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Role of Humic Acid in Enhancing Physiological Characteristics, Growth, and Sustainable Yield of Fresh and Frozen Strawberry (*Fragaria* × *ananassa* Duch.) Transplants

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Abstract: The study of foliar spraying with different concentrations of humic acid (HA) (0, 7, and 9 mL HA L^{-1}) of two types of strawberry transplants (fresh) and (frozen)) individually or combined in improving physiological traits, growth and yield of strawberry (*fragaria* × *ananassa* Duch.) transplants grown under unheated plastic greenhouse, was conducted at the department of horticulture and landscape engineering, college of agriculture and forestry, university of mosul, during the growing season 2025-2026, application of humic acid foliar spray maybe particularly 9 mL HA L^{-1} and the (fresh) transplants type either alone or in combination, led to significant different in all studied traits except fruit acidity caused higher in (fresh) transplants. The combination of foliar application of humic acid with (fresh) strawberry transplants (9 mL HA L^{-1} + (fresh) transplants) was found to be the best treatment. This treatment increased the number of leaves and leaf area of the plant. It also enhanced number of crowns per plant, number of flowers per plant, fruit set % (HI) and number of days from planting to 50% flowering. In addition, 9 mL HA L^{-1} + (fresh) transplants increased marketable yield t ha^{-1}, total soluble solids (TSS) in fruit, total acidity in fruit, vitamin C and anthocyanin content as compared to most of the other treatments including control.

Key words: Strawberry, Humic Acid, (fresh) Transplants, (frozen) Transplants.

1. Introduction

The strawberry (*Fragaria* × *ananassa* Duch.) is one of the popular soft fruits. The strawberry is a member of the family Rosaceae and its name in the genus Fragaria means pleasant fragrance. The Rosaceae family contains many important fruits such as apple, pear, quince and peach (**Kashani *et al.*, 2025**). Strawberry is a perennial herbaceous plant that is a global small fruit crop with widespread distribution. Strawberry is a berry which is also called the 'queen of fruits' (**Yousif, 2024**). Strawberries are normally cultivated in temperate regions, but a few varieties can be grown in subtropics, which provide quicker returns than many other fruit crops (**Quddus *et al.*, 2025**). The strawberry is native to North America. From there it spread to other countries across the world (**Habib and Al-Faraoun, 2013**).

According to **de Jesus *et al.*, 2024** the strawberry fruit can be classified as an accessory fruit since it consists mainly of supportive tissue compared to other accessory fruits. The red., tasty, sweet, and highly nutritious fruit. The taste is primarily determined by sugar (0.5%) acids (0.90–1.85%) and aromatic compounds. With their high vitamin C and antioxidants content, strawberries help to keep the heart healthy and regulate blood sugar levels. Upon the whole, strawberries have a relatively high iron content among fruits and vegetables (**Raghavan *et al.*, 2025**). They also contain vitamins B, E, folic acid, and minerals like potassium and carotenoids, as well as flavonoids and dietary fibers (**Danyo and Ivantsova, 2025**).

Across the world strawberry is one of the most popular small fruit crops. Strawberry is cultivated in over 380,000 ha. Its production capacity is about 9 million tonnes (**FAO, 2022**). Strawberries are high in commercial and industrial value as per FAOSTAT, more than 80% strawberries are consumed (fresh) or raw. Remainder is processed into value-added products like jams, juices, jellies and confectioneries, ice cream and yogurt (**Soni *et al.*, 2025**).

Due to modernization of agriculture, there were replacements of old practices with new advanced technologies and conventional nutrients were replaced with synthetic fertilizers. In spite of significant impact of chemical fertilizer on crop productivity, inappropriate use, over dose and poor management has made it an important cause of soil and environmental pollution, degradation of soil quality and nutrient imbalance. To avoid such negative effects, soil and environment need to follow a transition from normal to organic farming so that long term soil and environment will not harm (**Verma *et al.*, 2019**). The organic amendment that is humic acid (HA) is a heterogeneous acid made up of a large variety of structures from small molecules to large complicated particles. It dissolves in alkaline media but builds up in acidic phases; mainly composed of carbon (C), with other elements making up the chemical structure. Humic acid comes from the decay and biological activities of plant and microbial residues in soil and water, and it has long been classified into three groups: humic acid, fulvic acid (FA), and humin; they differ in terms of solubility, molecular weight as well as chemical functions (**Machado *et al.*, 2020**). In a process of physical, biological and chemical processes, humic acid is formed from decomposition of plant lignin, cellulose as well as proteins, and products coming from microbes which are eventually leading to larger and complex molecules possessing numerous different functional groups (like carboxyl, hydroxyl, phenolic, amino) present in these molecules offers it the ability for exchange of ions and further complexing with metals (**Krivdin, 2025**). Based on work by **Ampong *et al.*, 2022**, humic acid can physically enhance the structure of soil. It can aggregate sand, silt and clay with organic and mineral matter into larger units. This aggregates enhances the porosity of soil which helps with the retention of water by the soil. Furthermore, additional benefits include the promotion of root growth and a reduction of topsoil erosion. It enhances cation exchange capacity (CEC); improves nutrient availability; forms complexes with Fe, Zn, and Cu; promotes phosphorus release; reduces nutrient losses through leaching; stimulates beneficial soil microorganisms (**Ma *et al.*, 2024**). Humic acid can have many benefits for the kids strawberry transplants. It acts as a biostimulant, enhances hormonal activity, releases auxins, regulates the response and enhances the tolerance towards stress and increases the resistance against pests and fungus diseases. It also aids in absorbing nutrients from the soil, safely furnishing the essential nutrient elements and causing the production of cleaner, safe, quality fruits that are also lower in nitrates with increased yields and fruit quality (**Zydlik & Zydlik, 2023**). Several studies have demonstrated that the application of organic acids enhances the growth and productivity of strawberry transplants, particularly humic acid. In this regard, **Alkharpotly *et al.* (2017)** reported that fertilizing strawberry (*Fragaria* × *ananassa* Duch.) cv. Festival with humic acid at three concentrations (0, 200, and 400 mg HA L^{-1}) over two growing seasons resulted in significant increases in the number of leaves, crowns, flowers per plant, and total yield per feddan, with the highest values recorded at 400 mg HA L^{-1} compared to other treatments. Similarly, **Ullah *et al.* (2017)** indicated that foliar application of humic acid to strawberry cv. Chandler at concentrations of (1.5, 3.0, and 4.5 mL HA L^{-1}), applied 30 days after planting, significantly increased the number of fruits per plant at 3.0 mL HA L^{-1}, whereas the total acidity percentage of fruits decreased at 4.5 mL HA L^{-1} compared with the other treatments. **Omer Ahmed (2021)**, in a study evaluating the response of strawberry cv. Albion to humic acid at concentrations of (0, 2.5, and 5 mg HA L^{-1}), found that the highest significant increases in total sugars percentage and vitamin C content in fruits were obtained at 5 mg HA L^{-1}, while the application of 2.5 mg HA L^{-1} resulted in increased anthocyanin content in the fruits. **Al-Shahoud Rana and Maher**

Hassan (2022) observed that foliar spraying of strawberry cv. Oso Grande with humic acid at 2 mL HA L^{-1} produced the highest significant increases in the number of leaves per plant, leaf area, number of flowers per plant, fruit set percentage, total soluble solids percentage, and vitamin C content, along with a reduction in total acidity percentage in fruits. Their study included four concentrations (0, 0.5, 1, and 2 mL HA L^{-1}). **Chakraborty *et al.* (2023)** further confirmed that foliar application of humic acid to strawberry cvs. Camarosa and Nabila at concentrations of (1 and 2 mL HA L^{-1}) significantly improved vegetative and reproductive traits, including number of leaves, leaf area, number of crowns, number of flowers per plant, fruit set percentage, total yield per hectare, vitamin C content, and total sugars percentage, with the best results observed at 2 mL HA L^{-1}. **Ahmed *et al.* (2023)** also reported that foliar spraying of strawberry transplants with humic acid at 4 g HA L^{-1} significantly increased leaf area and vitamin C content in fruits compared with the control and 2 g HA L^{-1} treatments, using three concentrations (0, 2, and 4 g HA L^{-1}). Moreover, **Mutlaq *et al.* (2024)** found that applying humic acid to strawberry cv. Ruby Gem at concentrations of 0, 5, and 10 mmol HA L^{-1} resulted in a significant increase in the number of leaves per plant, particularly at 10 mmol HA L^{-1}. Finally, **Al-douri and Al-Douri (2024)** demonstrated that the application of humic acid at concentrations of (0, 5, and 10 mL HA L^{-1}) to strawberry cv. Rubygem significantly affected fruit acidity and anthocyanin content, with the most pronounced effects observed at 10 mL HA L^{-1}.

(fresh) strawberry transplants (fresh) are newly propagated plants from runners and are the most common technique of vegetative propagation. These plants that are grown under controlled conditions can be directly transplanted into the fields or new production systems. The mother plants from which the runners originate are strong and healthy greenhouses or special cultivation systems. Once the runners establish roots and receive enough moisture, small rooted transplants are formed that can be shifted to plastic bags or directly in the field for hardening off. Horticultural applications are subsequently applied ensuring optimal growth (**Türemiş et a.l، 1998**). According to **Lieten (2005)**, (fresh) transplants are widely used in establishing new strawberry farms as they have high reproduction potential and good health status.

On the other hand, (frozen) transplants are previously stored plants obtained during dormancy, normally late autumn or early winter seasons (**Lee *et al.*، 2020**). Studies show that (frozen) transplants can be stored at −1 to −2 °C for up to 11 months (**Lieten *et al.*، 2005**). After a period of storage, it is advisable to gradually acclimatize the transplants by hydrating the roots or soaking for a few hours. (frozen) transplants are generally planted in spring or early summer when they are taken out of cold storage (**Duralija *et al.*, 2006**).

Prior research has highlighted the value of both (fresh) and (frozen) transplants. **Economides and Gregoriou (1988)** reported that, under greenhouse conditions, planting (fresh) and (frozen) transplants of different cultivars (Aliso, Tufts, Taro, Aiko, Cruz) resulted in (frozen) transplants producing significantly greater total yield per hectare than (fresh) transplants. Likewise, **Türemiş *et al.* (1996)** reported that a mixture of ten strawberry cultivars cultivated in plastic bags under greenhouse conditions achieved greater total yield per hectare in (frozen) transplants than in (fresh) transplants. **Duralija *et al.* (2006)** also stated that (fresh) transplants significantly improved the total yield of refrigerated (frozen) ones. According to **Usanmaz (2019)**، the total yield significantly increased in (frozen) the cultivars Florida and Fortuna. Likewise, there were no significant differences in fruit acidity in comparison to (fresh) in a greenhouse environment. As per (**Salkić *et al.*, 2024**), Growing in seedling trays Clery cultivar (fresh) and (frozen) transplants at 25 × 25 cm spacing significantly led to an increase in leaf number and leaf area for (fresh) transplants; whereas (frozen) transplants spent fewer days from planting to 50% flowering compared to (fresh) transplants.

2. Materials and Methods

The experiment was conducted in the unheated plastic house of the Department of Horticulture and Landscape Engineering, College of Agriculture and Forestry, University of Mosul, 2025-2026 growing season. The length of the greenhouse is 54 m and width is 9 m. The strawberry transplants were procured from a reputed local nursery and brought to the experimental site in plastic boxes. Before the planting, one minute prior to planting, the roots of the transplants were dipped in Bentanol fungicide at a concentration of 1 mL L^{-1} to avoid fungal infection. After that, the soil was proper plough and split into three raised beds, 70 cm wide which were experimental replicates. To determine physical and chemical properties of soil, random soil samples were collected from three places each at 30 cm depth within the greenhouse. The laboratory analysis of samples was carried out as described by **Page *et al.* (1982)** and **Black (1965)** given in Table (1)

Table (1). Some physical and chemical properties of the trial soil

Parameter	Unit	Value
Electrical Conductivity (EC)	(dsm. m^{-1})	0,744
(pH)	-----	7,69
Organic mater	(gm.Kg^{-1})	5,28
Sand	(gm.Kg^{-1})	610,7
Clay	(gm.Kg^{-1})	239,6
Silt	(gm.Kg^{-1})	156,7
Soil texture	-----	Clay loam
Available N	(mg.Kg^{-1})	95
Available P	(mg.Kg^{-1})	21
Available K	(mg.Kg^{-1})	116

* "Soil analysis was conducted at the Central Laboratory, College of Agriculture and Forestry, University of Mosul".

Once the soil was prepared, a drip was laid out, and the raised beds were mulched with black polyethylene. Holes were created for planting at intervals of 25 cm with a plant-to-plant distance of 25 x 25 cm. An experimental isolation distance of 50 cm was maintained between the units of experiment. The individual measurement of my experimental unit was 1.50 m length, 1.10 m width, and area of 1.65 m^2. This study employed a factorial experiment in a randomized complete block design (RCBD) with a split-plot arrangement to conduct the experiment. It consisted of two factors: the first factor was foliar application of humic acid (HA), while the second factor was the type of strawberry transplants. The humic acid foliar spray (13% HA) was applied in three concentrations on 20/11/2024, having three applications during the experimental period at intervals of 20 days, Accordingly, the total number of strawberry transplants used in the experiment was 180. Three concentrations of humic acid (0, 7, and 9 mL HA L^{-1}) and two types of strawberry transplants ((fresh) and (frozen)) were used, with three replicates and ten plants per experimental unit. The strawberry transplant types occupied the main plots, while the humic acid levels were assigned to the sub-plots.

2.1. Measured Parameters

1. Number of leaves perplant (leaf $plant^{-1}$)

The count of fully developed leaves formed on each plant was recorded from the inception to completion of the experiment. The total number of leaves at harvest also included those removed for chlorophyll determination.

2. Leaf area per plant (cm^2 $plant^{-1}$)

The method given by **Patton (1985)** has been used for calculating leaf area using the equation given:

"**Leaf area per plant (cm^2)** = Area of a single leaf (cm^2) × Total number of leaves per plant"

This equation was applied after accurately determining the average area of a single leaf, providing a quantitative estimate of the total leaf area per plant, which is considered an important indicator of photosynthetic efficiency and vegetative growth.

3. Number of crowns per plant (crown plant^{-1})

During the last week of May, the number of crowns was counted in the selected plants of each experimental unit (eight plants). The average number of crowns per plant was calculated by dividing total number of crowns by eight.

4. Total number of flowers per plant (flower plant^{-1})

The flowers of eight plants in each experimental unit were counted from the beginning to the end of flowering. The total average number of flowers per plant was calculated using the following formula.

Total number of flowers per plant = Total number of flowers for eight plants ÷ 8

5. Fruit set percentage (%)

The fruit set was calculated for the eight experimental plants from the commencement of flowering up to the trial completion using the following formula:

Fruit set (%) = (Total number of fruits per plant ÷ Total number of flowers per plant) × 100

6. Number of days from planting to 50% flowering

The days were counted from the planting date (10 October 2024) until 50 per cent of the selected transplants (eight plants per experimental unit) were in flowering.

7. Marketable yield per hectare (kg ha^{-1})

The number of plants per hectare was calculated using proportional estimation between the number of plants in the experimental unit (1.65 m²) and one hectare, according to the following equation:

Number of plants per hectare =
(Area of one hectare (10,000 m²) × number of plants per experimental unit (10 plants)) ÷ area of the experimental unit (1.65 m²)= **60,606.06 plants ha^{-1}**

The marketable yield per plant was then calculated using the following equation:

Marketable yield per plant = Total plant yield − weight of deformed and non-marketable fruits per plant

Later, the marketable yield per hectare was estimated as below:

Marketable yield per hectare = Number of plants per hectare × Marketable yield per plant

8. Total sugars in fruits (%)

The method of **Joslyn (1970)** was used to determine this property. During the eighth harvest, ten fruits from each experimental unit were collected and finely chopped. The mixture of fruit was blended for about 2-3 minutes after which it was filtered through cotton. One milliliter of the filtrate was carried in a 50 mL flask taking after to this was added 1 mL of 5 % phenol and 18 mL of distilled water. The mixture was shaken well and 5mL of concentrated sulphuric acid (97%) was added to it. The solution was kept in a 60 °C water bath for 30 minutes. Subsequently, 10 mL of the supernatant was taken and transferred to a test tube, then analyzed with a spectrophotometer. After the solution cooled to room temperature, the supernatant was withdrawn. A spectrophotometer at 490 nm measured total sugars.

9. Total titratable acidity in fruits (TA %)

Total titratable acidity was determined by **A.O.A.C. Method (1970)**. Fruits from every experimental unit were collected on the eighth harvest and cut fine. The juice was collected and filtered through the use of cotton cloth after blending for 2-3 minutes. A sample of five milliliters of the filtrate was taken and diluted to a final volume of 50 mL with distilled water. A 10 mL portion of this solution was titrated with 0.1 N sodium hydroxide (NaOH) endpoint using 2–3 drops of phenolphthalein indicator. The total acidity, which is citric acid in strawberry fruits, was calculated using the equation below:

$$\%\,\mathbf{TA} = \frac{\mathbf{T.N.Eq.Vt.}}{\mathbf{Vs.Vi\ 1000}} \times \mathbf{100}$$

Where:

TA = Titratable acidity
T = Volume of the base used in titration (mL)
N = Normality of the base used (0.1 N)
Eq = Equivalent weight of citric acid (70)
Vt = Final volume of juice after dilution (50 mL)
Vs = Volume of juice used in titration (10 mL)
Vi = Initial volume of juice before dilution (5 mL)

10. Vitamin C content in fruits (mg 100 g^{-1} fresh weight)

Samples of fruit juice from all experimental treatments were tested for ascorbic acid content (juice fresh and preserved in 2% oxalic acid). Titration with 2,6–dichlorophenol indophenol dye was carried out to determine. Ascorbic acid alone is the reducing agent which changes blue to pink in alkaline and acidic medium respectively, thus indicating the end point. This method was suggested by **Ranganna (1977)** for the use of ascorbic acid as reducing agent for quality testing of foods.

11. Anthocyanin content in fruits (mg 100 g^{-1} fresh weight)

We took 10 mL of fruit juice and mixed with 10 mL of extraction solution of 85% methanol + 15% hydrochloric acid (1.5 N HCl). The resulting mixture was filtered using filter paper, and the volume was made up to 100 ml. The solution was subsequently kept at 4–5°C for a period of 24 hours. Next, a spectrophotometer was used to measure the absorbance of the filtrate at a wavelength of 520 nm. Anthocyanin content was determined as follows equation:

Anthocyanin content (mg 100 g^{-1} fresh weight) =
(Total solution volume × Spectrophotometer reading) / (98.2 × Sample volume) × Dilution factor.

3. Results and Discussion

1. Number of leaves per plant (leaf $plant^{-1}$) and leaf area (cm^2 $plant^{-1}$).

As depicted in Table (2), the foliar application of humic acid significantly influenced the number of leaves formed on the transplants and also the leaf area per plant. The control treatment was significantly surpassed by 7 and 9 mL HA L^{-1} treatments. Also, the 9 mL HA L^{-1} treatment was significantly better than that of 7 mL HA L^{-1} treatment. In addition, the type of strawberry transplants also had a significant effect on these traits. (freshly) transplanted strawberry plants had a much greater number of leaves formed as well as leaf area per plant over the transplants of (frozen) strawberry. It was also found that the studied factors interacted significantly influencing these traits. The interaction treatment between the highest humic acid level (9 mL HA L^{-1}) and (fresh) strawberry transplants shows the highest value for the number of leaves per transplant and leaf area per plant.

2. Number of crowns per plant (crowns $plant^{-1}$) and total number of flowers per plant (flowers $plant^{-1}$)

The data in Table (3) indicate that the application of humic acid by foliar route and the type of strawberry transplants had a significant impact on the number of crowns and flowers formed per plant. In terms of humic acid treatments, the 9 mL HA L^{-1} spray recorded the maximum number of crowns and flowers per plant, significantly superior to the control treatment (which recorded the least crowns and flowers per plant) and to the 7 mL HA L^{-1}, which in turn was significantly superior to the control. In contrast, (fresh) strawberry transplants formed the highest number of crowns and flowers per plant. In addition, their values- that is, number of flowers and crowns – were significantly higher than those of (frozen) strawberry transplants, which formed the least. The results also indicated that the two-way interaction between humic acid and strawberry transplant type had a significant effect on the number of crowns and flowers formed per transplant. The interaction between the highest concentration of humic acid (9 mL HA L^{-1}) and (fresh) strawberry transplants produced the highest number of crowns and flowers per plant, significantly outperforming all other two-way interaction treatments.

Table (2). Role of Humic Acid in Enhancing Physiological Characteristics, Growth, and Sustainable Yield of (Fresh) and (Frozen) Strawberry (*Fragaria* × *ananassa* Duch.) Transplants of the number of leaves per seedling (leaves plant $^{-1}$) and leaf area (cm² plant $^{-1}$)

Treatments	Humic acid concentration (mL HA L^{-1})			Means of Strawberry Varieties
	0	7	9	
Strawberry Varieties	Number of Leaves (leaf plant^{-1})			
(fresh)	e 38.40	b 39.33	a 40.52	a 39.42
(frozen)	f 35.41	d 37.29	c 38.50	b 37.06
Means of HA	c 36.90	b 38.31	a 39.51	
Strawberry Varieties	Plant leaves area (cm^2 Plant^{-1})			
(fresh)	e 3094	b 4359	a 5268	a 4240
(frozen)	d 3278	d 3768	c 4022	b 3689
Means of HA	c 3186	b 4063	a 4645	

According to Duncan's multiple range test, the means of each factor separately and the interactions between the studied factors, each on its own, followed by different letters, indicate that they all show significant differencesfrom each other at 0.05 probability level

Table (3). Role of Humic Acid in Enhancing Physiological Characteristics, Growth, and Sustainable Yield of (Fresh) and (Frozen) Strawberry (*Fragaria* × *ananassa* Duch.) Transplants of the Number of Crowns per Seedling (Crown plant $^{-1}$) and Total Number of Flowers per Seedling (Flower plant $^{-1}$)

Treatments	Humic acid concentration (mL HA L^{-1})			Means of Strawberry Varieties
	0	7	9	
Strawberry Varieties	Number of Crown (Crown plant^{-1})			
(fresh)	c 5.82	b 6.22	a 6.77	a 6.27
(frozen)	f 3.76	e 4.26	d 4.73	b 4.25
Means of HA	c 4.79	b 5.24	a 5.75	
Strawberry Varieties	Number of Flower (Flower plant^{-1})			
(fresh)	c 31.52	b 32.60	a 33.38	a 32.50
(frozen)	f 26.57	e 27.44	d 28.23	b 27.41
Means of HA	c 29.04	b 30.02	a 30.81	

According to Duncan's multiple range test, the means of each factor separately and the interactions between the studied factors, each on its own, followed by different letters, indicate that they all show significant differences from each other at 0.05 probability level.

3. Fruit Set Percentage (%), Number of Days from Planting to 50% Flowering, and Marketable Yield per Hectare (kg ha^{-1})

Table (4) results illustrated that humic acid (foliar application) significantly influenced the fruit set %, number of the days from planting to 50 % flowering, and marketable (yield / hectare) in capsicum. The individual application of foliar spraying with 9 mL HA L^{-1} and (fresh) strawberry transplants significantly enhanced fruit set percentage and marketable yield and drastically reduced the number of days to reach 50% flowering compared to the control and 7 mL HA L^{-1}. The findings further indicated that the interaction of humic acid with (fresh) strawberry transplants significantly influenced the studied traits, among which the combined treatment had the highest fruit set percentage, the least number of days to 50% flowering, and the highest marketable yield.

Table (4). Role of Humic Acid in Enhancing Physiological Characteristics, Growth, and Sustainable Yield of (Fresh) and (Frozen) Strawberry (*Fragaria* × *ananassa* Duch.) Transplants of the Fruit Set Percentage (%), Number of Days from Planting to 50% Flowering, and Marketable Hectare Yield (kg ha^{-1})

Treatments	Humic acid concentration (mL HA L^{-1})			Means of Strawberry Varieties
	0	4	8	
Strawberry Varieties	Fruit set (%)			
(fresh)	c 85.62	b 86.44	a 87.52	a 86.53
(frozen)	f 75.52	e 76.25	d 77.44	b 76.40
Means of HA	c 80.57	b 81.34	a 82.48	
Strawberry Varieties	Days from planting to 50% flowering			
(fresh)	d 80.44	e 78.77	f 77.11	b 78.77
(frozen)	a 93.22	b 91.66	c 90.00	a 91.62
Means of HA	a 86.83	b 85.22	c 83.55	
Strawberry Varieties	Total Fruits Yield (kg.ha^{-1})			
(fresh)	e 241324	b 440697	a 530142	a 404054
(frozen)	f 201531	d 291695	c 370965	b 288063
Means of HA	c 221427	b 366196	a 450553	

According to Duncan's multiple range test, the means of each factor separately and the interactions between the studied factors, each on its own, followed by different letters, indicate that they all show significant differences from each other at 0.05 probability level.

4. Total sugars percentage in fruits (%) and Total Acidity (TA%) in Fruits

According to the results presented in table (5), the TSS percentage of fruits increased significantly and directly proportionally with the rise in levels of humic acid foliar application. Analysis revealed the 9 mL HA L^{-1} treatment was significantly superior to the 7 mL HA L^{-1} treatment and the control, while the 7 mL HA L^{-1} treatment was significantly higher than the control. The kind of strawberry transplant performed significantly the same among (frozen) and (fresh) transplants for TSS percentage, with (fresh) outperforming (frozen) ones.

On total acidity (TA) percentage of the fruits, foliar spraying with humic acid has a significant effect on this trait. The application of humic acid indicated significantly lower total acidity (TA) values at both 7 mL HA L^{-1} and 9 mL HA L^{-1} as compared to control. Also, the type of transplants strawberry it was established that (frozen) transplants showed a significantly lower TA as compared to (fresh) transplants. Findings show that the interaction among the studied factors significantly affect the percentage total sugars and the percentage of total acidity (TA) of the fruits. In the interaction treatment of high humic acid level (9 mL HA L^{-1}) and (fresh) strawberry transplants was observed the highest total sugar content and the lowest total acidity. Total sugars increased and total acidity decreased.

Table (5). Role of Humic Acid in Enhancing Physiological Characteristics, Growth, and Sustainable Yield of (Fresh) and (Frozen) Strawberry (*Fragaria* × *ananassa* Duch.) Transplants of the Total Soluble Solids Percentage in Fruits (%) and Total Acidity Percentage in Fruits (%TA)

Treatments	**Humic acid concentration (mL HA L^{-1})**			**Means of Strawberry Varieties**
	0	**7**	**9**	
Strawberry Varieties	**Total sugars (%)**			
(fresh)	**d 9.09**	**b 10.03**	**a 11.02**	**a 10.05**
(frozen)	**f 8.33**	**e 8.85**	**c 9.24**	**b 8.81**
Means of HA	**c 8.71**	**b 9.44**	**a 10.13**	
Strawberry Varieties	**Titratable acidity (%)**			
(fresh)	**b 0.75**	**c 0.71**	**d 0.68**	**a 32.50**
(frozen)	**a 0.77**	**b 0.74**	**c 0.71**	**b 27.41**
Means of HA	**a 0.76**	**b 0.72**	**c 0.69**	

According to Duncan's multiple range test, the means of each factor separately and the interactions between the studied factors, each on its own, followed by different letters, indicate that they all show significant differences from each other at 0.05 probability level.

5. Vitamin C in fruits (mg 100 g^{-1} fresh weight) and anthocyanin content in fruits (mg 100 g^{-1} fresh weight)

According to the data predicted in Table 6, the foliar spray application of 9 mL HA L^{-1} produced the highest amounts of vitamin C and anthocyanins in the fruits which were significantly higher compared to control and 7 mL HA L^{-1} treatment which in turn produced significantly higher amounts than control for both strawberry cultivars. The type of strawberry transplants was also observed to significantly affect vitamin C and anthocyanin content, where the (fresh) transplants had the highest of them, significantly higher than the (frozen) ones.

As for the interaction between the factors studied, the results confirmed a significant effect, with the application of the high level of humic acid (9 mL HA L^{-1}) with (fresh) transplants producing the highest values of vitamin C and anthocyanin content.

Table (6). Role of Humic Acid in Enhancing Physiological Characteristics, Growth, and Sustainable Yield of (Fresh) and (Frozen) Strawberry (*Fragaria* × *ananassa* Duch.) Transplants of the Vitamin C in Fruits (mg 100 g^{-1} fresh weight) and Anthocyanin Content in Fruits (mg 100 g^{-1} fresh weight)

Treatments	Humic acid concentration (mL HA L^{-1})			Means of Strawberry Varieties
	0	7	9	
Strawberry Varieties	Ascorbic acid (mg 100 g-1 FW)			
(fresh)	c 16.72	b 17.62	a 18.74	a 17.69
(frozen)	f 14.52	e 15.40	d 16.44	b 15.45
Means of HA	c 15.62	b 16.51	a 17.59	
Strawberry Varieties	Anthocyanin content (mg 100 g^{-1} FW)			
(fresh)	c 37.89	b 39.64	a 40.81	a 39.45
(frozen)	f 35.68	e 36.58	d 37.64	b 36.64
Means of HA	c 36.78	b 38.11	a 39.23	

According to Duncan's multiple range test, the means of each factor separately and the interactions between the studied factors, each on its own, followed by different letters, indicate that they all show significant differences from each other at 0.05 probability level.

4. Discussion

These results are consistent with those reported by **Al-Shahoud Rana and Maher Hassan (2022)**, **Chakraborty *et al.* (2023**), and **Mutlaq *et al.* (2024)** in their studies on strawberry transplants. This may be attributed to the role of humic acid and its positive effect on strawberry transplants, which influences both directly and indirectly the physiological processes occurring in strawberry seedlings. Foliar application of humic acid on strawberry transplants increased nitrogen concentration in strawberry leaves, especially at the concentration of 9 mL HA L^{-1}, which affected chlorophyll concentration and development, a key factor in photosynthesis, as well as in the accumulation of sugars, amino acids, and enzymes necessary for chlorophyll synthesis (**Chen *et al.*, 2004**). Humic acid also plays a role in plant growth by stimulating cell division and activating some enzymes that promote seedling growth and enhance photosynthetic efficiency through increasing leaf area, which leads to an increase in the amount of synthesized carbohydrates and proteins in leaves required for the formation of seedling tissues (**Ahmed *et al.*, 2023**). In addition, humic acid enhances the metabolic activities of seedlings due to the activation of enzymes responsible for chlorophyll synthesis required for photosynthesis, as well as the formation of sugars, proteins, and energy compounds, all of which positively affect vegetative growth and subsequently flowering and yield (**Lateef *et al.*, 2021**). Humic acid also contributes to increasing the concentrations of some nutrient elements in leaves such as iron and magnesium. Since humic acid contains carbon, hydrogen, oxygen, and nitrogen in its structure, these elements collectively play a role in increasing chlorophyll content in leaves, either by participating in its structure such as magnesium or through stimulating and activating biochemical pathways responsible for its synthesis in the cell (**Havlin *et al.*, 2005**). The nitrogen present in humic acid is involved in the formation of IAA, which enhances vegetative growth in strawberry seedlings. Moreover, humic acid plays an important role in regulating nitrate uptake through its interaction with the H^+-ATPase enzyme in the plasma membrane, which accelerates nitrogen and nitrate uptake, enhances nitrogen metabolism, and increases protein production. These effects are positively reflected in increasing leaf growth, leaf number, leaf area, and crown number per plant, which in turn increases the number of flowers per plant and fruit set percentage, and reduces the number of days from planting to 50% flowering. All these improvements contribute to enhancing marketable yield per hectare and improving strawberry fruit quality, including total soluble solids, vitamin C content, and anthocyanin concentration, while reducing titratable acidity (**Ferrara and Brunetti, 2010**).

The results also confirm the role of) fresh non-chilled) strawberry transplants in enhancing physiological, growth, and yield characteristics of strawberry plants. (fresh) transplants are characterized by physiologically active tissues and higher levels of carbohydrates, enzymes, and plant hormones compared to stored seedlings. This physiological activity leads to rapid formation of new leaves, increased leaf number and leaf area, which enhances photosynthetic efficiency and carbohydrate production necessary for vegetative and reproductive growth, including increased flower number and fruit set percentage. This ultimately increases the number of fruits per plant and total marketable yield. Leaf number and leaf area are directly related to strawberry productivity because leaves are the primary source of carbohydrates that are translocated to flowers and fruits (**Roosta *et al.*, 2024**). These results are in agreement with those reported by **Salkić *et al.* (2024).**

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دور حامض الهيوميك في تحسين الصفات الفسيولوجية ،النمو والحاصل المستدام لشتلات الشليك (*Fragaria* × *ananassa* Duch.) الفريش والمجمد

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الخلاصة

أظهرت نتائج دراسة لبيان تأثير الرش بحامض الهيوميك وبثلاثة تراكيز (0 و7 و9 مل HA لتر$^{-1}$) ونوعين من شتلات الشليك المزروعة (frozen و fresh) ، كلٌ على حدة أو بالتداخل فيما بينهما، في تحسين الصفات الفسيولوجية النمو والحاصل لشتلات الشليك (*Fragaria* × *ananassa* Duch.) المزروعة داخل البيت البلاستيكي غير المدفأ في قسم البستنة وهندسة الحدائق / كلية الزراعة والغابات / جامعة الموصل خلال الموسم الزراعي 2025–2026، أن الرش بحامض الهيوميك خاصةً وبتركيز 9 مل HA لتر$^{-1}$ ونوع شتلات الشليك المزروع الـ (fresh) ، منفردين أو متداخلين، أدى الى حصول فرق معنوي في جميع صفات الدراسة ما عدا نسبة الحموضة في الثمار التي كانت مرتفعة في نوع شتلات الشليك المزروع الـ (fresh). وكانت أفضل المعاملات هي رش شتلات الشليك بحامض الهيوميك مع نوع شتلات الشليك المزروع الـ (fresh) (9 مل HA لتر$^{-1}$ + نوع شتلات الشليك المزروع الـ (fresh) ، إذ أعطت فرقا معنوياً في (عدد الأوراق ، المساحة الورقية ، عدد التيجان للشتلة الواحدة ، عدد الازهار للشتلة الواحدة ، نسبة العقد ، عدد الأيام من الزراعة حتى تزهير 50 % من الشتلات ، حاصل الهكتار التسويقي ، النسبة المئوية للسكريات الكلية في الثمار ، النسبة المئوية للحموضة الكلية في الثمار ، فيتامين C في الثمار ، وصبغة الانثوسيانين في الثمار) مقارنةً بمعظم معاملات التداخل الأخرى بما فيها معاملة المقارنة.