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Improving the Quality and Production of *Philodendron* Plants Using Nanoparticles and Humic Acid

Ghada M. R. El-Shawa [1], Khadiga Alharbi [2,*], Muneera AlKahtani [2], Latifa AlHusnain [2], Kotb A. Attia [3,4] and Khaled Abdelaal [5]

[1] Ornamental Plants and Landscape Gardening Research Department, Hort. Res. Institute, Agricultural Research Center, Giza 12619, Egypt; ghadaelshawa@yahoo.com
[2] Department of Biology, College of Science, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia; muneeraalkahtani@gmail.com (M.A.); laalhusnain@pnu.edu.sa (L.A.)
[3] Center of Excellence in Biotechnology Research, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia; kattia1.c@ksu.edu.sa
[4] Rice Biotechnology Lab., Rice Department, Field Crops Research Institute, ARC, Sakha 33717, Egypt
[5] Plant Pathology and Biotechnology Laboratory, Excellence Center (EPCRS), Faculty of Agriculture, Kafrelsheikh University, Kafr Elsheikh 33516, Egypt; khaled.elhaies@gmail.com
* Correspondence: kralharbi@pnu.edu.sa

Abstract: A pot experiment was conducted during the 2019/2020 and 2020/2021 seasons to evaluate the effect of silver nanoparticles (SNPs), iron nanoparticles (FeNPs), zinc nanoparticles (ZnNPs), and nitrogen, phosphorus, and potassium nanoparticles (NPK NPs) and humic acid (HA) in improving the growth of *Philodendron* plants. Our findings indicated that the highest increase in plant height and leaf width was recorded with 60 mg/L SNPs. Additionally, the highest values in the number of leaves/plant were recorded with 60 mg/L SNPs compared to the control. FeNPs at 150 mg/L treatment gave the best result of total chlorophyll and carotenoid content, followed by SNPs at 60 mg/L and then NPK NPs at 2 mL/L in the two seasons. Furthermore, ZnNPs at 200 mg/L, SNPs at 20 mg/L, SNPs at 40 mg/L, and SNPs at 60 mg/L gave the best results of enzyme activity (catalase, peroxidase, and polyphenol oxidase). However, the treatments with 40 and 60 mg/L SNPs led to improve the anatomical characters of leaves and stem such as thickness of the blade, mesophyll tissue, xylem vessel diameter, vascular bundle dimension, stem diameter, and epidermis cell dimension compared with other treatments and the control.

Keywords: *Philodendron*; silver nanoparticles; chlorophyll; enzymes; anatomical characters

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1. Introduction

The *Philodendron* (*Philodendron bipinnatifidum* Schott ex Endl.syn. *Philodendron selloum* K. Koch.), popularly known as "lacy tree philodendron", is a member of the family Araceae. It is a tropical plant native to South America. It is widely used as a potted plant in the interior arrangement of plants and is highly valuable for its attractive dark green leaves, large and shiny with deeply lobed foliage, and tolerance to indoor environments. Recently, nanoparticles (NPs) and nanotechnology have been used significantly in the horticulture field as bio stimulators that improve plant propagation, growth, development, productivity, and health in the form of agrochemicals, use in the genetic engineering of plants, the bioremediation of contaminated soil, and improving plant tolerance to stress [1,2]. The mechanism of nanoparticle action is due to the fact that NPs can easily enter plant cells by the stomata and trichomes because they have fewer diameters smaller than the diameter of pores of the cell wall, then transferred to other plant parts by the transfer tissues [3]. Moreover, NPs react with plants at the cellular and subcellular planes after entry, promoting changes in physiological and morphological cases [4]. On the other hand, some studies reported that the application of nano fertilizer leads to an increase in the efficiency of the elements, decreases the toxicity of the soil caused by the consumption of excessive fertilizers,

and decreases the frequency of the application of fertilizers [5]. Nano fertilizers improve the availability of nutrients for the plants that improve photosynthesis rate, chlorophyll formation, total plant growth, and production of dry matter [6,7]. Additionally, a previous study revealed that nano fertilizer NPK at 4.5 g/L gave the best growth of Codiaeum plants [7]. Additionally, nano NPK increased the leaf area, shoot length, and the number of leaves of pea plants [8]. The foliar nanotechnology liquid fertilizer improves the yield and all-over plant growth of cucumbers [9]. Micronutrient shortages in plants led to a decrease in growth characters; Fe and Zn shortage is the most injurious to the growth of plants between the micronutrients [10]. Iron NPs have a great surface area and higher reactivity. Furthermore, it is constant, inexpensive, and less toxic compared to numerous other metallic NPs [11]. Iron is one of the main elements for the development and growth of the plant; it plays a substantial role in the photosynthetic reactions, including chloroplast evolution and the synthesis of chlorophyll and thylakoid [12]. Fe is a cofactor for activating several enzymes [13]. It contributes to the synthesis of RNA and promotes the representation of photosystems. It also shares several physiologic processes comprising redox reactions and respiration [14]. Recent studies have reported that FeNPs are more efficient in supplying plants with Fe than commonly used Fe chemical fertilizers in agricultural production [15,16]. Elfeky et al. [12] reported that Fe NPs significantly affects iron content, total carbohydrate, total chlorophyll, and the plant growth of sweet basil. Nano zinc oxide particles (ZnNPs) have a small size and a large surface area, ideal for use as a fertilizer for plants as a Zn fertilizer. Additionally, zinc plays a major role in plant resistance to drought and salinity stress [17,18]. It plays a substantial role in stomata control through its capability to maintain membrane safety and keep the potassium content in the cells, as well as its role in the water relations of the plant [19]. Moreover, it has an important role in the synthesis of auxin or indole acetic acid (IAA) from tryptophan, as well as in biochemical reactions needed for the formation of carbohydrates and chlorophyll [20]. Zinc is used as a cofactor for several enzymes, such as superoxide dismutase and catalase, to prevent plant cells from oxidative damage [4]. The better results in the plant growth were observed when plants were treated with ZnNPs [21] on cowpea and okra. Silver nanoparticles have a high overall surface area due to their small size. So, the adherence of SNPs to the cell surface is powerful, which leads to high efficiency [22]. SNPs release Ag^{+} ions, which react with cytoplasmic organelles and nucleic acids to prevent respiratory enzymes and intervene with cellular functions like membrane leakage [23]. In addition, SNPs affect respiration, metabolism, and the proliferation of microorganisms [24]. Additionally, a previous study indicated that SNPs at 60 ppm increase leaf surface area, shoot and root lengths, chlorophyll, protein, and carbohydrate contents in common bean and corn plants [6]. Hatami and Ghorbanpour [22] reported that the application of SNPs reduces the degradation of leaf chlorophyll and carotenoids, decreases petal abscission, maintains antioxidative enzyme activity, and improves the longevity of pelargonium. Nowadays, bio-organic fertilizer is used to reduce the use of chemical fertilizers and hence reduce environmental pollution, as well as reduce the production cost of many crops [25–29]. Humic acid (HA) is a natural polymer containing phenolic and carboxyl positions for the exchange process [30]. The mode of action of HA on plant growth can be split into direct and indirect effects as it increases cell membrane permeability resulting in an improved transfer of nutrients, promoted photosynthesis, promoted protein synthesis, solubilization of micronutrients, reduced active levels of poisonous elements, enhanced microbe population, promoted soil structure, incremented water retention and cation interchange capacity [31], and improved formalization of ATP and amino acids resulting in the best growth and development [31]. Additionally, Piccolo et al. [32] reported that it can be utilized as a growth regulator to organize hormone levels, promote plant growth, and increase stress toleration. Nanoparticles can provide effective solutions to reduce the cost of production, and reduce environmental pollution, consequently leading to the achievement of some sustainable development goals in agriculture. Hence, our study aimed to evaluate the effect of silver nanoparticles, iron nanoparticles, zinc nanoparticles, NPK nanoparticles, and humic acid as a new strategy

for improving the growth and physiological as well as anatomical characteristics of the *Philodendron* plant compared with the control treatments.

2. Materials and Methods

A pot experiment was conducted at Sahl El-Husseinieh Research Station, Agriculture Research Center, Sharqia Governorate, Egypt in an uncontrolled plastic house, and the laboratory investigations were conducted in PPBL lab. and EPCRS excellence center, Department of Agricultural Botany, Faculty of Agriculture, Kafrelsheikh University, during the 2019/2020 and 2020/2021 seasons.

2.1. Plant Materials and Experimental Design

Seedlings of *Philodendron* were obtained from Elzoharia garden, Hort. Res. Inst., ARC, Egypt. The plants were transplanted individually in 15 cm pots in diameter filled with peat moss, vermiculite, and perlite (2:1:1, v/v) on September 4th in both seasons. All plants were sprayed with NPK (19:19:19) fertilizer at 2 g/L every one month during experiments, starting after 21 days from transplanting, then the plants were watered as needed. The six-month-old plants (the average number of leaves was 3 ± 1 leaves/plantlet and the average height was 15 ± 1 cm) were sprayed with different treatments as follows:

1. Control.
2. 1 ml/L humic acid (HA)
3. 2 ml/L humic acid (HA)
4. 1.5 ml/L nano fertilizer NPK (NPK NPs)
5. 2 ml/L nano fertilizer NPK (NPK NPs)
6. 100 mg/L iron nanoparticles (FeNPs)
7. 150 mg/L iron nanoparticles (FeNPs)
8. 150 mg/L zinc nanoparticles (ZnNPs)
9. 200 mg/L zinc nanoparticles (ZnNPs)
10. 20 mg/L Silver nanoparticles (SNPs)
11. 40 mg/L Silver nanoparticles (SNPs)
12. 60 mg/L Silver nanoparticles (SNPs)

Nano fertilizer NPK (Fast tri volume 7:6:7) and humic acid (10% humic and 6% potassium) were obtained from Bio Nano Technology company at Mansoura-Dakahlia-Egypt. Iron and Zinc oxide nanoparticles used in experiments were obtained from Sigma-Aldrich Company. The size of particles for FeNPs was about (50–100 nm) with 99% purity, while the size of particles for ZnNPs was <50 nm with a purity of 97%. SNPs with diameters ranging from 8–20 were prepared according to Hebeish et al. [33].

The treatments were sprayed on the foliage of *Philodendron* plants until the fall of the first drop from the leaf each time one month after transplanting in October in both seasons (2019/2020 and 2020/2021) and were repeated four times at 2-week intervals. The pots were arranged in a completely randomized block design. The experimental treatments were 12 treatments, with three replicates; each replicate had four pots and one plant in each pot. The plant height, plant width, the number of leaves, and the leaf dimensions (length and width of leaf blades, length of petioles) were determined to evaluate the quality and the production of *Philodendron* plants.

2.2. The Growth Parameters

After 6 months (April 2020) and 12 months (October 2020) from starting treatments in both seasons, the data were recorded of the plant height (cm), plant width (cm), the number of leaves/plant, and the leaf dimensions (length and width of leaf blades, length of petioles).

At the end of the experiment (after 12 months), the measurements taken of the leaf area (cm^2) were specified according to the method of Matthew et al. [34] of the 4th leaf from the top, root length (cm), stem diameter (cm) at a height 4 cm from the soil surface, and the fresh and dry weight of leaves, stems, and roots (g/plant).

2.3. Physiological Characters

The samples were collected at the end of the experiments to determine the following characters:

- Total chlorophyll and carotenoid contents in leaves were determined according to Allel et al. [35].
- Activities of the catalase (CAT) enzyme were measured according to Giannopolitis and Ries [36]. POX was measured according to Hammerschmidt et al. [37]. PPO activity was measured according to Malik and Singh [38].
- Nitrogen (N) (%) was determined by micro Kjeldahl as per the method described by the A.O.A.C. [39]. Phosphorus (P) (%) was determined by spectrophotometer as per the method described by Jackson [40]. Potassium (K) (%) was determined by flame emission spectrometry according to Page et al. [41]. Iron (Fe mg/kg) and zinc (Zn mg/kg) were specified by using inductively coupled spectrometry plasma (ICP) Model Ultimate-Jobin Yvonzz.e.

2.4. Anatomical Studies

The samples of leaves and stems (5 mm length) were taken at the end of the second season (2019/2020). Samples were fixed in fixation solution, consisting of formalin, alcohol, and acetic acid mixture (1:18:1 v/v). They were washed and dehydrated in alcohol series and embedded in paraffin wax (62–64 °C m. p.). Samples were sectioned using a rotary microtome (Leica RM 2125) with 15 µm of thickness. The sections were launched on slides and dipped in xylene to remove the wax. Then the sections were stained using safranine and light green [42]. The slides were cleared in xylene and mounted in Canada balsam [43]. The sections were examined and photographed with an electric microscope (Lieca DM LS) with a digital camera (Leitz Wetzler, Wetzler, Germany) at 100× magnification.

2.5. Statistical Analysis

The data were the mean of two seasons (2019/2020 and 2020/2021). The experiment includes 12 treatments with three replicates, each replicate had four pots and one plant in each pot. The data were subjected to statistical analysis of variance using CoStat Computer Software version 6.303. The mean was compared by Duncan's Multiple Range Test [44] (DMRT, $p \leq 0.05$) [45].

3. Results

3.1. Morphological Growth Characters

3.1.1. Plant Height, Plant Width and Number of Leaves/Plants

From this investigation, it is clear that the impact of SNPs, FeNPs, ZnNPs, NPK NPs, and HA on vegetative growth traits of *Philodendron bipinnatifidum* had significant effects in comparison to the control plants. The data showed that SNPs at (40 and 60 mg/L) resulted in better growth parameters compared with any treatments followed by NPK NPs at 2 mL/L, while the control treatment was the least. The highest increase in plant height and plant width after six and twelve months was achieved by plants sprayed with 60 mg/L SNPs (Table 1). Additionally, 60 mg/L SNPs were found to be more effective in increasing the number of leaves after 6 and 12 months. The highest values in the number of leaves after 6 and 12 months were recorded at 60 mg/L SNPs (5.00 and 11.67 leaf/plant, respectively), while the lowest values (3.75 and 6.42 leaf/plant respectively) were recorded with the control.

Table 1. Effect of nanoparticles and humic acid on plant height, plant width and number of leaves/plant of *Philodendron bipinnatifidum* after 6 months and 12 months during the 2019/2020 and 2020/2021 seasons.

Treatments	Plant Height (cm)		Plant Width (cm)		Number of Leaves/Plant	
	6 Months	12 Months	6 Months	12 Months	6 Months	12 Months
Control	22.63 ^{i}	37.62 ^{f}	24.30 ^{f}	28.67 ^{g}	3.75 ^{d}	6.42 ^{g}
HA at 1 mL/L	29.17 ^{defg}	46.25 ^{cd}	30.38 ^{cde}	44.33 ^{cde}	4.17 ^{bcd}	8.00 ^{ef}
HA at 2 mL/L	29.42 ^{def}	46.62 ^{cd}	31.25 ^{cde}	47.00 ^{bcde}	4.25 ^{bcd}	8.55 ^{de}
NPK NPs at 1.5 mL/L	30.18 ^{cde}	47.03 ^{cd}	31.98 ^{cd}	47.83 ^{bcd}	4.42 ^{abcd}	9.11 ^{cd}
NPK NPs at 2 mL/L	32.63 ^{bc}	50.24 ^{bc}	35.73 ^{bc}	51.41 ^{abc}	4.67 ^{ab}	9.67 ^{bc}
FeNPs at 100 mg/L	25.97 ^{h}	40.04 ^{ef}	25.83 ^{ef}	35.13 ^{fg}	3.83 ^{cd}	7.17 ^{fg}
FeNPs at 150 mg/L	26.67 ^{fgh}	44.93 ^{cde}	30.27 ^{cde}	41.50 ^{def}	4.08 ^{bcd}	7.58 ^{f}
ZnNPs at 150 mg/L	26.29 ^{gh}	43.92 ^{de}	29.20 ^{def}	39.21 ^{ef}	3.83 ^{cd}	7.25 ^{fg}
ZnNPs at 200 mg/L	27.81 ^{efgh}	45.49 ^{cde}	31.08 ^{cde}	46.68 ^{bcde}	4.33 ^{abcd}	7.67 ^{ef}
SNPs at 20 mg/L	31.18 ^{cd}	48.85 ^{bcd}	35.38 ^{bc}	51.33 ^{abc}	4.50 ^{abc}	9.22 ^{cd}
SNPs at 40 mg/L	34.22 ^{ab}	53.49 ^{b}	38.33 ^{b}	53.25 ^{ab}	4.75 ^{ab}	10.17 ^{b}
SNPs at 60 mg/L	36.63 ^{a}	60.75 ^{a}	51.04 ^{a}	59.25 ^{a}	5.00 ^{a}	11.67 ^{a}

The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

3.1.2. The Leaf Dimensions (Length and Width of Leaf Blades, Length of Petioles)

The data in Table 2 revealed that the response of Length and Width of leaves blade and Length of petiole to the treatments followed a similar direction as in height and width of plant and number of leaves/plant. Plants treated with SNPs at (20, 40, and 60 mg/L), ZnNPs at 200 mg/L, NPK NPs at (1.5 and 2 mL/L), and HA at (1 and 2 mL/L) had significantly higher lengths compared to control plants after 6 months and 12 months. Most treatments had significantly increased the width of the leaf blade and length of the petiole more than the untreated control plants in both periods. Here also, the application of SNPs at 60 mg/L was the more effective treatment in increasing leaf parameters, giving the greatest mean blade length, blade width, and length of petiole in both periods.

Table 2. Effect of nanoparticles and humic acid on length and width of leaves blade and length of petiole in *Philodendron bipinnatifidum* after 6 months and 12 months during 2019/2020 and 2020/2021 seasons.

Treatments	Length of Leaves Blade (cm)		Width of Leaves Blade (cm)		Length of Petiole (cm)	
	6 Months	12 Months	6 Months	12 Months	6 Months	12 Months
Control	7.67 ^{f}	10.12 ^{f}	6.31 ^{e}	9.76 ^{g}	15.63 ^{f}	23.60 ^{g}
HA at 1 mL/L	9.80 ^{de}	13.09 ^{cde}	8.03 ^{d}	13.06 ^{cdef}	18.94 ^{cd}	29.55 ^{de}
HA at 2 mL/L	9.99 ^{d}	13.48 ^{cde}	8.10 ^{d}	13.35 ^{cde}	19.68 ^{cd}	31.25 ^{cd}
NPK NPs at 1.5 mL/L	12.17 ^{c}	14.12 ^{bcd}	9.03 ^{c}	13.47 ^{cd}	20.45 ^{c}	31.51 ^{cd}
NPK NPs at 2 mL/L	13.49 ^{bc}	14.38 ^{bc}	9.89 ^{c}	14.29 ^{bc}	22.66 ^{b}	33.08 ^{c}
FeNPs at 100 mg/L	8.46 ^{ef}	10.66 ^{f}	7.18 ^{de}	11.71 ^{f}	15.70 ^{f}	24.34 ^{fg}
FeNPs at 150 mg/L	8.68 ^{def}	11.48 ^{ef}	7.64 ^{d}	11.92 ^{ef}	16.71 ^{ef}	28.72 ^{e}
ZnNPs at 150 mg/L	8.86 ^{def}	12.08 ^{def}	7.85 ^{d}	12.32 ^{def}	17.98 ^{de}	26.06 ^{f}
ZnNPs at 200 mg/L	9.50 ^{de}	13.09 ^{cde}	7.88 ^{d}	12.94 ^{cdef}	18.78 ^{cd}	29.26 ^{de}
SNPs at 20 mg/L	13.42 ^{bc}	14.24 ^{bc}	9.22 ^{c}	14.20 ^{bc}	20.75 ^{c}	32.02 ^{c}
SNPs at 40 mg/L	13.86 ^{b}	16.14 ^{b}	11.65 ^{b}	15.27 ^{b}	24.65 ^{a}	36.63 ^{b}
SNPs at 60 mg/L	15.66 ^{a}	18.17 ^{a}	13.19 ^{a}	17.62 ^{a}	26.51 ^{a}	41.77 ^{a}

The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

3.1.3. Leaf Area, Stem Diameter, and Root Length

The data presented in Table 3 showed that most of the nanoparticle treatments and humic acid caused a significant increase in leaf area, stem diameter, and root length of

Philodendron plants compared with control plants. The application of 60 mg/L SNPs resulted in significant increases in these parameters compared with other treatments and the control. The highest values were recorded with 60 mg/L SNPs (295.22 cm^2 for leaf area, 2.30 cm for stem diameter, and 54.33 cm for root length). The lowest values were recorded with the control plants (91.06 cm^2 for leaf area, 1.14 cm for stem diameter, and 32.38 cm for root length).

Table 3. Effect of nanoparticles and humic acid on leaf area, stem diameter, and root length in *Philodendron bipinnatifidum* during 2019/2020 and 2020/2021 seasons.

Treatments	Leaf Area (cm^2)	Stem Diameter (cm)	Root Length (cm)
Control	91.06 ^{g}	1.14 ^{g}	32.38 ^{g}
HA at 1 mL/L	158.20 ^{cde}	1.55 ^{e}	44.00 ^{cd}
HA at 2 mL/L	166.75 ^{cd}	1.59 ^{de}	45.25 ^{c}
NPK NPs at 1.5 mL/L	173.18 ^{c}	1.70 ^{de}	46.75 ^{c}
NPK NPs at 2 mL/L	187.34 ^{c}	2.00 ^{bc}	51.17 ^{ab}
FeNPs at 100 mg/L	117.14 ^{fg}	1.22 ^{g}	34.92 ^{g}
FeNPs at 150 mg/L	125.96 ^{ef}	1.28 ^{g}	35.50 ^{fg}
ZnNPs at 150 mg/L	137.90 ^{def}	1.32 ^{fg}	39.00 ^{ef}
ZnNPs at 200 mg/L	156.37 ^{cde}	1.53 ^{ef}	41.25 ^{de}
SNPs at 20 mg/L	186.64 ^{c}	1.80 ^{cd}	47.67 ^{bc}
SNPs at 40 mg/L	228.28 ^{b}	2.21 ^{ab}	54.08 ^{a}
SNPs at 60 mg/L	295.22 ^{a}	2.30 ^{a}	54.33 ^{a}

The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

3.1.4. The Fresh and Dry Weights of Leaves, Stems, Roots, and the Whole Plant

In the context of the presented data, it should be underlined that the application of most of the nanomaterials and humic acid led to an increase in the fresh and dry weights of the leaves, stems, roots, and the whole plant when compared to the control plants (Table 4). There were no significant differences in the fresh and dry weights of leaves, stems, roots, and the whole plant between 100 mg/L FeNPs and the control. The most significant effective treatment on the fresh and dry weights of leaves, stems, and the whole plant was the application of SNPs at 60 mg/L. The highest fresh weight of the whole plant (176.15 g/plant) and the highest dry weight of the whole plant (15.57 g/plant) were obtained by the application of 60 mg/L SNPs. The lowest values of the fresh weight of whole plant (77.47 g/plant) and the lowest dry weight of the whole plant (5.66 g/plant) were recorded with the control treatment.

Table 4. Effect of nanoparticles and humic acid on fresh and dry weights of leaves, stems, and roots in *Philodendron bipinnatifidum* during 2019/2020 and 2020/2021 seasons.

Treatments	Fresh Weight (g/Plant)				Dry Weight (g/Plant)			
	Leaves	Stems	Roots	Total	Leaves	Stems	Roots	Total
Control	48.94 ^{f}	14.92 ^{f}	13.67 ^{e}	77.47 ^{f}	3.44 ^{g}	0.81 ^{f}	1.40 ^{f}	5.66 ^{h}
HA at 1 mL/L	65.50 ^{de}	17.48 ^{cd}	19.86 ^{cd}	102.83 ^{de}	5.01 ^{def}	1.17 ^{def}	2.50 ^{cde}	8.83 ^{def}
HA at 2 mL/L	71.61 ^{cd}	18.98 ^{c}	22.55 ^{bc}	113.14 ^{d}	5.75 ^{cde}	1.21 ^{cde}	2.60 ^{bcde}	9.40 ^{de}
NPK NPs at 1.5 mL/L	78.83 ^{c}	27.25 ^{b}	26.66 ^{ab}	132.74 ^{c}	6.30 ^{cd}	1.25 ^{cde}	2.79 ^{bcd}	10.33 ^{cd}
NPK NPs at 2 mL/L	92.67 ^{b}	28.00 ^{b}	28.42 ^{a}	149.08 ^{b}	6.91 ^{bc}	1.53 ^{bc}	3.08 ^{bc}	11.32 ^{c}
FeNPs at 100 mg/L	58.70 ^{ef}	15.05 ^{ef}	15.05 ^{de}	89.61 ^{ef}	3.86 ^{fg}	0.97 ^{ef}	1.71 ^{ef}	6.54 ^{gh}
FeNPs at 150 mg/L	63.86 ^{de}	16.52 ^{def}	16.19 ^{de}	96.57 ^{e}	4.84 ^{ef}	1.00 ^{ef}	2.07 ^{cdef}	7.91 ^{efg}
ZnNPs at 150 mg/L	59.51 ^{ef}	15.97 ^{def}	15.60 ^{de}	90.27 ^{ef}	4.82 ^{ef}	0.99 ^{ef}	1.76 ^{def}	7.57 ^{fg}
ZnNPs at 200 mg/L	65.10 ^{de}	16.65 ^{de}	17.90 ^{cde}	99.65 ^{e}	5.00 ^{def}	1.07 ^{def}	2.48 ^{cde}	8.57 ^{ef}
SNPs at 20 mg/L	92.04 ^{b}	27.52 ^{b}	27.17 ^{ab}	146.72 ^{b}	6.81 ^{bc}	1.43 ^{bcd}	2.85 ^{bc}	11.29 ^{c}
SNPs at 40 mg/L	97.33 ^{b}	28.07 ^{b}	28.80 ^{a}	154.20 ^{b}	7.79 ^{ab}	1.70 ^{b}	3.58 ^{ab}	13.07 ^{b}
SNPs at 60 mg/L	111.70 ^{a}	34.267 ^{a}	30.18 ^{a}	176.15 ^{a}	9.01 ^{a}	2.19 ^{a}	4.37 ^{a}	15.57 ^{a}

The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

3.2. Physiological Characters

3.2.1. Photosynthetic Pigments

The data in Figure 1A,B reveal a significant effect of SNPs, NPK NPs, FeNPs, ZnNPs, and humic acid at all concentrations on leaf pigments of *Philodendron* plants compared to the control. It is clear that the best total chlorophyll content was obtained under FeNPs at 150 mg/L and SNPs at 60 mg/L treatments. Additionally, the highest value in chlorophyll content was obtained under FeNPs at 150 mg/L treatment. Moreover, the highest values in carotenoid content were obtained under NPK NPs at 2 mL/L, FeNPs at 150 mg/L, and SNPs at 60 mg/L treatments. The lowest concentration of all leaf pigments was obtained from the untreated plants. The highest values (1.14 mg/g FW for chlorophyll and 0.181 mg/g FW for carotenoid) were recorded when plants were sprayed with 150 mg/L FeNPs.

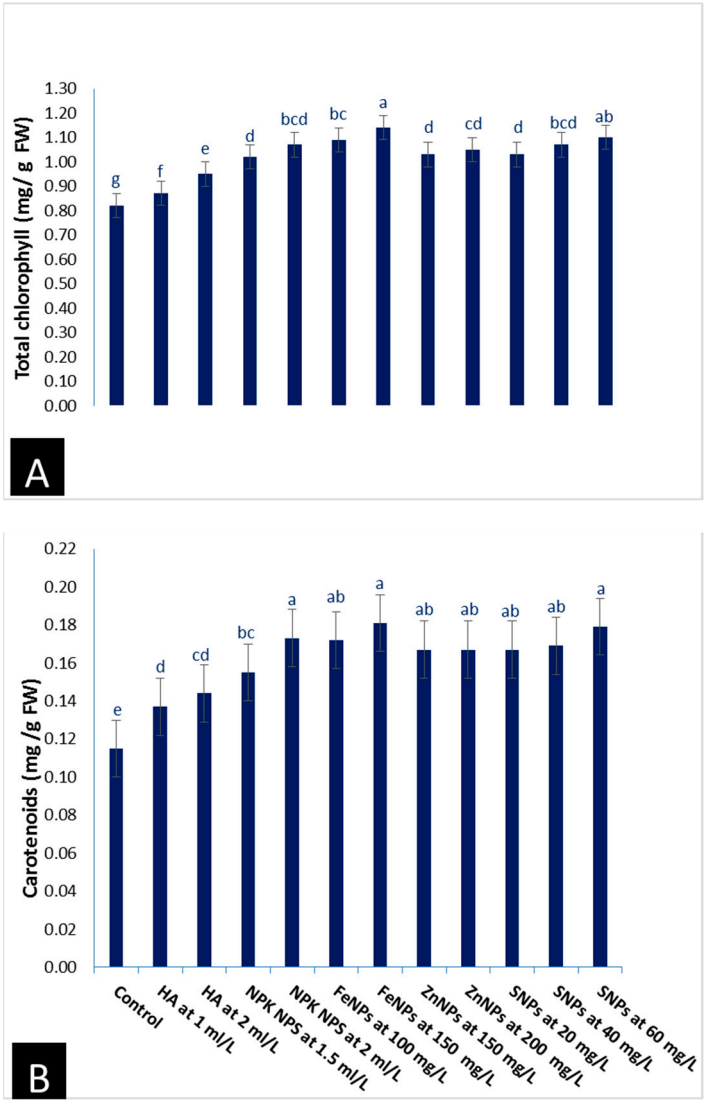

Figure 1. Effect of nanoparticles and humic acid on total chlorophyll (**A**) and carotenoid (**B**) (mg/g FW) content in *Philodendron bipinnatifidum* during 2019/2020 and 2020/2021 seasons. The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

3.2.2. Mineral Contents

The results of our present study depicted that NPs (Ag, Fe, Zn, and NPK) and humic acid had significantly increased Fe (except for the SNPs at 20 mg/L treatment) and Zn contents in leaves of *Philodendron* plants compared to the control (Figure 2A,B). The foliar

application FeNPs had significantly increased the Fe content in leaves compared with other treatments and the control plants (Figure 2A). The highest content of iron (1.75 mg/kg dry matter) was achieved when the plants were sprayed with 150 mg/L FeNPs, and the unsprayed plants recorded the lowest values of Fe content (0.80 mg/kg dry matter). As seen in Figure 2B, the recorded data revealed that plants treated with ZnNPs had significantly increased Zinc content in plant leaves compared to other treatments and the control plants. The highest mean values of Zn content were recorded for the treatment of 200 mg/L ZnNPs (0.68 mg/kg dry matter) while the lowest ones were recorded with the control plants (0.53 mg/kg dry matter).

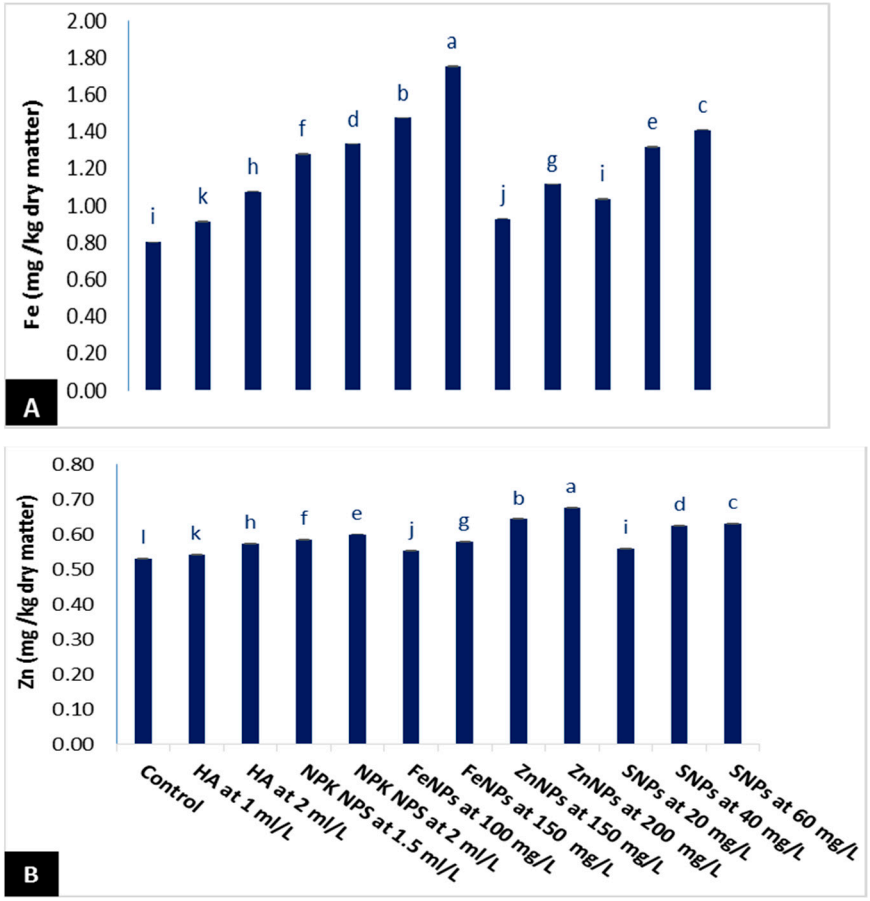

Figure 2. Effect of nanoparticles and humic acid on Iron (**A**) and Zinc content (**B**) (mg/Kg DW) content in *Philodendron bipinnatifidum* during 2019/2020 and 2020/2021 seasons. The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

Regarding the effect of nanoparticles (Ag, Fe, Zn, and NPK) and humic acid on N, P, and K contents, the results in Figure 3A–C revealed that all treatments led to a great increase in N, P and K elements (%) in the leaves of *Philodendron* compared to control plants. The highest values of N (%) in the leaves were obtained with 2 mL/L NPK NPs followed by 1.5 mL/L NPK NPs, then SNPs at 60 mg/L. The highest value of nitrogen (4.44%) content in leaves was obtained with 2 mL/L NPK NPs, while the control recorded the lowest value (Figure 3A). As shown in Figure 3B, there were non-significant differences in phosphorus (%) between 2 mL/L NPK NPs, 1.5 mL/L NPK NPs, SNPs at 60 mg/L, SNPs at 40 mg/L, and HA at 2 mL/L. The highest value of P (%) was obtained with 2 mL/L NPK NPs, while the control treatment achieved the lowest values. The highest content of potassium was recorded in the leaves of the plants sprayed with NPK NPs treatments followed by Humic

acid treatments; the highest values were recorded at 2 mL/L NPK NPs (Figure 3C). The lowest values of K contents were obtained in the control plants (2.72%).

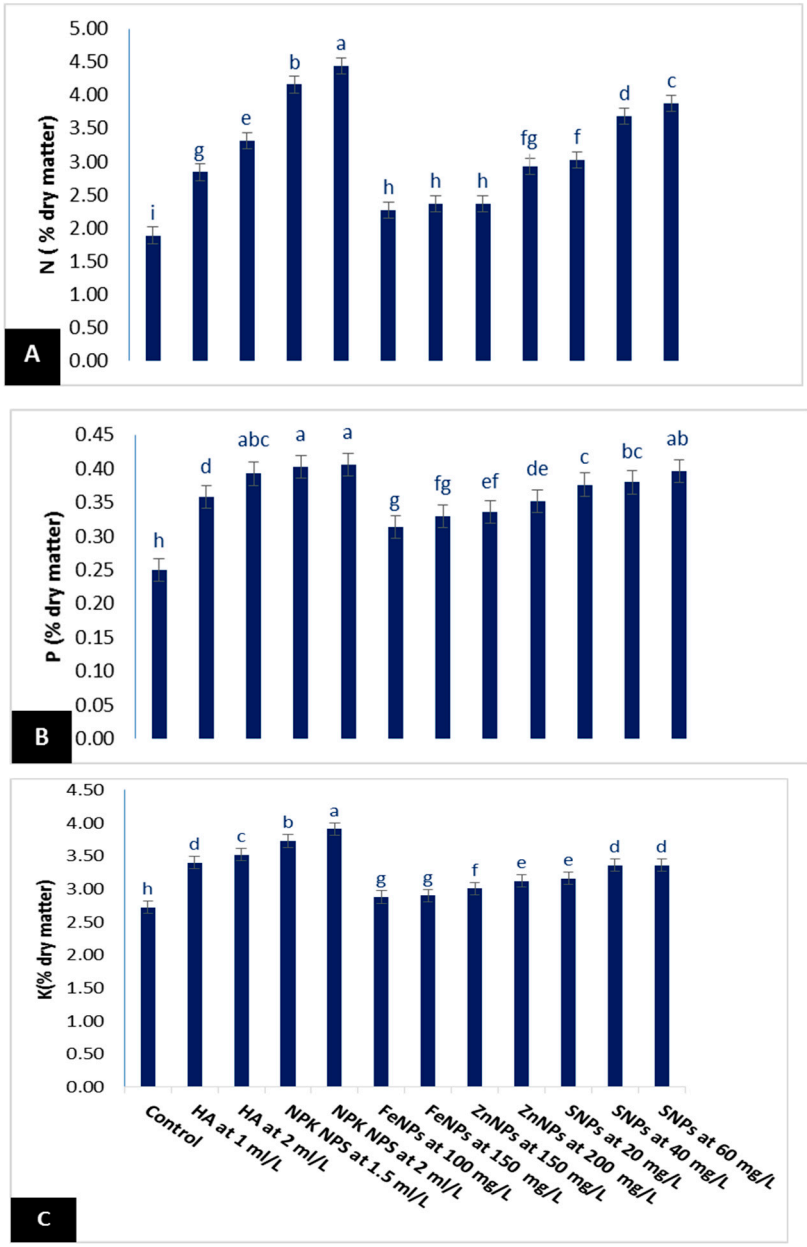

Figure 3. Effect of nanoparticles and humic acid on nitrogen (**A**), phosphorus (**B**), and potassium (**C**) contents (% dry matter) in *Philodendron bipinnatifidum*. The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean of both seasons (±SE) of three replicates.

3.2.3. Enzymes Activities

The obtained results indicated that humic acid and NPs (Ag, Fe, Zn, and NPK) treatments led to improvements in the up-regulation of enzyme activities, mainly catalase, peroxidase, and polyphenol oxidase in the leaves of *Philodendron* plants (Figure 4). The plants showed a higher CAT activity than the control when treated with SNPs at 60 and 40 mg/L, ZnNPs at 150 mg/L, FeNPs at 100 mg/L, and NPK NPs at 2 mL/L. Additionally, a higher POX activity was recorded in treated plants compared to the control when treated with HA at 2 mL/L, SNPs at 40 mg/L, SNPs at 60 mg/L, and ZnNPs at 150 mg/L nanopar-

ticles. However, the plants showed a higher PPO activity compared to the control when treated with SNPs at 60 mg/L nanoparticles.

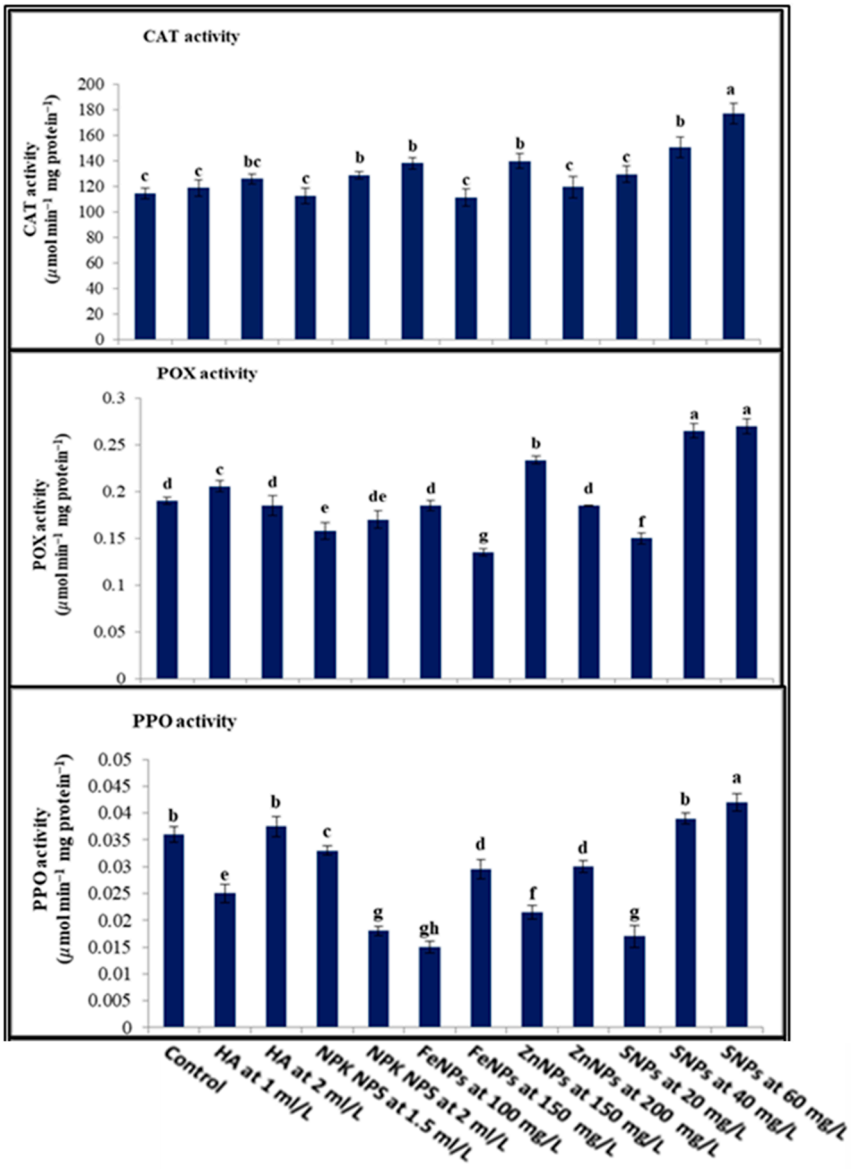

Figure 4. Effect of nanoparticles and humic acid on catalase, peroxidase, and polyphenol oxidase activities in *Philodendron bipinnatifidum* leaves in the second season. The same letters show no significant differences between the treatments according to ANOVA, Duncan's multiple range test at 0.05 level. Data are the mean (±SE) of three replicates.

3.3. Anatomical Structure of Leaves and Stems

The obtained results showed that humic acid and NPs (Ag, Fe, Zn, and NPK) treatments led to improved anatomical characteristics of the leaves and stems of *Philodendron* plants (Figures 5 and 6) compared to the control without treatments. The anatomical structure of the leaf of *Philodendron*, as a monocotyledonous plant, showed the upper and lower epidermis as well as mesophyll tissue (Figure 5). The treatments with NPK NPs at 2 mL/L (nano fertilizer NPK), ZnNPs at 200 mg/L (zinc nanoparticles), SNPs at 20 mg/L (Silver nanoparticles), SNPs at 40 mg/L (Silver nanoparticles), and SNPs at 60 mg/L (Silver nanoparticles) caused an improvement in the thickness of the blade, the thickness of mesophyll tissue, xylem vessel diameter, and vascular bundles dimension. The best results were obtained with SNPs at 40 mg/L and 60 mg/L (Silver nanoparticles). Additionally,

the anatomical characters of treated *Philodendron* stems with NPK NPs at 2 mL/L, ZnNPs at 200 mg/L, SNPs at 20 mg/L, SNPs at 40 mg/L, and SNPs at 60 mg/L exhibited an increment in stem diameter and epidermis cell dimension. The best result was recorded with 40 and 60 mg/L Silver nanoparticles compared with other treatments and the control (Figure 6A).

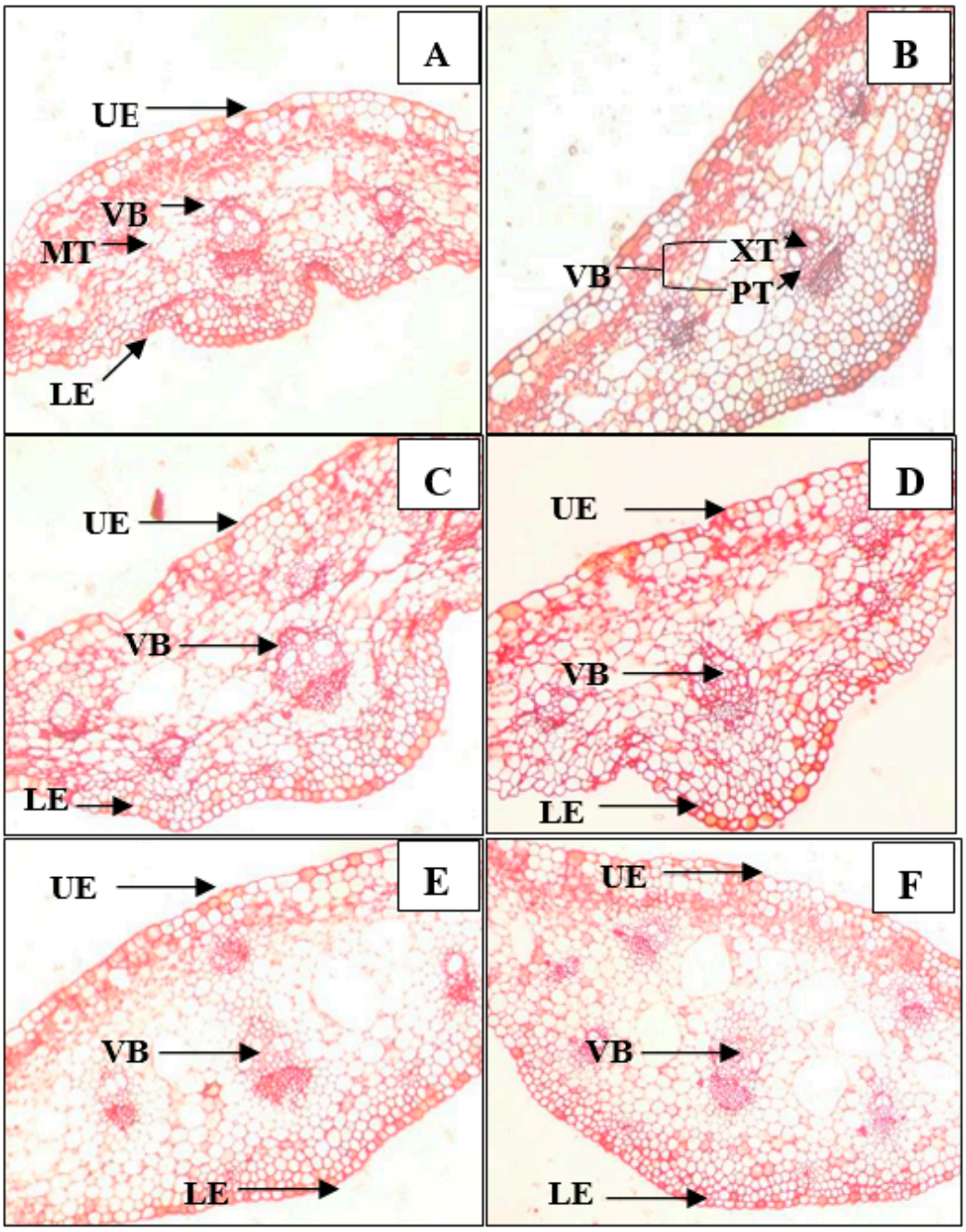

Figure 5. Anatomical structure of *Philodendron bipinnatifidum* leaves in the second season. (**A**): control, (**B**): NPK NPs at 2 ml/L, (**C**): ZnNPs at 200 mg/L, (**D**): SNPs at 20 mg/L, (**E**): SNPs at 40 mg/L, (**F**): SNPs at 60 mg/L, UE: Upper epidermis, MT: Mesophyll tissue, VB: Vascular bundle, XT: Xylem tissue, PT: Phloem tissue, LE: Lower epidermis (Magnification 100×).

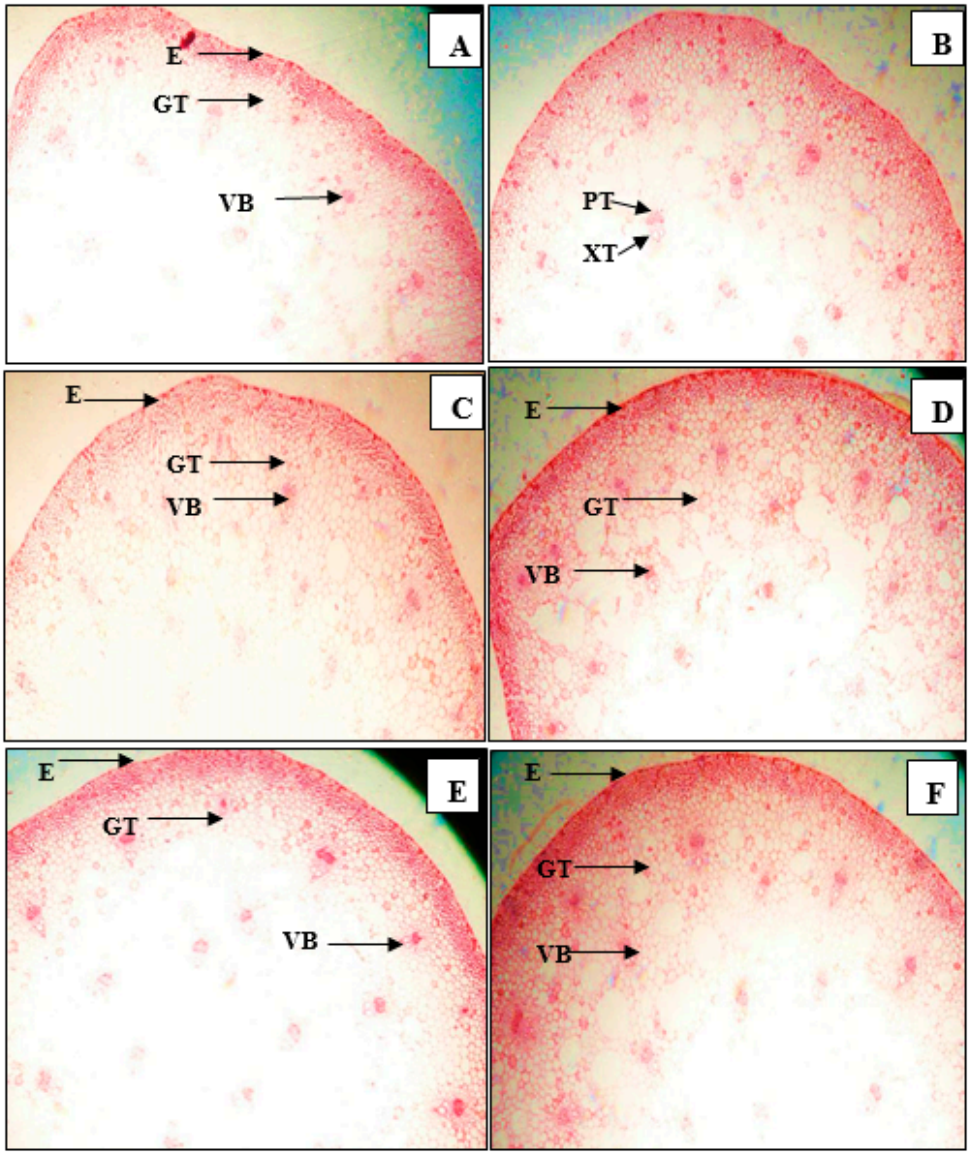

Figure 6. Anatomical structure of *Philodendron bipinnatifidum* stems in the second season. (**A**): control, (**B**): NPK NPs at 2 ml/L, (**C**): ZnNPs at 200 mg/L, (**D**): SNPs at 20 mg/L, (**E**): SNPs at 40 mg/L, (**F**): SNPs at 60 mg/L, E: Epidermis, GT: Ground tissue, VB: Vascular bundle, XT: Xylem tissue, PT: Phloem tissue (Magnification 100×).

4. Discussion

The present investigation demonstrated that all nutrition treatments had positive effects on the *Philodendron* growth and chemical and physiological parameters. Our results clearly indicated that the plant quality characters such as plant height and width, number of leaves, leaf parameters, leaf area, stem diameter, fresh and dry weights, as well as root length were improved with the application of SNPs at 60 mg/L compared with the other treatments. Ghorbanpour and Hatami [46] reported that the plant growth parameters of pelargonium increased with increasing concentrations of SNPs up to 40 mg/L. Additionally, the results of this investigation were in conformity with the previous results on the fenugreek plants. Growth parameters of fenugreek plants (e.g., shoot length, number of leaves/plant, and shoot dry weight) were significantly activated by silver nanoparticles [47]. Moreover, the stimulation effect of SNPs on the morphological growth of *Oriental Lilies* was observed with silver nanoparticles [1]. SNPs promoted root length and the number of roots in tomato seedlings [48]. Our current study recorded that the application of SNPs

improves the morphological parameters due to the highly developed surface area of SNPs which makes them more reactive. Moreover, their Physico-chemical properties allow them to interact with living cells [49]. Syu et al. [50] showed that SNPs can promote root growth and increase the accumulation of proteins that are linked to the cell cycle, carbohydrate metabolism, and chloroplast biogenesis, and stimulate the biosynthesis of auxins associated with ROS Scavenging. Additionally, NPK NPs led to improvements in the morphological characters of *Philodendron*, especially in higher concentrations. Our findings were in accordance with the results of AL-Gym and Al-Asady [51] who indicated that spraying with NPK NPs 1.5 g/L and 7.5 kg/ha mixing with soil significantly increased vegetative growth and yield in yellow corn. The application of a mixture of N, P, and K recorded high growth characteristics and chemical composition of the sage plant [52]. NPK NPs play an important role in increasing plant growth due to the stimulating effect of nitrogen on Auxin production, which encourages cell division and elongation in the vegetative growth stage of the plant. Additionally, it is an essential element to construct the amino acid Tryptophan, which is the main constructing material for constructing indole acetic acid (IAA) as a major hormone in the plant [51]. Sun et al. [53] reported that nitrogen may have a positive effect on the amount of IAA in rice plants. The same trend was recorded by Xu et al. [54] in rice plants. The importance of nitrogen, phosphorus, and potassium for plant production was studied by some researchers in several economic crops such as rice [55,56], maize [57,58], wheat [59,60], and sugar beet [61].

In this investigation, spraying *Philodendron* plants with NPs treatments and humic acid led to increasing photosynthetic pigments (Figure 1). The highest values of chlorophyll and carotenoids were obtained when plants were sprayed with 150 mg/L FeNPs. This increase may be a result of stimulating the activity of some specific enzymes which play an important role in chlorophyll synthesis [12], such as NADPH protochlorophyllide oxidoreductase (POR), which is the main enzyme of chlorophyll synthesis in flowering plants. It can catalyze the light-requiring step of the C_5 pathway [62]. Additionally, iron functions in the synthesis of a specified type of RNA that regulates chlorophyll synthesis through a series of unbeknownst reactions [63,64]. Approximately, iron atoms were found in photosynthetic apparatus per electron transport chain in different heme- and [Fe–S] cluster-containing proteins where it was essential for the photosynthetic activities [62]. The same trend was recorded by Elfeky et al. [12] on basil and Dawa et al. [65] on tomato. They reported that the foliar application of FeNPs increased photosynthetic pigments. Additionally, SNPs at 60 mg/L significantly increased photosynthetic pigments in *Philodendron*. A similar result was obtained by Salachna [1] on Oriental Lilies, by Ghorbanpour and Hatami [21,46] on pelargonium, and by Sadak [47] on the fenugreek plant. They showed that SNPs increased photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids). This might be because Ag^+ can replace Co_3+ in protein receptors, resulting in a slowdown of ethylene action in plant cells due to the fact that Co^{3+} plays a significant role in ethylene binding to its receptors [66]. Moreover, Purvis [67] reported that the activity of chlorophyllase induced by ethylene leads to the destruction of the internal membrane of the chloroplast.

In the current study, spraying with NPs (Ag, Fe, Zn, and NPK) and humic acid enhanced the mineral contents in the plants compared to the control (Figures 2 and 3). Spraying with FeNPs at 150 mg/L recorded the highest values in iron in *Philodendron* leaves, however, the application of ZnNPs at 200 mg/L achieved the highest Zn concentrations in leaves. The application of 2 mL/L NPK NPs recorded the highest % of N, P, and K in *Philodendron* leaves. Previous studies have depicted that NPs could significantly increase nutrients in plants. Manzoor et al. [68] (on wheat) and Elfeky et al. [12] (on basil) reported that FeNPs increased iron concentration in the shoot system. Rizwan et al. [69] reported that using FeNPs increased the Fe concentrations and ZnNPs increased the Zn concentrations in wheat. Munir et al. [70] indicated that ZnO NPs could transport in wheat and increase the Zn contents in plants. The ZnO NPs applied in the soil increased the Zn concentrations in maize [71]. The increase in Zinc content in *Philodendron* plants by spraying with ZnNPs may be due to the role of Zinc in enhancing the cation exchange capacity of the roots, which

in turn enhances the absorption of essential nutrients [72]. Moreover, the application of nano-NPK mixture led to an increase in macro and microelement content in sage plants [52]. AL-Gym and Al-Asady [51] reported that spraying with NPK nanoparticles recorded the highest averages of nutrient contents (NPK) in the roots and leaves of corn. The increase in the contents of N, P, and K may be due to the role of nano fertilizer in increasing bioavailability which leads to an increase in the absorption of the elements [73] and increased efficiency of nutrients by the controlled supply of nutrients [74]. Similarly, nano fertilizers give more area for various metabolic reactions which increase the photosynthetic rate and nutrient contents, resulting in an increase in dry matter and yield production [75].

Additionally, the improvement of enzyme activity in *Philodendron* plants due to the treatments with NPK NPs at 2 ml/L (nano fertilizer NPK), ZnNPs at 200 mg/L (zinc nanoparticles), SNPs at 20 mg/L, SNPs at 40 mg/L, and SNPs at 60 mg/L (Silver nanoparticles) might be attributed to the role of NPK nanoparticles in increasing the availability and the uptake of the necessary elements for plant growth and development [70], consequently improving the upregulation of catalase, peroxidase, and polyphenol oxidase activity. The positive effects of ZnNPs at 200 mg/L, SNPs at 20 mg/L, SNPs at 40 mg/L, and SNPs at 60 mg/L could be due to their small size that helps in easy penetration into the plant cells and regulates stomatal movement and increases the leaf length and width [76]. Additionally, nanoparticles have a significant role in the formation of lateral roots [77], root biomass [78,79], increasing water uptake, improving the soil nutrient availability, and membrane stability, as well as the water status of *Philodendron* plants. The helpful impact of AgNPs was recorded by Khan et al. [80] who reported that AgNPs at 60 mg/L significantly increased the growth and biomass of pearl millet seedlings when compared with control plants. These results are in accordance with those recorded by Rashwan and Abdelaal [81], Ragab et al. [82], and Abdelaal et al. [83,84].

Furthermore, the anatomical characters of leaves and stems such as the upper and lower epidermis, mesophyll tissue, the thickness of the blade, the thickness of mesophyll tissue, xylem vessel diameter and vascular bundle dimension, stem diameter, and epidermis cell dimension were improved due to the application of NPK NPs at 2 ml/L (nano fertilizer NPK), ZnNPs at 200 mg/L (zinc nanoparticles), SNPs at 20 mg/L, SNPs at 40 mg/L, and SNPs at 60 mg/L (Silver nanoparticles). This helpful effect of this treatment may be due to the role of NPK NPs, ZnNPs, and SNPs in improving shoot length, the number of leaves/plants, shoot dry weight, cell membrane stability, nutrient status, and chlorophyll content consequently increasing the anatomical features of the leaf such as the thickness of the blade, mesophyll tissue, xylem vessel diameter, and vascular bundle dimension, as well as the anatomical structure of *Philodendron* stems, such as stem diameter and epidermis cell dimension. These results are in agreement with the results of Rashwan et al. [85] and El-Flaah et al. [86].

5. Conclusions

Generally, the results obtained from this investigation reveal that all nanoparticles and humic acid treatments stimulated morphological growth such as plant height, the number of leaves/plant and leaf width, photosynthetic pigments such as total chlorophyll and carotenoid content, as well as mineral contents. Additionally, the anatomical characteristics of *Philodendron bipinnatifidum* leaves and stems such as the stem diameter and epidermis cell dimension, upper and lower epidermis, mesophyll tissue, the thickness of mesophyll tissue, xylem vessel diameter, and vascular bundle dimension were improved with nanoparticles and humic acid treatments. In most characteristics, the best effects were achieved for SNPs at 60 mg/L. It recommends silver nanoparticle treatments as a new strategy for improving the quality and production of Philodendron pot plants. As far as we know, this is the first record of using nanoparticles and humic acid in improving the quality and production of philodendron plants associated with the anatomical structure of stems and leaves.

Author Contributions: Conceptualization, G.M.R.E.-S. and K.A. (Khaled Abdelaal); methodology, G.M.R.E.-S. and K.A. (Khaled Abdelaal); software, G.M.R.E.-S. and K.A. (Khaled Abdelaal); validation,

G.M.R.E.-S. and K.A. (Khaled Abdelaal); formal analysis, G.M.R.E.-S. and K.A. (Khaled Abdelaal); investigation, G.M.R.E.-S. and K.A. (Khaled Abdelaal); resources, G.M.R.E.-S. and K.A. (Khaled Abdelaal); data curation, G.M.R.E.-S. and K.A. (Khaled Abdelaal); writing—original draft preparation, G.M.R.E.-S., K.A. (Khadiga Alharbi), M.A., L.A., K.A.A. and K.A. (Khaled Abdelaal); writing—review and editing, G.M.R.E.-S. and K.A. (Khaled Abdelaal); supervision, G.M.R.E.-S. and K.A. (Khaled Abdelaal); funding acquisition, K.A. (Khadiga Alharbi), M.A., L.A. and K.A.A. All authors have read and agreed to the published version of the manuscript.

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