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Effect of Growth Medium and Foliar Application with Normal and Nano Microelements on the Qualitative Traits of Strawberry Cv. Festival

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Abstract: During the 2019–2020 and 2020–2021 seasons, the study was carried out in the greenhouse of the Department of Horticulture and Landscape Engineering, College of Agriculture, University of Anbar. In a protected environment, the objective was to examine the effects of growing medium type and foliar application of normal and nano zinc and iron on the qualitative traits of strawberry plants (cv. "Festival"). M1 (river soil + peat moss at a 3:1 ratio), M2 (river soil + 50% *Ceratophyllum demersum* + 50% alfalfa at a 3:1 ratio), and M3 (river soil + poultry manure at a 3:1 ratio) were the growing media utilized. Among the normal and nano micronutrient treatments were S0 (spraying with distilled water only, which was the control treatment), S1 (normal zinc at 50 mg L^{-1}), S2 (nano zinc at 10 mg L^{-1}), S3 (nano zinc at 20 mg L^{-1}), S4 (normal iron at 150 mg L^{-1}), S5 (nano iron at 20 mg L^{-1}), and S6 (nano iron at 40 mg L^{-1}). Every qualitative traits was significantly impacted by the growth media. For the two study seasons, the M3 medium produced the best results for total acidity, total sugars, total sugar/total acidity ratio, anthocyanin pigment, and ascorbic acid content for the two studies seasons. Similarly, the foliar treatment of normal and nano zinc and iron strongly impacted all planting parameters. During the first season, the S4 treatment produced the greatest results for ascorbic acid content, total sugars, total sugar/total acidity ratio, and acidity percentage. In contrast, the S6 treatment yielded the greatest values for total acidity, total sugars, total sugar/total acidity ratio, anthocyanin pigment, and ascorbic acid content. All of the qualities that were investigated were significantly impacted by the interaction between the research factors. Depending on the attribute under study, the interaction treatments M3S5 and M3S6 showed the highest values, while the control treatment (M1S0) had the lowest values for all traits under study.

Keywords Growth medium, normal micronutrients, nanoparticles micronutrients, foliar spraying, qualitative traits, strawberry

Introduction

The strawberry is a perennial herbaceous crop that may grow in various environments. It is a member of the Fragaria × ananassa Duch species, the Fragaria genus, and the Rosaceae family. One of the most significant and extensively grown little fruits in the world is the strawberry. Because of its excellent nutritional content and quick growth and production, it is widely grown in various countries [1]. Strawberry plants have a shallow, somewhat spreading root system and are highly productive for their tiny size [2]. Strawberries are currently grown in over 63 countries, with an anticipated 395,844 hectares under cultivation in 2019 and a global yield of over 9.2 million tons that year. With 3.72 million tons, China is the top producer, followed by Mexico, Egypt, Turkey, and the United States [3]. Strawberry cultivation is a relatively new practice in Iraq [4] and is only found in small agricultural areas, some residential gardens, and scientific research stations. The majority of strawberries consumed in Iraq are imported from Turkey, Iran, and Syria, indicating that its consumption is still quite low [5].

By strengthening the soil's physical, chemical, and biological qualities, the choice of an appropriate growing medium can significantly increase plant growth and yield. It improves the activity of helpful microbes, controls temperature, holds moisture, and stimulates soil aeration [6,7]. Water availability during the growing season and soil fertility affects strawberry variety yield. Therefore, necessary nutrients must be provided in an available and sufficient amounts for plant nutrition in order to produce a high yield of good-quality fruits [8].

Strawberry fruits are known for their exceptional nutritional and therapeutic value due to their high nutrient, fiber, vitamin, protein, carbohydrate, and phenolic component content [9]. strawberries are an excellent source of vitamin C and phenolic chemicals, including hydroxycinnamic acid derivatives, flavonols, anthocyanins, and ellagic acid. These chemicals have been shown to have protective effects against cardiovascular diseases, arterial problems, cancer, hypertension, and other chronic illnesses [10,11,12].

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Because of their enormous fruit yield in relation to their small size, strawberries require a lot of fertilizer. Foliar fertilization is essential for making up for nutritional deficits, especially those involving micronutrients like iron and zinc, which increase plant productivity and produce fruits with better morphological and qualitative qualities [13]. Alkaline soils, like those in Iraq, can have poor levels of micronutrient availability, especially for iron and zinc. Due to adsorption and precipitation, these elements are frequently inaccessible for plant uptake, even if their total concentrations are high in the majority of soils [14,15].

By improving the effectiveness of applied fertilizers, such as nano-based micro- and macronutrient fertilizers, green nanotechnology found to raise crop yield and quality [16]. Whether sprayed on leaves or mixed into the growing media, nanofertilizers are essential for plant nourishment. They preserve desired genetic features, boost the accumulation of bioactive chemicals, improve crop tolerance to various stressors, and promote photosynthesis [17,18]. A comprehensive analysis of recent research on plant–nanoparticle interactions was presented by [19], detailing the processes of nanoparticle absorption and translocation and the resulting physiological, morphological, genetic, and energetic changes in plants. In general, the kind, physicochemical characteristics, plant species, and growing environment of nanoparticles determine their influence [20,21]. This study's goal is to find out how various growing media and foliar applications of iron and zinc, both conventional and nano-based, might enhance the quality characteristics of strawberry plants cv. Festival in protected environments.

MATERIALS AND METHODS

Experimental site

The study was carried out in the greenhouse of the Department of Horticulture and Landscape Gardening, College of Agriculture, University of Anbar, from 15 October 2019 to 15 March 2020 for the first season, and from 20 October 2020 to 25 March 2021 for the second season, within the geographical coordinates of 33°24′10″N and 43°15′44″E. The goal was to find out how different growing media and foliar applications of normal and nano zinc and iron could enhance the quality of strawberry fruits (cv. "Festival") grown in protected environments.

Plant organic fertilizers (*Ceratophyllum demersum* L. and *Medicago sativa* L.)

The process outlined by [22], which may be summed up as follows, was used to create these fertilizers: The main ingredients were alfalfa, which was gathered from an agricultural field in the Al-Bu Dhiyab area of Anbar Province, and *Ceratophyllum demersum*, which was acquired from the Al-Kraishan region of Anbar Province. After being delivered to the fermentation location, the components were soaked for eighteen hours in basins filled with water. From June 1 to October 1 of both research seasons, they were then taken out of the basins and put on a polyethylene sheet. The fermenting materials were coated with a second layer of polyethylene and treated with 2% urea fertilizer [23]. The materials were regularly turned over for four months until the fermentation process was completed. The materials were regularly turned over for four months until the fermentation process was completed. During this period, the moisture content was monitored weekly using the portable soil moisture meter (PMS-714) to ensure optimal moisture levels for the fermentation process, which ranged between 50-60%.

Animal organic fertilizers (Poultry manure)

The fermentation process was carried out using poultry dung, as explained by [24]. A compost pile of 3 m in length, 2 m in width, and 1.5 m in height was created after the earth was first covered with a polyethylene sheet. In order to maintain the proper moisture levels, the manure was wet, covered with a polyethylene sheet, and turned frequently. Between June 1 and October 1 of both study seasons, the fermentation process continued for four months. When the experiment started, the manure was used after being allowed to dry in an open area.

Experimental treatments

A factorial experiment was conducted with two factors:

First Factor: Growing media (M): Three types of growing media were used:

- Medium 1 (M1): River soil + peat moss at a ratio of (1:3). The river soil consists of Available phosphorus 2.213 mg Kg^{-1}, total nitrogen 0.011%, CaCO3 216.36 g Kg^{-1}, Bulk density 1.29 g cm-3, organic matter 3.08%, electrical conductivity 0.72 ds m^{-1}, pH 7.47, Cl^- 2.69 Meq L^{-1}, $HCO_3^=$ 1.40 Meq L^{-1}, $CO_3^=$ Nil Meq L^{-1}, Na^+ 0.12 Meq L^{-1}, Mg^{++} 6.20 Meq L^{-1}, Ca^{++} 7.40 Meq L^{-1}, Available potassium 37.62 mg Kg^{-1}, SO_4= 3.48 Meq L^{-1}, Sand 972.0 g Kg^{-1}, Silt 20.0 g Kg^{-1}, Clay 8.0 g Kg^{-1}, Texture Sandy. As for the peat moss (according to the specifications of the German manufacturing company), it is composed of organic matter 40.36 g Kg^{-1}, total nitrogen 10.5 g Kg^{-1}, total phosphorus 7.10 g Kg^{-1}, total potassium13.50 g Kg^{-1}, EC 3.78 ds m^{-1}, pH 6.20 and C/N 16.67.
- Medium 2 (M2): River soil + (50% *Ceratophyllum demersum* + 50% Alfalfa) at a ratio of (1:3). The *Ceratophyllum demersum* is composed of organic carbon 210.89 g Kg^{-1}, total nitrogen 9.21 g Kg^{-1}, total phosphorus 4.63 g Kg^{-1}, total potassium7.58 g Kg^{-1}, EC 8.92 ds m^{-1}, pH 7.65 and C/N 22.90. On the other hand, the plants of Alfalfa consist of organic carbon 243.16 g Kg^{-1}, total nitrogen 13.84 g Kg^{-1}, total phosphorus 7.34 g Kg^{-1}, total potassium11.76 g Kg^{-1}, EC 8.92 ds m^{-1}, pH 6.91 and C/N 17.57.
- Medium 3 (M3): River soil + poultry manure at a ratio of (1:3). The poultry waste is characterized by organic carbon 390.15 g Kg^{-1}, total nitrogen 32.87 g Kg^{-1}, total phosphorus 13.78 g Kg^{-1}, total potassium26.00 g Kg^{-1}, EC 14.30 ds m^{-1}, pH 6.46 and C/N 11.87.

Second Factor: Normal and nano zinc (ZnO) and iron (Fe) were applied as foliar sprays at the following concentrations:

1. (S0): Using only distilled water for the spray (control).
2. (S1): Normal zinc is 50 mg L^{-1} (S1) [25].
3. (S2): Nano zinc at 10 mg L^{-1} concentration.
4. (S3): Nano zinc at a 20 mg L^{-1} concentration.
5. (S4): Normal iron at 150 mg L^{-1} [26].
6. (S5): Nano iron with a 20 mg L^{-1} concentration.
7. (S6): Nano iron at 40 mg L^{-1} concentration.

In the experiment, normal iron was used in the form of ferrous sulfate ($FeSO_4 \cdot 7H_2O$) with a purity of 98%, while normal zinc was in the form of zinc sulfate ($ZnSO_4 \cdot 7H_2O$) with a purity of 99%. Regarding the nano-fertilizers, the nano iron used in the experiment was nano iron oxide (Fe_2O_3) with particle sizes around 30–50 nanometers and a purity of 99%, whereas the nano zinc was nano zinc oxide (ZnO) with particle sizes around 20–40 nanometers and a purity of 99%.

Liquid soap was added as a surfactant at a rate of 0.1 mL L^{-1} to lower the surface tension of the spraying solution and improve plant absorption of the sprayed solutions. A 16-liter sprayer was used for foliar sprays until complete wetting. The same schedule was used for both growth seasons, with four treatments spread out throughout the dates of 12/1, 20/12, 10/1, and 1/2. The spraying was done at 20-day intervals. To avoid cross-contamination of the spraying solutions, a movable wooden barrier was positioned in between treatments during the early morning spraying. The German company Direvo Industrial Biotechnology produced Polyvinylpyrrolidone K-90 (PVP), which was used to dissolve the nano elements at a concentration ratio of 1 nano Zn or Fe: 2 PVP.

Agricultural practices

The greenhouse was cleaned, sprayed with fungicides, bactericides, and insecticides. To keep the area warm and weed-free while promoting mobility and productivity, the floor was covered with black polyethylene. Two 90-cm-diameter exhaust fans were fitted to ventilate the greenhouse and reduce its temperature as necessary. It was also equipped with a temperature and humidity monitoring system. Using a drip irrigation system that included a fertigation unit and pump, plants were irrigated.

Plant preparation and cultivation

The "Festival" variety of strawberry seedlings was acquired from the Al-Nakheel Company in Baghdad, Iraq. Prior to sowing, a concentration of 1 mL L^{-1} of the broad-spectrum fungicide Uniform was applied to the seedlings. On October 15, the seedlings for both growing seasons were then moved into plastic pots that measured (19 × 19 cm). After filling the pots halfway with the appropriate growing media, the pots were treated with a fungicide and insecticide mixture (Ridomil + Marshal + Furadan) at a ratio of 1:1:1, and the remaining material was added.

Experimental design

A Randomized Complete Block Design (RCBD) was used to carry out a factorial experiment with two components. With seven plants per experimental unit and 21 treatments spread across three replicates, the study included 441 plants in total. Least Significant Difference (LSD) at a 5% probability level was used to do mean comparisons after the data had been statistically examined [27]. GenStat software was used to do the statistical analysis.

Studied traits

1. The percentage of total sugar was calculated according to the methodology described by [28].

2. The percentage of total acidity in fruit juice was calculated using [29] methodology.

3. The ratio of total sugars to total acidity is determined by dividing the two.

4. Anthocyanin pigment content (mg 100 g^{-1} fresh weight): determined using [29] methodology.

5. The amount of ascorbic acid (Vitamin C) in fruit juice (mg 100 mL^{-1}) was calculated using the direct colorimetric method as described by [30].

Results and Discussion

Total sugar content in fruits (%)

The growing media treatments had a major impact on the strawberry fruits' overall sugar content at the first and second growing seasons, the M3 medium (River soil + poultry manure) showed the greatest value which came to 5.56 and 5.54%, respectively. While, plants cultivated on the M1 medium (River soil + peat moss) had the lowest sugar content as shown in Table1 which amounted 4.23 and 4.88%, respectively. Significant impacts on the characteristic under study were noted in relation to the foliar application of iron and zinc (both normal and nano forms). The S4 treatment (Normal Fe 150 mg L^{-1}) in the first season, and S6 treatment (Nano Fe 40 mg L^{-1}) in the second season showed the greatest sugar concentration which came to 5.62 and 5.62%, respectively. In contrast, the control treatment (S0) had the lowest sugar content which amounted 4.72 and 4.34% for the first and second season. The interaction between the two study parameters also shown a significant impact Particularly in the M3S6 treatment (first season) and M3S5 treatment (second season), which attained the greatest total sugar percentages, whereas, the M1S0 (control) treatment showed the lowest values.

Table (1): Effect of growth medium and foliar application with normal and nano microelements (Fe and Zn), and their interaction on the total sugar percentage in the strawberry fruits cv. Festival.

Microelements / Media culture	M1 River soil + peat moss	M2 River soil + *Ceratophyllum demersum* + Alfalfa	M3 River soil + poultry manure	Mean of microelements
First season				
S0 Control (distilled water only)	3.92 **d**	4.83 **bc**	5.41 **abc**	**4.72 a**
S1 Normal Zn (50 mg L^{-1})	4.35 **cd**	5.24 **abc**	5.34 **abc**	**4.98 ab**
S2 Nano Zn (10 mg L^{-1})	4.11 **d**	5.42 **abc**	5.16 **abc**	**4.90 ab**
S3 Nano Zn (20 mg L^{-1})	4.63 **c**	5.28 **abc**	5.52 **abc**	**5.14 ab**
S4 Normal Fe (150 mg L^{-1})	4.07 **d**	6.53 **a**	6.26 **ab**	**5.62 b**
S5 Nano Fe (20 mg L^{-1})	4.15 **d**	5.74 **abc**	4.42 **cd**	**4.77 a**
S6 Nano Fe (40 mg L^{-1})	4.40 **cd**	4.87 **bc**	6.78 **a**	**5.35 ab**
Mean of media culture	**4.23 a**	**5.42 b**	**5.56 b**	
LSD 5%	**M**	**S**	**M×S**	
	0.37	**0.56**	**0.98**	
Second season				
S0 Control (distilled water only)	4.18 **c**	4.24 **c**	4.60 **c**	**4.34 a**
S1 Normal Zn (50 mg L^{-1})	5.24 **abc**	5.45 **abc**	5.52 **abc**	**5.40 ab**
S2 Nano Zn (10 mg L^{-1})	4.52 **c**	4.96 **bc**	4.36 **c**	**4.61 ab**
S3 Nano Zn (20 mg L^{-1})	4.69 **c**	6.12 **ab**	5.14 **abc**	**5.32 ab**
S4 Normal Fe (50 mg L^{-1})	5.78 **abc**	5.23 **abc**	4.57 **c**	**5.19 ab**
S5 Nano Fe (20 mg L^{-1})	4.46 **c**	4.65 **c**	7.48 **a**	**5.53 ab**
S6 Nano Fe (40 mg L^{-1})	5.28 **abc**	4.46 **c**	7.13 **a**	**5.62 b**
Mean of media culture	**4.88 a**	**5.02 a**	**5.54 b**	
LSD 5%	**M**	**S**	**M×S**	
	0.53	**0.81**	**1.40**	

Total acidity percentage (%)

The data in Table 2 in both growth seasons showed that growing media treatments had a major impact on the fruits' acidity levels. In the first and second seasons, the M3 medium (River soil + poultry manure) yielded the lowest acidity content which came to 0.53 and 0.59, respectively. However, the M1 medium (River soil + peat moss) had the highest acidity level for both seasons which amounted 0.67 and 0.72 During the first season, there were no impacts from the foliar treatment of iron and zinc (both normal and nano forms). In contrast, the S0 treatment (control) recorded the highest acidity in the second season which came to 0.73%, whereas the S6 treatment (Nano Fe 40 mg L^{-1}) considerably decreased acidity, providing the lowest acidity percentage which amounted 0.57%. The M3S6 and M3S4 treatments in the first season produced the lowest acidity percentage, while, the M3S6 treatment once more yielded the lowest acidity percentage in the second season. In the first and second seasons, the control treatment M1S0 had the greatest acidity levels. Although an increase in acidity in strawberry fruits prolongs their storage period, this trait is considered undesirable as it reduces the market value of the fruits. Therefore, the positive role of applying growing media-such as the mixture of alfalfa and *Ceratophyllum demersum*, or poultry manure-in reducing fruit acidity becomes evident.

Table (2): Effect of growth medium and foliar application with normal and nano microelements (Fe and Zn), and their interaction on the total acidity percentage in the strawberry fruits cv. Festival.

Microelements / Media culture	M1 River soil + peat moss	M2 River soil + *Ceratophyllum demersum* + Alfalfa	M3 River soil + poultry manure	Mean of microelements
		First season		
S0 Control (distilled water only)	0.73 **a**	0.52 **ab**	0.61 **a**	**0.62 a**
S1 Normal Zn (50 mg L^{-1})	0.57 **ab**	0.47 **bc**	0.62 **a**	**0.56 a**
S2 Nano Zn (10 mg L^{-1})	0.65 **a**	0.60 **ab**	0.57 **ab**	**0.60 a**
S3 Nano Zn (20 mg L^{-1})	0.64 **a**	0.58 **ab**	0.54 **ab**	**0.59 a**
S4 Normal Fe(150 mg L^{-1})	0.69 **a**	0.48 **bc**	0.42 **c**	**0.53 a**
S5 Nano Fe (20 mg L^{-1})	0.71 **a**	0.56 **ab**	0.55 **ab**	**0.61 a**
S6 Nano Fe (40 mg L^{-1})	0.67 **a**	0.64 **a**	0.42 **c**	**0.58 a**
Mean of media culture	**0.67 a**	**0.55 b**	**0.53 b**	
LSD 5%	**M**	**S**	**M×S**	
	0.05	**N.S**	**0.14**	
		Second season		
S0 Control (distilled water only)	0.81 **a**	0.78 **a**	0.62 **b**	**0.73 a**
S1 Normal Zn (50 mg L^{-1})	0.68 **b**	0.60 **bc**	0.57 **c**	**0.62 bcd**
S2 Nano Zn (10 mg L^{-1})	0.77 **a**	0.67 **b**	0.68 **a**	**0.71 ab**
S3 Nano Zn (20 mg L^{-1})	0.74 **a**	0.54 **c**	0.58 **c**	**0.62 bcd**
S4 Normal Fe (150 mg L^{-1})	0.65 **b**	0.63 **b**	0.76 **ab**	**0.68 abc**
S5 Nano Fe (20 mg L^{-1})	0.76 **a**	0.65 **b**	0.47 **c**	**0.63 bcd**
S6 Nano Fe (40 mg L^{-1})	0.62 **b**	0.63 **b**	0.45 **c**	**0.57 d**
Mean of media culture	**0.72 a**	**0.64 b**	**0.59 b**	
LSD 5%	**M**	**S**	**M×S**	
	0.05	**0.08**	**0.15**	

Total sugars/Total acidity ratio

The total sugar/total acid ratio was significantly influenced by the growing media treatments, as shown in Table 3 for both the first and second seasons. Among the treatments, the M3 medium (River soil + poultry manure) resulted in the highest ratio which came to 11.04 and 10.20, respectively, while the M1 medium (River soil + peat moss) produced the lowest ratio which amounted 6.45 and 6,97, respectively. On the other hand, strawberry plants treated with normal and nano forms of iron and zinc exhibited notable impacts, the S4 treatment (Normal Fe 150 mg L^{-1}) in the first season and the S6 treatment (Nano Fe 40 mg L^{-1}) in the second season produced the highest results which came to 11.64 and 10.63, respectively, on the other side the control treatment (S0) had the lowest ratios which came to 7.97 and 6.07, respectively. Additionally, there were notable effects from the interaction between the two components, especially with the M3S6 treatment, which yielded the highest values for the first and second seasons, while the M1S0 interaction had the lowest values.

Table (3): Effect of growth medium and foliar application with normal and nano microelements (Fe and Zn), and their interaction on the total sugar/total acid ratio in the strawberry fruits cv. Festival.

Microelements / Media culture	M1 River soil + peat moss	M2 River soil + *Ceratophyllum demersum* + Alfalfa	M3 River soil + poultry manure	Mean of microelements
		First season		
S0 Control (distilled water only)	5.43 b	9.51 a	8.98 a	**7.97** b
S1 Normal Zn (50 mg L^{-1})	7.58 b	11.26a	8.79 a	**9.21** b
S2 Nano Zn (10 mg L^{-1})	6.40 b	9.07a	9.38 a	**8.28** b
S3 Nano Zn (20 mg L^{-1})	7.27 b	9.60 a	10.25 a	**9.04** b
S4 Normal Fe (150 mg L^{-1})	5.96 b	13.64 a	15.33 a	**11.64** a
S5 Nano Fe (20 mg L^{-1})	5.91 b	10.68 a	8.28 a	**8.29** b
S6 Nano Fe (40 mg L^{-1})	6.57 b	7.84 b	16.26 a	**10.22** ab
Mean of media culture	**6.45** b	**10.23 a**	**11.04 a**	
LSD 5%	**M**	**S**	**M×S**	
	1.28	**1.95**	**3.38**	
		Second season		
S0 Control (distilled water only)	5.16 c	5.45 c	7.60 b	**6.07** c
S1 Normal Zn (50 mg L^{-1})	7.74 b	9.25 a	9.90 a	**8.96** ab
S2 Nano Zn (10 mg L^{-1})	5.83 c	7.43 b	6.48 c	**6.58** bc
S3 Nano Zn (20 mg L^{-1})	6.74 c	11.44 a	9.11 a	**9.10** ab
S4 Normal Fe (150 mg L^{-1})	8.92 a	8.34 b	6.03 c	**7.77** b
S5 Nano Fe (20 mg L^{-1})	5.87 c	7.15 b	16.09 a	**9.70** a
S6 Nano Fe (40 mg L^{-1})	8.50 b	7.23 b	16.17 a	**10.63** a
Mean of media culture	**6.97 b**	**8.04 ab**	**10.20 a**	
LSD 5%	**M**	**S**	**M×S**	
	1.07	**1.64**	**2.84**	

Anthocyanin pigment content (mg 100g^{-1} fresh weight)

Anthocyanin content was strongly impacted by the growing media treatments, according to the first season results shown in Table 4, the M3 (River soil + poultry manure) medium yielded the greatest anthocyanin levels which amounted 48.19 and 42.30 mg 100g^{-1} fresh weight, respectively, while, the M1 medium (River soil + peat moss) exhibited the lowest anthocyanin concentration which came to 42.00 and 35.72 mg 100g^{-1} fresh weight for the two seasons, respectively. Demonstrating the considerable impact of foliar spraying with zinc and iron (both normal and nano forms) The S5 treatment (Nano Fe 20 mg L^{-1}) for the first season, and S6 treatment (Nano Fe 40 mg L^{-1}) produced the greatest anthocyanin content which came to 47.54 and 43.29 mg 100g^{-1} fresh weight, respectively. The control treatment (S0) had the lowest values which amounted 40.68 and 33.95 mg 100g^{-1} fresh weight, respectively. Additionally, the two components' interaction had a considerable impact, especially when it came to the M3S5 treatment in the first season and the M3S6 treatment in the second season. On the other hand, the M1S0 interaction had the lowest anthocyanin content for the first and second seasons.

Table (4): Effect of growth medium and foliar application with normal and nano microelements (Fe and Zn), and their interaction on the anthocyanin pigment content (mg 100g^{-1} fresh weight) in the strawberry fruits cv. Festival.

Microelements / Media culture	M1 River soil + peat moss	M2 River soil + *Ceratophyllum demersum* + Alfalfa	M3 River soil + poultry manure	Mean of microelements
		First season		
S0 Control (distilled water only)	38.42 d	42.39 cd	41.23 d	**40.68** c
S1 Normal Zn (50 mg L^{-1})	42.83 cd	39.26 d	43.71 cd	**41.93** c
S2 Nano Zn (10 mg L^{-1})	43.50 cd	43.67 cd	51.58 a	**46.25** ab
S3 Nano Zn (20 mg L^{-1})	45.28 bcd	45.83 abc	44.54 bcd	**45.22** ab
S4 Normal Fe (150 mg L^{-1})	39.65 d	50.21 ab	47.28 ab	**45.71** ab
S5 Nano Fe (20 mg L^{-1})	40.83 d	46.18 abc	55.62 a	**47.54** a
S6 Nano Fe (40 mg L^{-1})	43.48 cd	43.06 cd	53.35 a	**46.63** ab
Mean of media culture	**42.00** b	**44.37** ab	**48.19** a	
LSD 5%	**M**	**S**	**M×S**	
	2.66	**4.07**	**7.05**	
		Second season		
S0 Control (distilled water only)	31.58 d	32.24 d	38.02 cd	**33.95** d
S1 Normal Zn (50 mg L^{-1})	36.29 cd	40.87 bc	41.74 bc	**39.63** cd
S2 Nano Zn (10 mg L^{-1})	32.47 d	43.93 ab	36.62 cd	**37.67** cd
S3 Nano Zn (20 mg L^{-1})	34.95 cd	42.28 ab	45.53 ab	**40.92** bc
S4 Normal Fe (150 mg L^{-1})	36.88 cd	46.00 a	37.11 cd	**40.00** bc
S5 Nano Fe (20 mg L^{-1})	36.24 cd	39.72 bc	48.19 a	**41.38** b
S6 Nano Fe (40 mg L^{-1})	41.62 b	39.39 bc	48.86 a	**43.29** a
Mean of media culture	**35.72** c	**40.63** b	**42.30** a	
LSD 5%	**M**	**S**	**M×S**	
	2.87	**4.39**	**7.61**	

Ascorbic acid content (mg 100 ml^{-1} of fruit juice)

The ascorbic acid concentration of strawberry fruits was considerably impacted by the growing media treatments, according to the statistical analysis results for both seasons, which are shown in Table 5, the M3 medium (River soil + poultry manure) yielded the highest values which amounted 82.3 and 72.3 mg 100 ml^{-1} of fruit juice for first and second season, respectively, while, the M1 medium (River soil + peat moss) had the lowest values for both seasons which came to 68.2 mg 100 ml^{-1} of fruit juice for the first season and 54.4 mg 100 ml^{-1} of fruit juice for the second. Furthermore, only during the first season did foliar spraying with zinc and iron (both normal and nano forms) demonstrate a significant impact, the S4 treatment (Normal Fe 150 mg L^{-1}) produced the greatest ascorbic acid level which amounted 84.5 mg 100 ml^{-1} of fruit juice, while, the S3 treatment (Nano Zn 20 mg L^{-1}) had the lowest value which came to 72.5 mg 100 ml^{-1} of fruit juice. The interaction between the two study parameters also shown a significant impact Particularly with the M2S4 treatment, which generated the highest ascorbic acid content which amounted 92.3 mg 100 ml^{-1} of fruit juice, on the other hand, M1S1 in the first season and M1S4 in the second season had the lowest levels which amounted 62.0 mg 100 ml^{-1} of fruit juice.

Table (5): Effect of growth medium and foliar application with normal and nano microelements (Fe and Zn), and their interaction on the ascorbic acid content (mg 100 ml^{-1} of fruit juice) in the strawberry fruits cv. Festival.

Microelements / Media culture	M1 River soil + peat moss	M2 River soil + *Ceratophyllum demersum* + Alfalfa	M3 River soil + poultry manure	Mean of microelements
		First season		
S0 Control (distilled water only)	68.2 a	73.0 a	84.7 b	**75.3 ab**
S1 Normal Zn (50 mg L^{-1})	62.0 a	81.6 ab	77.5 ab	**73.7 a**
S2 Nano Zn (10 mg L^{-1})	70.5 a	86.8 b	85.8 b	**81.0 bc**
S3 Nano Zn (20 mg L^{-1})	63.7 a	72.5 a	81.3 ab	**72.5 a**
S4 Normal Fe(150 mg L^{-1})	77.3 a	92.3 c	83.9 b	**84.5 c**
S5 Nano Fe (20 mg L^{-1})	68.6 a	75.0 a	87.6 b	**77.1 ab**
S6 Nano Fe (40 mg L^{-1})	67.4 a	84.8 b	75.3 a	**75.8 ab**
Mean of media culture	**68.2 a**	**80.8 b**	**82.3 b**	
LSD 5%	**M**	**S**	**M×S**	
	3.05	**4.66**	**8.07**	
		Second season		
S0 Control (distilled water only)	52.8 a	56.7 a	65.3 b	**58.3 a**
S1 Normal Zn (50 mg L^{-1})	58.6 a	54.3 a	70.5 c	**61.1 bc**
S2 Nano Zn (10 mg L^{-1})	57.2 a	58.5 a	74.2 c	**63.3 c**
S3 Nano Zn (20 mg L^{-1})	52.5 a	61.8 b	68.4 b	**60.9 bc**
S4 Normal Fe(150 mg L^{-1})	50.3 a	57.4 a	78.4 d	**62.0 c**
S5 Nano Fe (0 mg L^{-1})	53.0 a	54.1 a	72.0 c	**59.7 b**
S6 Nano Fe (40 mg L^{-1})	56.7 a	63.4 a	70.3 c	**63.5 c**
Mean of media culture	**54.4 a**	**58.0 b**	**71.3 c**	

LSD 5%	M	S	M×S
	2.84	N.S	7.53

Table (6): Correlation analysis among the studied traits under the effect of different growing media during the first and second seasons.

Trait	First season				
	Total sugars	**Total acidity**	**Sugars/Acidity**	**Anthocyanin**	**Ascorbic acid**
Total sugars	1.000	−0.999*	+0.998*	+0.846	+1.000***
Total acidity	−0.999*	1.000	−0.999*	−0.865	−0.999*
Sugars/Acidity	+0.998*	−0.999*	1.000	+0.881	+0.998*
Anthocyanin	+0.846	−0.865	+0.881	1.000	+0.847
Ascorbic acid	+1.000***	−0.999*	+0.998*	+0.847	1.000
Trait	**Second season**				
	Total sugars	**Total acidity**	**Sugars/Acidity**	**Anthocyanin**	**Ascorbic acid**
Total sugars	1.000	−0.991*	+0.988*	+0.910	+0.997**
Total acidity	−0.991*	1.000	−0.996**	−0.933	−0.990*
Sugars/Acidity	+0.988*	−0.996**	1.000	+0.964	+0.985*
Anthocyanin	+0.910	−0.933	+0.964*	1.000	+0.910
Ascorbic acid	+0.997**	−0.990*	+0.985*	+0.910	1.000

Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table (4): Correlation analysis among the studied traits under the effect of foliar application with normal and nano microelements (Fe and Zn) during the first and second seasons.

Trait	First season				
	Total sugars	Total acidity	Sugars/Acidity	Anthocyanin	Ascorbic acid
Total sugars	1.000	−0.848*	+0.973***	+0.336	+0.442
Total acidity	−0.848*	1.000	−0.906**	−0.082	−0.435
Sugars/Acidity	+0.973***	−0.906**	1.000	+0.261	+0.485
Anthocyanin	+0.336	−0.082	+0.261	1.000	+0.389
Ascorbic acid	+0.442	−0.435	+0.485	+0.389	1.000
Trait	**Second season**				
	Total sugars	**Total acidity**	**Sugars/Acidity**	**Anthocyanin**	**Ascorbic acid**
Total sugars	1.000	−0.859*	+0.943**	+0.559*	+0.503*
Total acidity	−0.859*	1.000	−0.945**	−0.328	−0.479
Sugars/Acidity	+0.943**	−0.945**	1.000	+0.441*	+0.616*
Anthocyanin	+0.559*	−0.328	+0.441*	1.000	+0.612*
Ascorbic acid	+0.503*	−0.479	+0.616*	+0.612*	1.000

Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

DISCUSSION

Fruits produced in the M2 (River soil + 50% M2 River soil + *Ceratophyllum demersum* + Alfalfa + 50% Alfalfa) and M3 (River soil + poultry manure) media had higher sugar concentrations than the control M1 (River soil + peat moss), indicating that organic compounds made from plant and poultry manure are an effective source of vital nutrients. These substances have enzymatic and hormonal effects that increase the number of leaves and their area, which improves photosynthesis and the movement of materials that have been generated to the fruits [31,32,33].

Along with light levels, which impact the amount of healthy leaf surface for the formation of photosynthetic compounds and eventually determine total soluble solids and fruit sweetness, nutrient availability is a major element impacting taste and flavor [34]. Because it improves the movement of carbohydrates from leaves to fruits, potassium in particular is essential for lowering acidity. According to research by [35,36], strawberries cultivated in organic media had increased levels of anthocyanin pigmentation, most likely as a result of the enzymatic and hormonal effects of decomposed organic matter. Furthermore, according to [37], higher root zone temperatures brought on by organic breakdown enhance anthocyanin synthesis.

Similarly, because carbohydrates produced by photosynthesis promote anthocyanin accumulation [38], it was observed that availability directly influences anthocyanin concentration. Additionally, the results support the findings of [39,40] that organic matter raises the amounts of ascorbic acid (Vitamin C) in fruits. Organic substances like sugars, proteins, amino acids, and humic acids are thought to have this impact because they promote plant development through enzymatic, hormonal, and nutrient-related processes. Higher chlorophyll content and leaf area result from increased food availability, especially nitrogen, which also improves photosynthetic carbon absorption and the buildup of proteins, carbohydrates, and enzymes-all of which are necessary for the synthesis of vitamin C.

Zinc and iron (both normal and nano forms) applied topically improve fruit quality by increasing photosynthesis and sugar production, which raises sugar accumulation in ripening fruits [41]. Additionally, zinc is involved in cell elongation, membrane function, and protein synthesis [42]. Furthermore, zinc aids in the production of auxin (IAA) and dehydrogenase enzymes, both of which encourage cell elongation [43].

Zinc is involved in the metabolism of carbohydrates, photosynthesis, starch synthesis, proteins, auxin control, and pollen development as a structural and regulatory element in a various of enzymes and proteins [44,45]. Additionally, zinc is necessary for the synthesis of tryptophan, a precursor to auxin (IAA), a crucial growth regulator that affects the development of plasma membranes and internode elongation [46,47]. Similar to this, iron is a necessary component of numerous enzymes that are involved in a number of physiological activities, including metabolism, photosynthesis, protein synthesis, and the creation of chlorophyll [48,49]. In this study, nano-Fe (S6) combined with M3 medium significantly lowered fruit acidity, likely due to enhanced chlorophyll synthesis and carbohydrate translocation, as supported by [50,51].

This results in higher sugar buildup and decreased fruit acidity. Increased vegetative growth, which boosts photosynthetic efficiency and biochemical production in the plant, is the reason for the rise in anthocyanin and vitamin C levels brought on by zinc and iron application. Both factors promote the growth of roots and shoots, boosting physiological activity and nutrient absorption [52]. Nano-fertilizers' small particle size and sophisticated formulation, which enable quick penetration and distribution within plant tissues, are probably the reasons for their beneficial effects on all examined features. Hormonal activity is stimulated, which encourages the formation of secondary roots and enhances plant growth and yield overall [53]. Additionally, by interacting with protein carriers like ion channels, endocytosis, and aquaporins, nanofertilizers create new pathways that improve water uptake and boost growth and productivity [54].

The use of nano-zinc increases growth indices by improving cell elongation and wall flexibility In a similar vein, nano-iron is highly effective in piercing cell membranes, where it is essential for energy transmission, metabolism, photosynthesis, chlorophyll synthesis, and cell division, all of which increase plant productivity [55]. According to [56,57], nano-iron also improves the effectiveness of the H-ATPase enzyme in guard cell plasma membranes, increasing stomatal opening by up to five times and enhancing CO_2 uptake and photosynthetic efficiency.

The correlation analysis of the chemical traits of the fruits under the influence of both growing media and foliar spraying with micronutrients (iron and zinc, in both normal and nano forms) during the two growing seasons revealed a consistent pattern reflecting physiologically expected relationships among components of nutritional and sensory quality. A very strong positive correlation was observed between total sugar content and vitamin C across all treatments, indicating that improved nutritional value of the fruits is generally accompanied by an increase in sugar accumulation, a relationship also emphasized by [58] in cherry fruits. A strong negative correlation was also detected between total sugars and total acidity, reflecting a characteristic shift in mature fruits where sugars tend to increase as acidity decreases, signifying an optimal sensory balance that enhances palatability-a pattern well-documented in mangoes by [59]. Additionally, the sugar-to-acid ratio showed a strong positive correlation with both total sugars and vitamin C, and a negative correlation with total acidity, thereby validating its reliability as an effective indicator for estimating maturity and flavor quality, consistent with the findings of [60]. in citrus fruits. Similar correlation patterns were evident under the micronutrient spraying treatments, albeit with varying intensities. Total sugar content showed a clear positive association with the sugar-to-acid ratio, highlighting the ratio's role as a key quality parameter under different foliar fertilization conditions, as reported in studies on micronutrient effects by [61,62]. Furthermore, total acidity demonstrated strong negative correlations with sugars and anthocyanin content, supporting the premise that a reduction in acidity is associated with the advancement of fruit ripening and accumulation of beneficial secondary metabolites-trends supported by the findings of [63] on sugar and acid dynamics during ripening. Regarding anthocyanins, a positive correlation was found with both total sugars and the sugar-to-acid ratio, indicating that improvements in sensory attributes such as color occur simultaneously with increases in sugars and nutritional compounds, particularly under the influence of foliar micronutrient treatments, corroborating the conclusions drawn by [64,65].

These correlations were more pronounced during the second season, which could be attributed to seasonal environmental factors or differences in treatment effectiveness in promoting pigment accumulation. It is worth noting that, despite the broader variation and number of treatments under micronutrient spraying compared to growing media, the direction and consistency of correlations remained physiologically logical, underscoring the importance of these elements-whether in nano or normal form-in influencing fruit chemical quality components.

CONCLUSIONS

All qualitative fruit features showed a substantial reaction in the strawberry seedlings of the "Festival" cultivar. All of the features under study were most significantly impacted by the organic medium M2 (River soil + 50% M2 River soil + *Ceratophyllum demersum* + Alfalfa + 50% Alfalfa), and M3 (River soil + poultry manure). The majority of qualitative yield traits were significantly impacted by foliar spraying with both normal and nano forms of zinc and iron, especially with treatments S4 (normal Fe at 150 mg L^{-1}) and S6 (nano Fe at 40 mg L^{-1}).

According to the study's findings, growing strawberries with organic growing media-particularly medium M2 (River soil + 50% M2 River soil + *Ceratophyllum demersum* + Alfalfa + 50% Alfalfa), and M3 (River soil + poultry manure) is advised because it yielded the greatest outcomes for the features under investigation. Additionally, as it produced superior results than the control, especially at greater concentrations for both elements and across the majority of examined attributes, foliar fertilization of strawberry seedlings with normal zinc and iron is recommended. Growth and productivity are adversely affected by inadequate plant nutrition.

DISCLOSURE DATA

- **Ethics approval and consent to participate:** The authors confirm that they respect the publication's ethics and consent to their work's publication
- **Consent for publication:** The authors consent to the publication of this work.
- **Author's contribution:** AFZA was responsible for creating the initial research idea and collecting the literature review to achieve the final idea for this research, as well as performing statistical analysis after collected data to investigate the effect of individual factors solely or interaction between them, moreover comprehensive reading for the final manuscript. MMM carried out the experiment, data collection, and interpretation of results; moreover, the initial writing of the manuscript also compared the findings with the literature and made the conclusions built into the output of this research.

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