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Enhancing fruit yield and quality of red sweet pepper under protected conditions with organic acids and bio-stimulants

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Abstract

The current study aimed to explore sustainable approaches to enhance the productivity of red sweet pepper due to its economic and nutritional importance. To achieve this objective, a plastic house experiment was conducted, and two main factors were studied under split-plot design. The first main factor focused on the application of organic acids (control, fulvic, humic acids at a rate of 5.0 and 10 kg fed.$^{-1}$. The sub main factor involved the use of bio-stimulants, specifically seaweed and yeast extracts, applied as foliar applications in addition control treatment. Concerning the individual effect of the main factor, the results showed that the superior treatment was T_3 treatment for recording the highest values of total yield, No. of fruits plant$^{-1,}$ average of fruit weight, length and diameter, fruits' chemical constituents (N, P, K), total sugars (%) and carbohydrates, vitamin C, and lycopene pigment compared to other treatments. In other words, the sequence order of the studied treatments which represented the main factor from more effective to less was as follows;$T_3 > T_5 > T_2 > T_4 > T_1$ treatments. Regarding the individual effect of the sub main factor, the superior treatment was F_3 treatment for recording the highest values of all aforementioned traits compared to other treatments. It is evident that the combination of T_3 treatment and F_3 treatment exhibited a significantly superior bilateral interaction compared to other interventions. By implementing these recommendations, growers can adopt effective and sustainable practices that enhance the productivity and nutritional quality of sweet pepper, ultimately benefiting both producers and consumers.

Keywords: Humic acid, fulvic acid, seaweed extract, yeast extract

Introduction

Sweet pepper (*Capsicum annuum* L.) is a widely cultivated vegetable crop known for its economic importance and high nutritional value. It is not only a valuable commodity in the agricultural sector but also a staple ingredient in various culinary traditions around the world. The cultivation of sweet peppers, especially under protected conditions, plays a significant role in ensuring a stable supply of this versatile vegetable throughout the year (**Cisternas-Jamet *et al.,* 2020**). It's worth noting that the nutritional composition of sweet peppers may vary slightly depending on their color and ripeness. Red, yellow, and orange peppers tend to have higher amounts of certain nutrients, including vitamin C and carotenoids, compared to green peppers (**Salamatullah *et al.,* 2022**). Incorporating sweet peppers into meals and snacks can provide a range of essential nutrients and contribute to a balanced and nutritious diet (**Hur *et al.,* 2023**). To optimize sweet pepper production and meet the growing demand, researchers and growers have been exploring various strategies to enhance plant growth, productivity, and nutritional quality. One promising approach involves the use of organic acids such as fulvic and humic acids as well as foliar applications like seaweed and yeast extracts (**Hamail *et al.,* 2014a,b,c**). These substances have gained attention due to their potential to improve soil fertility, nutrient availability, plant growth, and stress tolerance in numerous agricultural systems (**Mohamed *et al.,* 2021**). Fulvic and humic acids, components of soil organic matter, have also shown great potential in enhancing plant performance. They possess unique physicochemical properties that improve nutrient solubility, chelation, and transport within the plant (**Hamail *et al.,* 2014a,b,c**). Moreover, their ability to stimulate root development, enhance nutrient uptake, and activate plant defense mechanisms makes them valuable additions to agricultural practices. Fulvic acid is a low molecular weight and water-soluble substance, as it is characterized by its yellow to light brown color (**Taha *et al.,* 2016**) (Fig.1). Humic acid, on the other hand, is a larger molecule and is insoluble in water. It appears as a dark brown to black-colored substance (**Taha *et al.,* 2023**) (Fig. 2).

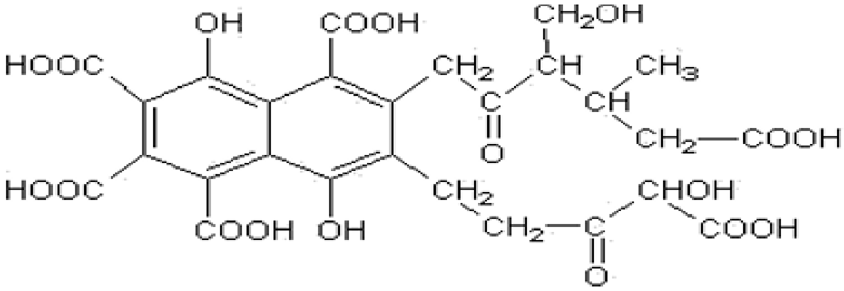

Fig. 1.

Model structure of fulvic acid (Peña-Méndez *et al.,* 2005)

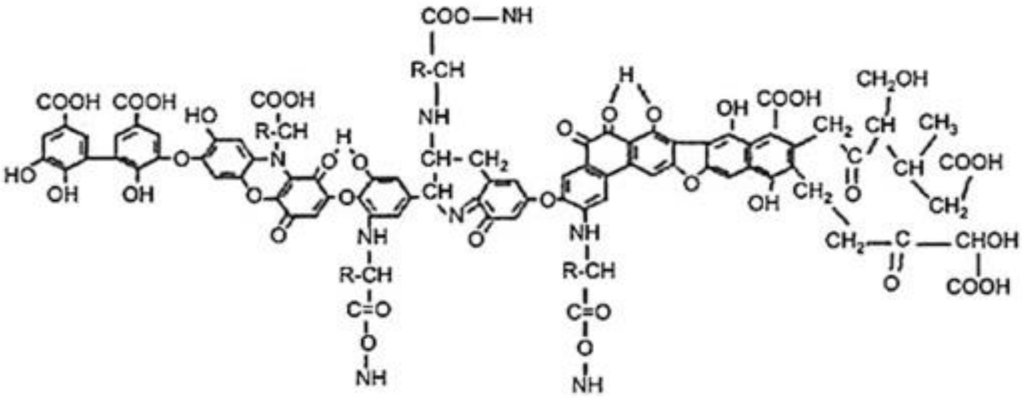

Fig. 2. Model structure of humic acid (De-Melo *et al.,* 2016)

In recent years, foliar applications of seaweed extract and yeast extract have gained popularity as bio-stimulants in horticultural crops. Seaweed extract, derived from marine algae, is rich in plant growth regulators, amino acids, vitamins, and minerals (**Abd El-Hady *et al.,* 2016 and Shehata *et al.,* 2019**). Its application has been associated with increased nutrient absorption, stress tolerance, and overall plant vigor (**Abd El-Hady and Doklega, 2023**). Similarly, yeast extract contains bioactive compounds that improve plant performance. Yeast foliar applications offer several potential benefits for pepper plants (**Aly *et al.,* 2019**). They can enhance nutrient uptake, improve plant health, increase disease resistance, boost stress tolerance, stimulate growth and development, and enhance the quality of fruit (**Ghazi, 2020**).

Considering the importance of sweet pepper from an economic and nutritional standpoint, there is a growing need to explore sustainable approaches to enhance its productivity by using organic acids that are beneficial for fruit quality and human health. Therefore, the main objective of this study is to investigate the effects of addition of fulvic and humic acids via fertigation system in addition seaweed and yeast extracts as foliar applications on the fruit quality, and nutritional composition of sweet pepper plants grown under protected conditions. Understanding the potential benefits of these substances will contribute to the development of effective and environmentally friendly strategies for sweet pepper cultivation, ultimately benefiting both growers and consumers alike.

Materials and methods

Plastic house experiment was conducted to investigate the effects of various treatments, including the application of fulvic and humic acids to the soil, as well as the foliar application of seaweed and yeast extracts, on the growth and development of sweet pepper plants "(Capsicum *annuum* L. Cv 58 red fruit)".

1. **Experimental location**

This research study was implemented over two consecutive seasons (2020/2021 and 2021/2022) in a private farm located in Tanta district, El-Gharbia governorate, Egypt (30°47′00″N 31°00′00″E).

2. **Soil sampling and analysis.**

Prior to transplanting, soil samples were collected for routine analysis following the methodology established by **Dewis and Freitas (1970)**. The purpose of this analysis was to assess the baseline characteristics of the soil before implementing any treatments or interventions in the experimental setup. The initial soil properties are presented in Table 1.

Table 1. Characteristics of the studied soil before transplanting (initial soil) (combined data over both studied seasons)

Particle size distribution, %				Texture class	Available nutrients, mg kg^{-1}			Organic matter,%	EC, dSm^{-1} (1: 5 soil suspension)	pH (1:2.5 soil suspension)
C. Sand	F. Sand	Silt	Clay		N	P	K			
4.50	12.8	33.7	49.0	Clay	49.6	7.90	240	١,٣٥	3.02	8.06

3. Bell pepper seeds

The bell pepper seeds used in the experiment were obtained from the Ministry of Agriculture and Soil Reclamation (MASR). These seeds, provided by MASR, were utilized to ensure the standardization and reliability of the plant material used in the research.

4. Studied substances preparation

1- Both humic and fulvic acids were purchased from the agriculture commercial market in Egypt. Table 2 illustrates their specification.

2- **Table 2**. Some characteristic of the studied humic substances

Humic substances	HA	FA	OM	Solubility	Moisture	pH	P_2O_5	N	K_2O	Phenolic groups	Carboxylic groups
	%						%			mmol/100g HS	
Fulvic acid (FA)	٥,٣٠	٧٤,٠	٨٨,٠	١٠٠	٢٦,٢٥	٥,٢٠	٢,٣٠	٥,٢٠	٤,٩٠	٣٥٥	٥٨٠
Humic acid (HA)	٧٠,٩	٣,٧	٨٤,٥	١٠٠	٢٥,٠	5.53	٣,٠	3.56	8.0	٣٣٤	٥٠٩

3- Seaweed extract was purchased from the agriculture commercial market in Egypt, as Table 3 indicates their characteristics. Subsequently, the seaweed extract was prepared at the studied rate.

4- The yeast extract used in this experiment was prepared according to the method described by **El-Ghamriny *et al.* (1999)**. The preparation involved mixing Baker's yeast (soft yeast) and sugar in a 1:1 ratio. The mixture was then left at room temperature for 3 hours to undergo freezing to disruption of yeast tissue and the release of its content. Subsequently, the yeast extract was prepared at the studied rate. Table 3 indicates the yeast extract characteristics.

The chemical analysis of all studied substances was done depending on **Tandon (2005)**.

5. Experimental design and treatments

The research was conducted using a split-plot design with three replicates. The experimental setup involved two factors. The first main factor focused on the application of organic acids (T_1: control (without),T_2: Fulvic acid at a rate of 5.0 kg fed.$^{-1}$,T_3: Fulvic acid at a rate of 10 kg fed.$^{-1}$,T_4: Humic acid at a rate of 5.0 kg fed.$^{-1}$ and T_5: Humic acid at a rate of 10 kg fed.$^{-1}$). The sub main factor involved the use of bio-stimulants, specifically seaweed and yeast extracts, applied as foliar applications (F_1: Control (without any treatment), F_2: Seaweed extract at a rate of 3 g L^{-1} and F_3: Yeast extract at a rate of 5.0 g L^{-1}), as shown in Fig. 3. The treatments included different combinations of these factors. This design allowed for the evaluation of the individual and combined effects of organic acids and bio-stimulants on the growth and development of the sweet pepper plants

Table 3. Some characteristic of the studied bio stimulants

Component	Seaweed extract	Yeast extract
Protein	19	47.1
Carbohydrate	50	32
Minerals	25	7.9
Nucleic Acids	/	9
Lipids	1	/

6. Experimental setup

The soil of the plastic house (6 m width, 40 m length and 2.5 m height) was ploughed and divided into five ridges (1 m width x 40 m length) as main plots. Each ridge was divided into three equal divisions (1 m width x 12 m length) as sub-main plots. Each sub-main plot was divided into three equal divisions (1.0 m width x 4 m length) as replicates. The space between ridges was 50 cm.

In both the first and second seasons, bell pepper seeds were planted in seedling trays filled with a mixture of peat moss and vermiculite in a 1:1 ratio (V:V). This process took place in the nursery area of the plastic house on August 20th. After the seedlings reached an appropriate stage of growth, uniform sweet pepper seedlings were transplanted into the soil of the plastic house on October 10th in both seasons.

Potassium nitrate and magnesium sulfate were applied to all plots every week at a rate of 2.0 kg fed.$^{-1}$ through a fertigation system. Phosphoric acid was also added twice at a rate of 2 liters fed.$^{-1}$ for each application through the fertigation system. Also, basic fertilizers application from N: P: K actual 48, 64, 64 kg fed.$^{-1}$, respectively was added. Humic and fulvic acids were added via the fertigation system, adhering to the specific treatments being studied. The sweet pepper plants were sprayed with the designated bio-stimulants using a hand sprayer until saturation point at four different times during the experiment: 20, 35, 50, and 65 days after transplanting. The plants were irrigated by drip irrigation daily at rate of 300 liter fed.$^{-1}$.

All other agricultural practices related to the cultivation of sweet peppers followed the guidelines recommended by the MASR. The mature pepper fruits were harvested at the full color stage. In the first season, harvesting commenced on January 10th and concluded on May 15th. In the second season, harvesting began on January 25th and ended on May 20th. No. of pickings was 18 in each season.

7. Measurement traits.

Ten fruits were randomly taken from the 3rd picking from each plot to measure the following criteria;

- Total yield (kg plant^{-1}), No. of fruits plant^{-1}were recorded after each harvesting cumulatively.
- Average of fruit weight (g), length (cm) and diameter (cm) were measured.
- The percentage of nitrogen (using the Kjeldahl method), phosphorous (using a spectrophotometer) and potassium (using a flame photometer) were determined in the dry matter of the fruits according to Cottenie *et al.* (1982). As the samples were dried at 70°C, then ground and subjected to wet digestion via addition of mixture of perchloric and sulfuric acids (1:1) as mentioned by Peterburgski (1968).
- Total sugars and carbohydrates (%): were determined according to the methods outlined in the A.O.A.C. (2007).
- Vitamin C (mg/100 g) in fruit was determined according to FAO (1980).
- Lycopene pigment (mg/100 g) was determined as described by Suwanaruang (2016).

8. Statistical analysis.

The data obtained from the experiment were analyzed using the analysis of variance (ANOVA) method following the guidelines outlined by Gomez and Gomez (1984). To compare the means of different treatments, the least significant difference (LSD) test was used at a significance level of 0.05. The statistical analysis was carried out using Version 6.303 of the CoHort software, developed by CoHort Software in the USA between 1998 and 2004. This approach was employed to determine any significant differences between the treatments and to ensure a robust and accurate evaluation of the experimental results.

Results

1. Total yield and its components

It can be noticed that the studied treatments [Control (without addition), fulvic and humic acids (via fertigation system), seaweed and yeast extracts (as foliar application] significantly affected yield and its components of sweet pepper plant *i.e.*, total yield (kg plant^{-1}), No. of fruits plant$^{-1,}$ average of fruit weight, length (cm) and diameter (cm) during growing season of 2020/2021 and 2021/2022 at maturity stage (Table 4).

Table 4. Effect of the applications of fulvic and humic acids as well as seaweed and yeast extracts on yield and its components of sweet pepper plant at maturity stage during growing season of 2020/2021 and 2021/2022.

Treatments		Total yield, kg $plant^{-1}$		No. of fruits $plant^{-1}$		Fruit weight, g		Fruit length, cm		Fruit diameter, cm	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor											
T_1		1.133d	1.083e	9.22e	8.89e	122.67d	121.56d	7.22d	6.67d	6.56d	6.33d
T_2		1.464c	1.498d	10.22d	10.56d	142.67b	141.22b	7.89c	7.67c	7.33c	7.22c
T_3		2.127a	2.298a	13.67a	14.44a	155.22a	158.78a	9.78a	10.00a	9.11a	9.56a
T_4		1.531c	1.604c	11.44c	12.00c	133.44c	133.22c	9.00b	8.78b	8.22b	7.78c
T_5		1.817b	1.913b	12.56b	13.33b	144.44b	143.11b	9.44ab	9.44ab	8.78ab	8.78b
Sub main factor											
F_1		1.415c	1.465c	10.67c	11.07c	131.13c	130.40c	8.20c	8.07c	7.60b	7.40c
F_2		1.619b	1.687b	11.47b	11.87b	140.00b	140.40b	8.67b	8.53b	8.00ab	7.93b
F_3		1.809a	1.885a	12.13a	12.60a	147.93a	147.93a	9.13a	8.93a	8.40a	8.47a
Interaction											
T_1	F_1	0.980	0.946	8.67	8.33	112.67	113.33	6.67	6.33	6.33	6.00
	F_2	1.150	1.095	9.33	9.00	124.00	121.67	7.33	6.67	6.67	6.33
	F_3	1.270	1.208	9.67	9.33	131.33	129.67	7.67	7.00	6.67	6.67
T_2	F_1	1.275	1.247	9.67	9.67	131.67	129.00	7.33	7.33	7.00	6.33
	F_2	1.480	1.512	10.33	10.67	143.00	141.67	8.00	7.67	7.33	7.33
	F_3	1.638	1.734	10.67	11.33	153.33	153.00	8.33	8.00	7.67	8.00
T_3	F_1	1.885	2.065	12.67	13.67	148.67	151.00	9.33	9.67	8.67	9.33
	F_2	2.115	2.298	13.67	14.33	154.67	160.33	9.67	10.00	9.00	9.67
	F_3	2.381	2.530	14.67	15.33	162.33	165.00	10.33	10.33	9.67	9.67
T_4	F_1	1.340	1.399	10.67	11.33	125.67	123.33	8.67	8.33	7.67	7.33
	F_2	1.504	1.616	11.33	12.00	132.67	134.67	9.00	8.67	8.33	7.67
	F_3	1.750	1.797	12.33	12.67	142.00	141.67	9.33	9.33	8.67	8.33
T_5	F_1	1.598	1.668	11.67	12.33	137.00	135.33	9.00	8.67	8.33	8.00
	F_2	1.845	1.915	12.67	13.33	145.67	143.67	9.33	9.67	8.67	8.67
	F_3	2.008	2.155	13.33	14.33	150.67	150.33	10.00	10.00	9.33	9.67
LSD at 5%		٠,١١	٠,١٤	٠,٦٧	٠,٩٣	5.43	2.88	0.80	0.72	0.92	1.11

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control;T_2: Fulvic acid at rate of 5 kg $fed.^{-1}$; T_3: Fulvic acid at rate of 10 kg $fed.^{-1}$;T_4: Humic acid at rate of 5 kg $fed.^{-1}$; T_5: Humic acid at rate of 10 kg $fed.^{-1}$; F_1: Control (without); F_2: Seaweed extract (3 g L^{-1}) and F_3: Yeast extract (5.0 g L^{-1})

Concerning the individual effect of the studied main factor (control, FA and HA), Table 4 illustrates that the superior treatment was fertigation with fulvic acid at rate of 10 kg $fed.^{-1}$gave the highest values of aforementioned parameters compared to other treatments. In other words, the sequence order of the studied treatments which represented the main factor from more effective to less was as follows;

T_3 treatment (fulvic acid at rate of 10 kg $fed.^{-1}$) > T_5 treatment (humic acid at rate of 10 kg $fed.^{-1}$) >T_2 treatment (fulvic acid at rate of 5.0 kg $fed.^{-1}$) >T_4 treatment (humic acid at rate of 5.0 kg $fed.^{-1}$) >T_1 treatment (control).

Regarding the individual effect of the studied sub main factor (seaweed and yeast extracts), Table 4 illustrates that foliar application with yeast extract at 5.0 g L^{-1} gave the highest values of total yield (kg $plant^{-1}$), No. of fruits $plant^{-1,}$ average of fruit weight (g), length (cm) and diameter (cm) compared to other treatments. In other words, according to the same Table, the treatments studied were arranged based on their effectiveness, with the most effective treatment listed first and the least effective treatment listed last as follows;.

F_3 treatment (yeast extract at rate of 5.0 g L^{-1}) > F_2 treatment (seaweed extract at rate of 3 g L^{-1}) > F_1 treatment (the corresponding plants grown without foliar application of bio stimulants).

Based on the data presented in Table 4, it is evident that the combination of fulvic acid and foliar application with yeast extract exhibited a significantly superior bilateral interaction. This interaction resulted in the highest values for various parameters, including total yield (kg $plant^{-1}$), number of fruits $plant^{-1}$, average fruit weight (g), length (cm), and diameter (cm). This trend of superior performance was observed consistently in both seasons studied.

2. Fruits nutritional status

The impact of fulvic and humic acids, seaweed, and yeast extracts on the chemical constituents (N, P, K %) of the fruits at the maturity stage during the growing seasons of 2020/2021 and 2021/2022 is presented in Table 5. The data clearly demonstrate that all of the studied treatments had a significant effect on these chemical characteristics of the fruits.

In terms of the individual effects of the main factor studied, it was observed that application with fulvic acid at rate of 10 kg fed.$^{-1}$, exhibited superior results in terms of achieving the highest values for the fruits' chemical constituents (N, P and K %) at the maturity stage during the growing seasons of 2020/2021 and 2021/2022. Application with humic acid at a rate of 10 kg fed.$^{-1}$ came in the second highest performance, followed by application with fulvic acid at a rate of 5.0 kg fed.$^{-1}$, then humic acid at a rate of 5.0 kg fed.$^{-1}$compared to control.

In terms of foliar application of bio-stimulants, the results indicate that the foliar application with yeast extract at 5.0 g L^{-1}, resulted in the highest values for the fruits' chemical constituents (N, P and K %), following with seaweed extract, at 3 g L^{-1}. On the other hand, the plants that were not subjected to foliar application of bio-stimulants exhibited the lowest values for the fruits' chemical constituents (N, P, K %).

Going along with combination treatments, it was obvious from Table 5 that the bilateral interaction between fulvic acid at rate of 10 kg fed.$^{-1}$and foliar application with yeast extract at 5 g L^{-1} was significantly superior in achieving the maximum values of the fruits chemical constituents (N, P and K %) at maturity stage during growing season of 2020/2021 and 2021/2022.

Table 5. Effect of the applications of fulvic and humic acids as well as seaweed and yeast extracts on fruits nutritional status of sweet pepper plant at maturity stage during growing season of 2020/2021 and 2021/2022.

Treatments		Nitrogen		Phosphorus		Potassium	
		(%)					
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor							
T_1		6.56e	6.57e	0.217e	0.221e	4.10e	4.19e
T_2		7.93c	7.89c	0.256c	0.262c	4.56c	4.62c
T_3		8.47a	8.52a	0.273a	0.279a	4.91a	4.99a
T_4		7.37d	7.40d	0.233d	0.238d	4.46d	4.51d
T_5		8.15b	8.22b	0.264b	0.266b	4.71b	4.77b
Sub main factor							
F_1		7.43c	7.52c	0.234c	0.239c	4.37c	4.46c
F_2		7.73b	7.76b	0.250b	0.254b	4.55b	4.62b
F_3		7.93a	7.88a	0.262a	0.266a	4.73a	4.76a
Interaction							
T_1	F_1	6.10	6.17	0.205	0.213	3.94	4.05
	F_2	6.63	6.76	0.218	0.223	4.12	4.21
	F_3	6.96	6.78	0.227	0.229	4.24	4.30
T_2	F_1	7.81	7.77	0.240	0.241	4.38	4.47
	F_2	7.89	7.88	0.256	0.264	4.53	4.64
	F_3	8.10	8.03	0.274	0.282	4.76	4.76
T_3	F_1	8.33	8.40	0.259	0.263	4.73	4.86
	F_2	8.47	8.50	0.276	0.281	4.89	4.96
	F_3	8.60	8.66	0.284	0.293	5.12	5.15
T_4	F_1	7.09	7.18	0.220	0.227	4.29	4.33
	F_2	7.40	7.44	0.234	0.239	4.46	4.52
	F_3	7.63	7.59	0.245	0.250	4.62	4.68
T_5	F_1	7.83	8.08	0.248	0.253	4.51	4.61
	F_2	8.26	8.22	0.265	0.266	4.73	4.80
	F_3	8.37	8.35	0.280	0.280	4.89	4.91
LSD at 5%		0.26	0.07	0.002	0.004	0.03	0.03

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control;T_2: Fulvic acid at rate of 5 kg fed.$^{-1}$; T_3: Fulvic acid at rate of 1.0 kg fed.$^{-1}$;T_4: Humic acid at rate of 5 kg fed.$^{-1}$; T_5: Humic acid at rate of 10 kg fed.$^{-1}$; F_1: Control (without); F_2: Seaweed extract (3 g L^{-1}) and F_3: Yeast extract (5.0 g L^{-1})

3. Fruits quality parameters

Table 6 shows the effect of the applications of fulvic and humic acids, seaweed and yeast extracts on the fruits quality traits of sweet pepper plant *i.e.*, total sugar (%) and carbohydrates (%), vitamin C (mg/100g), and lycopene pigment (mg/100g) at maturity stage during growing season of 2020/2021 and 2021/2022. The data illustrate that all aforementioned traits were significantly affected due to all studied treatments.

Concerning the individual effect of the studied main factor, Application with fulvic acid at rate of 10 kg fed.$^{-1}$ was the superior treatment for obtaining the highest values of the total sugar (%) and carbohydrates (%), vitamin C (mg/100g), and lycopene pigment (mg/100 g) followed by humic acid at 10 kg fed.$^{-1}$ then fulvic acid at 5.0 kg fed.$^{-1}$ then humic acid at rate of 5.0 kg fed.$^{-1}$ compared to control.

According to the data presented in Table 6, the individual effect of the sub-main factor (seaweed and yeast extracts) reveals that the superior treatment for achieving the highest values of total sugar (%) and carbohydrates (%), vitamin C (mg 100 g^{-1}), and lycopene pigment (mg 100 g^{-1}) was spraying with yeast extract at a rate of 5.0 g L^{-1}. This treatment outperformed the other treatments in terms of these specific chemical constituents.

Based on the information provided in the same table, the treatments studied can be ranked based on their effectiveness, with the most effective treatment listed first and the least effective treatment listed last, as follows:

1. Firstly, F_3 treatment (yeast extract at a rate of 5.0 g L^{-1})
2. Secondly, F_2 treatment (seaweed extract at a rate of 3 g L^{-1})
3. Thirdly, F_1 treatment (corresponding plants grown without foliar application of bio-stimulants)

It is evident that the combination of fulvic acid at rate of 10 kg fed.$^{-1}$and foliar application with yeast extract at 5 g L^{-1} exhibited a significantly superior bilateral interaction. This interaction resulted in the highest values for various parameters, including total sugars (%) and carbohydrates (%), vitamin C (mg 100g^{-1}), and lycopene pigment (mg 100g^{-1}). This trend of superior performance was observed consistently in both seasons studied.

Table 6. Effect of the applications of fulvic and humic acids as well as seaweed and yeast extracts on fruits quality traits of sweet pepper plant at maturity stage during growing season of 2020/2021 and 2021/2022.

Treatments		Total sugars		Carbohydrates		VC		Lycopene	
		(%)				(mg 100g^{-1})			
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor									
T_1		48.37e	48.39d	25.24e	25.23e	37.78e	37.75e	0.316e	0.329e
T_2		48.82c	48.70c	25.57c	25.64c	39.47c	39.74c	0.372c	0.390c
T_3		49.65a	49.71a	26.08a	26.16a	41.32a	41.53a	0.488a	0.514a
T_4		48.63d	48.63b	25.43b	25.48b	38.27d	38.62d	0.348d	0.366d
T_5		49.21b	49.28c	25.73d	25.78d	40.25b	40.41b	0.406b	0.422b
LSD at 5%		0.03	0.17	0.0	0.03	0.17	0.13	0.006	0.004
Sub main factor									
F_1		48.78c	48.78b	25.43c	25.50c	39.00c	39.16c	0.364c	0.385c
F_2		48.96b	49.01a	25.63b	25.67b	39.42b	39.75b	0.389b	0.404b
F_3		49.08a	49.04a	25.77a	25.81a	39.84a	39.92a	0.405a	0.424a
LSD at 5%		0.02	0.10	0.02	0.02	0.12	0.08	0.003	0.002
Interaction									
T_1	F_1	48.27	48.29	25.13	25.14	37.42	37.55	0.305	0.317
	F_2	48.40	48.40	25.24	25.22	37.67	37.78	0.314	0.324
	F_3	48.46	48.47	25.35	25.35	38.26	37.91	0.330	0.345
T_2	F_1	48.66	48.66	25.39	25.44	39.28	39.59	0.353	0.373
	F_2	48.84	48.89	25.61	25.68	39.48	39.74	0.373	0.387
	F_3	48.96	48.56	25.71	25.81	39.65	39.91	0.390	0.409
T_3	F_1	49.48	49.43	25.85	25.94	40.77	40.94	0.461	0.493
	F_2	49.67	49.81	26.09	26.17	41.43	41.72	0.492	0.519
	F_3	49.82	49.90	26.30	26.36	41.77	41.92	0.510	0.531
T_4	F_1	48.49	48.46	25.24	25.32	37.86	37.93	0.324	0.346
	F_2	48.64	48.62	25.44	25.50	38.28	38.92	0.352	0.366
	F_3	48.77	48.82	25.61	25.63	38.67	39.01	0.368	0.387
T_5	F_1	49.00	49.06	25.54	25.65	39.66	39.77	0.378	0.395
	F_2	49.25	49.34	25.76	25.78	40.26	40.62	0.413	0.424
	F_3	49.37	49.44	25.89	25.90	40.83	40.84	0.429	0.447
LSD at 5%		0.05	0.23	0.04	0.05	0.26	0.19	0.004	0.004

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control;T_2: Fulvic acid at rate of 5 kg fed.$^{-1}$; T_3: Fulvic acid at rate of 10 kg fed.$^{-1}$;T_4: Humic acid at rate of 5 kg fed.$^{-1}$; T_5: Humic acid at rate of 10 kg fed.$^{-1}$; F_1: Control (without); F_2: Seaweed extract (3 g L^{-1}) and F_3: Yeast extract (5.0 g L^{-1})

Discussion

In order to enhance the quality of sweet pepper, there is a growing need to explore sustainable approaches to enhance its productivity by using organic acids that are beneficial for fruit quality and human health, thus this study focused the impact of humic and fulvic acids in addition yeast and seaweed extracts of yield and quality of sweet pepper.

The observed significant effects on yield, quality, and qualitative traits of sweet pepper plants can be attributed to the application of fulvic and humic acids, seaweed, and yeast extracts. Here are some scientific reasons explaining these effects:

Fulvic and humic acids (applied via fertigation system in T_2, T_3, T_4, and T_5 treatments) are known to enhance nutrient uptake, stimulate plant growth, and improve plant resilience to abiotic stress. These organic acids interact with soil minerals, increasing their availability for plant uptake. The improved nutrient uptake and utilization contribute to increased yield and better fruit quality. The beneficial effects of both fulvic and humic acids on the yield, quality, and nutritional traits of sweet pepper plants can be attributed to several reasons. Firstly, fulvic and humic acids are rich sources of organic matter. When applied to the soil, they enhance the soil's organic content, leading to improved soil structure, nutrient retention, and moisture-holding capacity. This, in turn, creates a more favorable environment for plant growth and development (Hamail *et al*., 2014a,b,c). Fulvic and humic acids also play a crucial role in nutrient availability and uptake. They have the ability to chelate or bind with essential nutrients, such as nitrogen, phosphorus, and potassium, making them more accessible to plants. This enhances nutrient uptake efficiency and ensures that the plants receive an adequate supply of essential nutrients for optimal growth (Taha *et al*., 2016).

Furthermore, fulvic and humic acids have been found to stimulate root development and enhance root function. They promote root growth, increase root surface area, and improve root penetration into the soil, facilitating better nutrient and water absorption by the plants. This enhanced root system contributes to improved overall plant growth, leading to increased yield, quality, and nutritional traits (Badr *et al.,* 2019 and Abdel-Baky *et al.,* 2019). However, it is important to note that the optimal concentration of fulvic and humic acids may vary depending on specific soil conditions, plant requirements, and other factors. The obtained results are in harmony with those of Šerá and Novák (2022). Also, it can be noticed the superiority of fulvic acid to humic acid when they were added at the same level. This may be due to that fulvic acid has a smaller molecular size compared to humic acid. This smaller size allows fulvic acid molecules to penetrate plant tissues more effectively and be readily absorbed by plant roots (Taha *et al*., 2023). This enhanced absorption and translocation within the plant can lead to more pronounced physiological responses and yield improvements. Also, fulvic acid has higher solubility and greater cation exchange capacity compared to humic acid. This means that fulvic acid can more efficiently bind with and transport nutrients, making them readily available for plant uptake. These findings are in agreement with those obtained by Taha *et al.* (2016).The increased bioavailability of nutrients can positively influence plant growth, leading to superior performance compared to humic acid. Fulvic acid has been reported to possess unique biostimulant properties (Lan *et al.,* 2022). It can act as a natural growth regulator, promoting cell division and elongation, stimulating enzyme activities, and enhancing hormonal balance within plants. These bio stimulant effects can contribute to improved plant growth and development, giving fulvic acid an advantage over humic acid in terms of growth response. FA has the ability to form complexes with various compounds, including trace elements and organic molecules. This complexation can enhance nutrient uptake and utilization by plants, resulting in improved growth (Aminifard *et al.,* 2012). HA, while also capable of complexation, may exhibit different affinities and interactions with different compounds, leading to varied effects on plant growth (Unlu *et al.,* 2010).

The superiority of yeast and seaweed extracts (F_2 and F_3 treatments) compared to the control group can be attributed to several scientific reasons. Firstly, both yeast and seaweed extracts enhance nutrient uptake by sweet pepper plants. They can chelate essential nutrients, increasing their availability and improving nutrient absorption by sweet pepper plants roots. This results in improved nutrient status and promotes overall plant performance, fruits yield and quality. Additionally, yeast and seaweed extracts possess bio stimulant properties that activate plant defense mechanisms. They induce the production of defense compounds such as phytoalexins, pathogenesis-related proteins, and antioxidants, which enhance the plants' ability to withstand biotic and abiotic stresses. These results are consistent with Dawa *et al.* (2014); Hamail *et al.* (2015); Ghazi (2020).The superiority of yeast extract compared to seaweed extract can be attributed to that yeast extract contain growth-promoting compounds such as amino acids, vitamins, enzymes, and plant hormones, which facilitate plant growth and development. These compounds provide essential building blocks for cellular processes and regulate growth-related activities.

The interaction between the main factor (fulvic acid, and humic acid) and sub-main factor (seaweed and yeast extracts) can result in synergistic effects on yield, quality, and nutritional traits. The combined application of fulvic acid and yeast extract (T_3 and F_3 treatment) demonstrated the highest performance in terms of yield, fruit quality, and nutritional constituents. This suggests that the combined application of these treatments may have complementary effects, enhancing nutrient uptake, metabolic processes, and plant growth.

Conclusion

Based on the results obtained from the study, the following conclusions can be drawn:

1. The application of humic substances (fulvic and humic acids) showed the most significant positive effects on the yield and fruit quality of sweet pepper plants compared to control, with the superiority of fulvic acid over humic.
2. The foliar application of biostimulants is beneficial (seaweed and yeast extracts) for sweet pepper cultivation.
3. The combination of fulvic acid at a rate of 1.0 kg fed.$^{-1}$ and the foliar application of yeast extract at a rate of 5.0 g L^{-1} is the best-combined treatment under the conditions of this study.

Recommendations:

Based on the findings of this study, the following recommendations can be made:

1. Farmers and growers can benefit from incorporating organic acids into the soil to enhance the productivity of sweet pepper plants. The application of fulvic acid at a rate of 10 kg fed.$^{-1}$ showed particularly promising results in terms of growth, yield, and fruit quality.
2. Foliar application of bio-stimulants, specifically yeast extract at a rate of 5.0 g L^{-1}, can be a beneficial practice to improve the growth, yield, and nutritional composition of sweet pepper fruits. This can be done alongside the application of organic acids for enhanced results.
3. Further research and experimentation should be conducted to optimize the application rates and timing of organic acids and bio-stimulants for sweet pepper cultivation. Different combinations and concentrations should be explored to identify the most effective and cost-efficient approaches.
4. The study focused on sweet pepper plants grown under protected conditions. Future studies can investigate the effects of these organic substances and bio-stimulants in open-field cultivation to assess their performance in different environments.
5. Long-term studies should be conducted to evaluate the sustainability and long-lasting effects of using organic substances and bio-stimulants on soil health, plant growth, and yield. This will help in developing comprehensive and environmentally friendly strategies for sweet pepper cultivation.

By implementing these recommendations, growers can adopt effective and sustainable practices that enhance the productivity and nutritional quality of sweet pepper, ultimately benefiting both producers and consumers.

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زيادة محصول وجودة ثمار الفلفل الأحمر الحلو بالأحماض العضوية والمنشطات الحيوية تحت الظروف المحمية

على فتحى على حمايل , محمود أحمد محمد عبد الهادى ، مصطفى محمد على داود
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تهدف هذه الدراسة الى إسستكشاف أساليب مستدامة لتعزيز إنتاجية الفلفل الأحمر الحلو نظرا لأهميته الإقتصادية والغذائية. للوصول لهذا الهدف تم إجراء تجربة تحت الصوب الزراعية لدراسة عاملين رئيسيين تحت تصميم القطع المنشقة مرة واحدة، حيث كان العامل الأول هو إضافة الأحماض العضوية مع ماء الرى (كنترول بدون إضافة، حمض الفالفيك ٥ كجم/فدان، حمض الفالفيك ١٠ كجم/فدان، حمض الهيوميك ٥ كجم/فدان، حمض الهيوميك ١٠ كجم/فدان)، بينما كان العامل الثانى الشقى هو الرش بالمنشطات الحيوية مثل مستخلص الطحالب البحرية بمعدل ٠,٥ جم/لتر ومستخلص الخميرة بمعدل ٥ جم/لتر بالإضافة الى الكونترول.

بالنسبة إلى تأثير الأحماض العضوية، أوضحت النتائج تفوق حمض الفالفيك بمعدل ١٠ كجم/فدان فى المحصول الكلى وعدد الثمار لكل نبات ووزن وطول وقطر الثمرة بالإضافة للمحتوى من العناصر المعدنية النيتروجين والفوسفور والبوتاسيوم والسكريات الكلية والكربوهيدرات وفيتامين ج وصبغة الليكوبين. أما بالنسبة لتأثير الرش بالمنشطات الحيوية فأوضحت النتائج أن الرش بمستخلص الخميرة بمعدل ٥ جم/لتر أعطى أعلى القيم بالنسبة للصفات السابقة. بينما أدى التفاعل بين إضافة حمض الفالفيك أرضيا بمعدل ١٠ كجم/فدان والرش بمستخلص الخميرة بمعدل ٥ جم/لتر إلى زيادة جميع الصفات المدروسة مقارنة بباقي التفاعلات.

ومن خلال هذه التوصيات يمكن للمزارعين إعتماد ممارسات فعالة ومستدامة لتعزيز إنتاجية وجودة الفلفل الحلو مما يعود بالنفع فى النهاية على المنتجين والمستهلكين.

الكلمات المفتاحية: حمض الهيوميك – حمض الفالفيك – مستخلص الطحالب البحرية – مستخلص الخميرة