, 19(3), 1-5.

CoStat version 6.303 copyright (1998-2004). CoHort Software 798 Lighthouse Ave. PMB 320, Monterey, CA, 93940, USA.

Davies, K. (2004). Plant pigments and their manipulation. Blackwell publishing. New Zealand Institute for Crop & Food Research Limited, Private Bag 11-600, Palmerston North, New Zealand.

Dewis, J., & Freitas, F. (1970). Physical and chemical methods of soil and water analysis. FAO soils Bulletin, (10).

Djangaopa, J. T., Mambu, S. M., & Nio, S. A. (2020). Variations in Leaf chlorophyll concentration in croton plants (Codiaeum variegatum L.) cultivar Gelatik at a different leaf age. Jurnal Ilmiah Sains, 78-87.

Duncan, D. B. (1955). Multiple range and multiple F tests. Biometrics, 11(1), 1-42.

El-Ghamriny, E. A., Arisha, H. M. E., & Nour, K. A. (1999). Studies on tomato flowering, fruit set, yield and quality in summer season. 1.-spraying with Thiamine, ascorbic acid and yeast. Zagazig J. Agric. Res. (Egypt), 26 (5), 1345-1367.

El-Shawa, G. M., Rashwan, E. M., & Abdelaal, K. A. (2020). Mitigating salt stress effects by exogenous application of proline and yeast extract on morpho-physiological, biochemical and anatomical characters of calendula plants. Scientific Journal of Flowers and Ornamental Plants, 7(4), 461-482.

El-Sherpiny, M. A., Kany, M. A., & Sakara, H. M. (2022). Enhancement of growth and yield quality of onion plant via foliar application of bio-stimulants under different nitrogen sources. Journal of Global Agriculture and Ecology, 13-24.

Farouk, S., El-Hady, M. A. A., El-Sherpiny, M. A., Hassan, M. M., Alamer, K. H., Al-Robai, S. A., ... & El-Bauome, H. A. (2023). Effect of dopamine on growth, some biochemical attributes, and the yield of crisphead lettuce under nitrogen Deficiency. *Horticulturae*, *9*(8), 945.

Gomez; K. A. & Gomez, A.A (1984). “Statistical Procedures for Agricultural Research”. John Wiley and Sons, Inc., New York.pp:680.

Gramza, A., Pawlak-Lemañska, K., Korczak, J., Wasowicz, E., & Rudzinska, M. (2005). Tea extracts as free radical scavengers. Polish Journal of Environmental Studies, 14(6), 861.

Ibrahim, F. R., El-Sherpiny, M. A., & Ghazi, D. A. (2023). Response of Feverfew Plant to Different Plant Residues Compost and Amino Acids. J. of Plant Production, 14(3), 141-147.

Kanedi, M., Setiawan, W. A., Handayani, K., & Febriyanti, V. (2021). Antipyretic effect of ethanol extract of plant leaves of garden croton (*Codiaeum variegatum*) in male mice. GSC Biological and Pharmaceutical Sci., 14(3), 202-206.

Khudair, T. Y., & Hajam, A. J. (2021). The effect of yeast extract and organic fertilizer algidex spray on the vegetative, root and floral growth of the *Chinese carnation*.Plant Cell Biotechnol. Mol. Biol,22,165-173.

Kirkby, E. A. (2023). Introduction, definition, and classification of nutrients. In Marschner's Mineral Nutrition of Plants, (pp. 3-9). Academic press.

Kisvarga, S., Farkas, D., Boronkay, G., Neményi, A., & Orlóci, L. (2022). Effects of biostimulants in horticulture, with emphasis on ornamental plant production. Agronomy, 12(5), 1043.

Li, S., Lo, C. Y., Pan, M. H., Lai, C. S., & Ho, C. T. (2013). Black tea: chemical analysis and stability. Food & function, 4(1), 10-18.

Malhotra, H., Vandana, Sharma, S., & Pandey, R. (2018). Phosphorus nutrition: plant growth in response to deficiency and excess. Plant nutrients and abiotic stress tolerance, 171-190.

Mengel, K. (2016). Potassium. In *Handbook of plant nutrition* (pp. 107-136). CRC press.

Młodzińska, E. (2009). Survey of plant pigments: molecular and environmental determinants of plant colors. Acta Biologica Cracovienca Series Botanica, 51(1), 7-16.

Nio, S. A., Songke, N. G., & Ludong, D. P. M. (2023). The content of chlorophyll a in croton (*Codiaeum variegatum* L.) leaves under water deficit. In *AIP Conference Proceedings* (Vol. 2694, No. 1). AIP Publishing.

Nofal, E. M. S., El-Mahrouk, M. E., El-Sayed, B. A., & Radwan, A. M. M. (2021). Effect of NPK fertilizer and some natural extract treatments on the vegetative growth and flowering of African marigold (*Tagetes erecta* L. var. Dwarf Chrysanthemum). Appl. Ecol. Environ. Res, 19, 3167-3179.

Pandey, G. K., & Mahiwal, S. (2020). Role of potassium in plants (pp. 45-49). Cham: Springer.

Rizk, G. W., & Elngar, M. A. (2020). Effect of soil conditioners, seaweed extracts and chemical fertilizers: on growth, flowering and bulbs production of *Narcissus tazetta* L. subsp. Egyptian Academic Journal of Biological Sciences, H. Botany, 11(2), 69-79.

Schoefs, B. (2005). Plant pigments: properties, analysis, degradation. Advances in food and nutrition research, 49, 42-92.

Senanayake, S. N. (2013). Green tea extract: Chemistry, antioxidant properties and food applications–A review. Journal of functional foods, 5(4), 1529-1541.

Sengul, M., Yildiz, H., Gungor, N., Cetin, B., Eser, Z., & Ercisli, S. (2009). Total phenolic content, antioxidant and antimicrobial activities of some medicinal plants. Pakistan Journal of Pharmaceutical Sciences, 22(1).

Singh, K., Sharma, R., & Sahare, H. (2022). Implications of synthetic chemicals and natural plant extracts in improving vase life of flowers. Scientia Horticulturae, 302, 111133.

Turkmen, N., Velioglu, Y. S., Sari, F., & Polat, G. (2007). Effect of extraction conditions on measured total polyphenol contents and antioxidant and antibacterial activities of black tea. Molecules, 12(3), 484-496.

Vieira, E. F., Carvalho, J., Pinto, E., Cunha, S., Almeida, A. A., & Ferreira, I. M. (2016). Nutritive value, antioxidant activity and phenolic compounds profile of brewer's spent yeast extract. Journal of Food Composition and Analysis, 52, 44-51.

Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W., & Novozamsky, I. (2013). Plant analysis manual. Springer Science & Business Media.

Zaman, G., Farooq, U., Bajwa, M. N., Jan, H., Shah, M., Ahmad, R. & Abbasi, B. H. (2022). Effects of yeast extract on the production of phenylpropanoid metabolites in callus culture of purple basil (*Ocimum basilicum* L. var purpurascens) and their in-vitro evaluation for antioxidant potential. Plant Cell, Tissue and Organ Culture (PCTOC), 150(3), 543-553.

تحسين المعايير الجمالية والصحية لنباتات الكروتن (*Codiaeum variegatum*) من خلال التسميد المتكامل بالمنشطات الطبيعية والمغذيات المعدنية

حكمت يحيى مسعود[1]، بشرة عبد الله محمد [2]، فاطمة رشاد ابراهيم [1]و محمد احمد محمد محمد العريان [2]

[1]قسم الخضر والزينة – كلية الزراعة -جامعة المنصورة-مصر

[2]معهد بحوث البساتين-مركز البحوث الزراعية – مصر

الملخص

الهدف من الدراسة هو تحديد افضل منشط طبيعي مع التسميد المعدني (NPK) وتقديم إرشادات تطبيقية للحصول علي نباتات كروتن ذات مظهر جمالي وجودة عالية. وتضمنت التجربة ثمانية عشر معاملة، والتي شملت جميع التداخلات الممكنة لمستويين من التسميد المعدني NPK (صفر و 2.0 جم لكل أصيص) وبعض المعاملات الورقية المختلفة عن طريق الرش الورقي [ماء الصنبور، مستخلص الخميرة(بمعدل 5.0 و 10.0 جم/ لتر)، مستخلص الطحالب البحرية (بمعدل 1.0 و2.0 سم^3/ لتر)، مستخلص الثوم (بمعدل 5.0 و 10.0 سم^3/ لتر)، مستخلص الشاي الأسود (بمعدل 5.0 و 10.0 سم^3/ لتر)].تشير النتائج التي تم الحصول عليها إلى أن التسميد المعدني اعطي أعلى نتائج [(طول النبات (سم)، وعدد الأوراق لكل نبات، والمساحة الورقية (سم^2 / نبات)، وكذلك محتوى الأوراق من النيتروجين، والفوسفور، والبوتاسيوم، والكلوروفيل (أ & ب)] مقارنة بمعاملة المقارنة. وعلى العكس من ذلك، أدى التسميد المعدني منفردا إلى انخفاض قيم محتوى الأوراق من الفينول الكلي وصبغات الكاروتين والأنثوسيانين مقارنة بمعاملة المقارنة. كان مستخلص الشاي الأسود بمعدل 10.0 سم^3/ لتر هو أفضل منشط طبيعي للحصول على أعلي قيم لجميع الصفات المذكورة باستثناء الكلوروفيل (أ وب). لذلك يوصي المزارعين باستخدام التسميد NPK مع الرش بمستخلص الشاي الأسود بتركيز 10.0 سم^3/لتر للحصول عي نباتات كروتن ذات مظهر جمالي وجودة عالية.