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Foliar Application of Nano-NPK in Combination with Nano-Micronutrients for Growth, and Flowering of *Tecoma stans* L. Plants

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ECO-FRIENDLY, cost-effective, and long-term solutions for agricultural systems should be explored, such as nano fertilizers, which can be employed as controlled-release or slow-release fertilizers. Therefore, pot experiments were conducted to investigate foliar application of nano-NPK and nano-micronutrients at different concentration on growth, flowering and chemical constituents of *Tecoma stans* plants compared to the traditional mineral fertilization (NPK) at a private nursery in Mansoura city, Dakahlia Governorate, Egypt over the course of two consecutive 2021 and 2022 seasons. The examined treatments included; 3 g L^{-1} of mineral NPK fertilizer as control, nano-NPK at 1, 2 and 3 ml L^{-1} and nano-NPK at 2 ml L^{-1} + nano-micronutrients at 0.5, 1, 1.5 ml L^{-1} for each. Results demonstrated that all treatments with nanofertilizers enhanced vegetative growth (plant height, branches number/plant, aerial fresh and dry weights/plant, leaves number and leaf area), root growth (length, fresh and dry weight), membrane stability index, relative water content, and flowering parameters (inflorescence number, and floret number/inflorescence). Additionally, chemical components such as total carotenoids in flowers; leaves chlorophyll a and b, total carotenoids, mineral N, P, and K, and peroxidase and catalase activity in leaves were all enhanced by all nano treatments. Treatment with 2 ml L^{-1} of nano NPK + 1.5 ml L^{-1} of nano-micronutrients produced the most statistically significant results for these characteristics. The same treatment exhibited the highest reduction in the period from planting date until emergence the first inflorescence. It could be concluded that applying mixture of nano-NPK fertilizer (2 ml L^{-1}) and nano-micronutrient (1.5 ml L^{-1}) at intervals of 15 days during the growth season achieved the most favorable results in terms of morphological, biochemical, and physiological parameters. Further stdies are needed on different crops under different plant stresses.

Keywords: Nano fertilizers, micronutrient, antioxidant activity, Photosynthetic pigments, Tecoma.

1. Introduction

The tall ornamental shrub *Tecoma stans* has been studied extensively for its potential medicinal uses as a source of bioactive chemicals; its ornamental value is well-known (Singh et al. 2024). The ornamental tree known as Tecoma stans, a member of the Bignoniaceae family, is endemic to America and is one of several kinds of evergreen trees (CABI 2023). It is a 5-7.6 m tall flowering perennial shrub or small tree with flower. The bark matures into a rough, pale brown to grey color. The leaves are compound, imparipinnate, opposite, and have two to five pairs of leaflets in addition to a larger solitary terminal leaflet. The trumpet-shaped flowers, which are clustered at the branches' tips,

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have five rounded lobes, are 6 cm long, and range in color from pale yellow to bright yellow. They also have faint orange stripes at the throat. Fruits are up to 20 cm long, slender, slightly flattened, and contain numerous winged seeds in pointed capsules (Rana et al. 2023). City entrances, main roadways, parks, and backyards often have *Tecoma stans* planted as an ornamental plant.

Biological nanofertilizers are thought to be a promising option for sustainable agriculture and nano-farming techniques, in addition to being nutrient fertilizers, like conventional fertilizers. They are composed, in whole or in part, of nanostructured formulations that can be delivered to the plant, allowing for efficient uptake or slow release of active ingredients (El-Saadony et al. 2021; El-Ramady et al. 2023). The goal of nano fertilizers is to increase plant availability of nutrients by improving nutrient usage efficiency. They also aim to reduce the amount of additional fertilizer needed, which will lower cultivation expenses and eliminate contamination of the environment, particularly of soil and ground water resources. Materials with a physical diameter between 1 and 100 nm in at least one dimension or those that already exist at the bulk scale but have been modified with nanoscale materials are both referred to as nanofertilizer in the literature on nanotechnology's agricultural applications (Shalaby et al. 2022a). When compared to their bulk counterparts, the remarkable characteristics of nanoparticles—such as their high surface area/volume size ratio and improved optoelectronic and physicochemical properties—are now showing promise as a means of fostering plant growth and production (Priyanka et al. 2022), these are either collected from various plant vegetative or reproductive components using various chemical, physical, mechanical, or biological ways utilizing nanotechnology, or they are synthetic or modified versions of the bulk ingredients used as mineral fertilizers. Additionally, due to their special qualities, nanoparticles may have a different impact on a plant's metabolic processes than do conventional materials. They may also be able to mobilize natural nutrients like phosphorus in the rhizosphere (El-Saadony et al. 2021). When compared to mineral fertilizers, nanofertilizers can produce more by increasing growth parameters like plant height, number of leaves, leaf area, dry matter production, and photosynthesis pigments, especially during the seedling growing stage (Shalaby et al. 2022b; Zhao et al. 2023; Haydar et al. 2024; Sundararajan et al. 2024). NPK-nanoparticles (NPK-NPs) may be crucial for food safety and can be seen as fundamental to the growth of agricultural yield. When these nano-NPK fertilizers are used to provide plants with the nutrients they need to thrive, their significance becomes clear (Nofal et al. 2024b; Nofal et al. 2024a).

By using foliar spray, nano micronutrients can be used as produced nano-fertilizers in the form of colloidal solutions. Research has shown that the economic yield and biomass production of a variety of crops are enhanced by nano micronutrients (Yasmin et al. 2021; Abdelaziz et al. 2022; Janmohammadi and Sabaghnia 2023; Muhammad and Al-Falahi 2023). Nano mixed foliar sprays with nanoparticles of micronutrients such as zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), boron (B), molybdenum (Mo), magnesium (Mg), sulfur (S), and zinc (Fe) are more sustainable, less mobile for plants, and better for field use. The synthesis of chlorophyll and some carbohydrates, as well as the conversion of starch to sugars, depend on nano zinc. Its presence in plant tissue also helps plants resist cold temperatures. On the other hand, nano iron is necessary for the upkeep of chloroplast structure and function and is involved in the creation of chlorophyll (Singh et al. 2023). Under drought stress, foliar spraying Zn-NPs on safflower plants enhanced biomass, the number of capitulum per plant, and other components of seed output (Ghiyasi et al. 2023). Additionally, (Muhammad and Al-Falahi 2023) found that for all vegetative growth indicators, including plant height, leaf area, dry weight, and chlorophyll, spraying nano fertilizer NPK and nano-microelements on yellow maize produced the highest significant results at 2.5 g L^{-1} nano-NPK + 2.0 g L^{-1} microelements.

However, little study has been done on use of nano-NPK and nano-micronutrient fertilizers on Tecoma. Based on all the above, the aim of this research is to compare different levels of nano-NPK and nano-micronutrients on vegetative growth, photosynthetic pigments, mineral concentrations, and leaf antioxidants in Tecoma compared to NPK as traditional fertilization.

2. Materials and Methods

The effect of foliar application of nano NPK and nano-microelements at different rates on the growth, biochemical composition, and chemical constituents of Tecoma stans was assessed in a pot experiment at a private nursery in Mansoura city, Dakahlia Governorate, Egypt (on the latitude 31.05° and longitude 31.3833° and 9 meters above sea level) over the course of two consecutive 2021 and 2022 seasons.

Figure 1 displays the climate data collected from the Agriculture Research Center during the course of the two experimental seasons. The soil used for cultivation was physically and chemically analyzed according to Sparks et al. (2020) before each season; the soil texture was clayey loam and the chemical properties during 2021 and 2022, respectively were 8.09 and 8.05 for pH and 1.09 and 1.17 % for OM, while available nutrients mg kg^{-1} were 39.19 and 41.51 for nitrogen, 6.32 and 8.32 for phosphorus and 232.35, 226.69 for potassium, with EC 2.23 and 2.71 dS m^{-1}, respectively during both seasons.

2.1 Plant materials

Two old stems of Tecoma stans trees uniform length of 15±1 cm was dipped in IBA solution at 250 ppm for five minutes and then planted on February 17^{th} and February 19^{th} during 2021 and 2022 in plastic pots of 8 cm size. After two months, the seedlings were transplanted and planted individually in plastic pots of 30 X 30 cm size contain (10 kg) of clay loam soil then the plants were manually irrigated interval three days using fresh tap water.

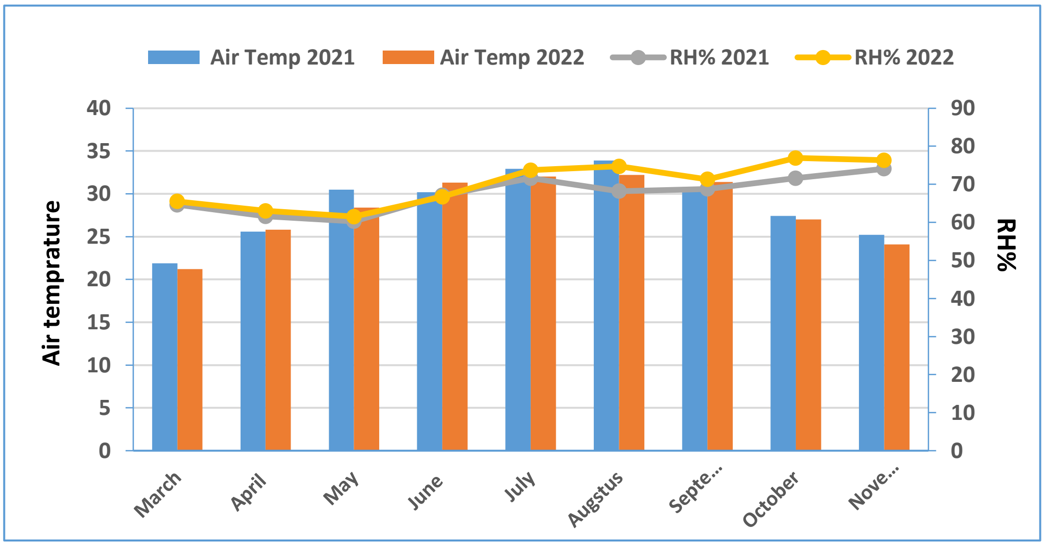


Fig. 1. Monthly air temperature and relative humidity (RH%), at the experimental during seasons of 2021 and 2022.

The pots were arranged in Randomized complete block design with 7 treatments and 3 replicates (10 plants for each one). On 1^{st} and 2^{nd} May in 2021 and 2022 seedlings were foliar sprayed was done at interval of 15 day by all treatments in early morning until run off (8 times). the treatments were mineral NPK (3 g L^{-1}), as a control, nano-NPK at 1, 2 and 3 ml L^{-1} and nano-NPK at 2 ml L^{-1} + mixture of nano micronutrient at 0.5, 1, 1.5 ml L^{-1} for each. Nano microelements were sprayed at the next day from applying nano NPK at 2 ml L^{-1} (**Figure 2**).

2.2 Sources of chemicals

The conventional NPK (EGY FLEX) (20:20:20) composed of 20% total nitrogen (N), 20% phosphorus (P_2O_5), and 20% potassium (K_2O), which manufactured by Egypt Chem International for Agrochemicals. Nano-NPK (19:6:20) were manufactured by Biota EG Company, which contains a 3.8% nitrogen, 2.0% phosphorus and 4.0% potassium. While, the mixture of nano micronutrients (n-MNs) containing 1% Fe, 3.39% Zn, 3.39% Mn, 0.5% Cu, 0.26% B, 0.1% Mo, 2.37% Mg, and 4% S.

Figure 3 shows the results of nano-NPK and nano-micronutrients Transmission Electron Microscopy (TEM). Thermo Fisher, Europe's Talos L120CG2 TEM model was used to measure these nanoparticles directly. For nan-NPK and nano-micronutrients (n-MNs), the applied nanomaterials' mean sizes were 317.9 and 323.5 nm, respectively.

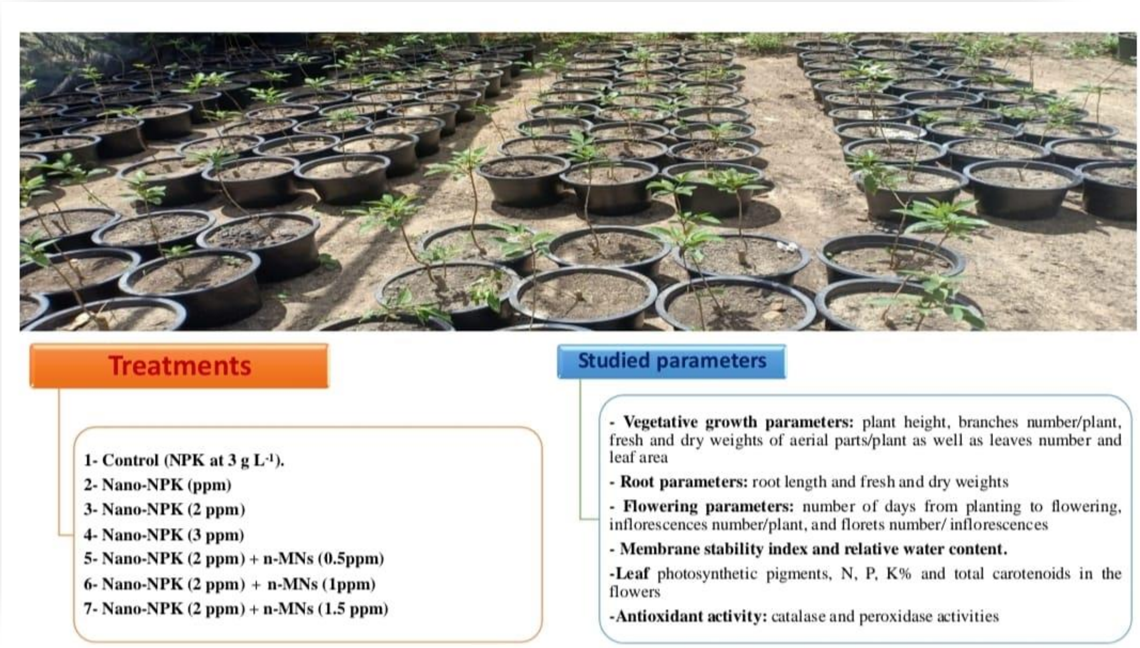


Fig. 2. A summary of the primary interventions and metrics used in the study.

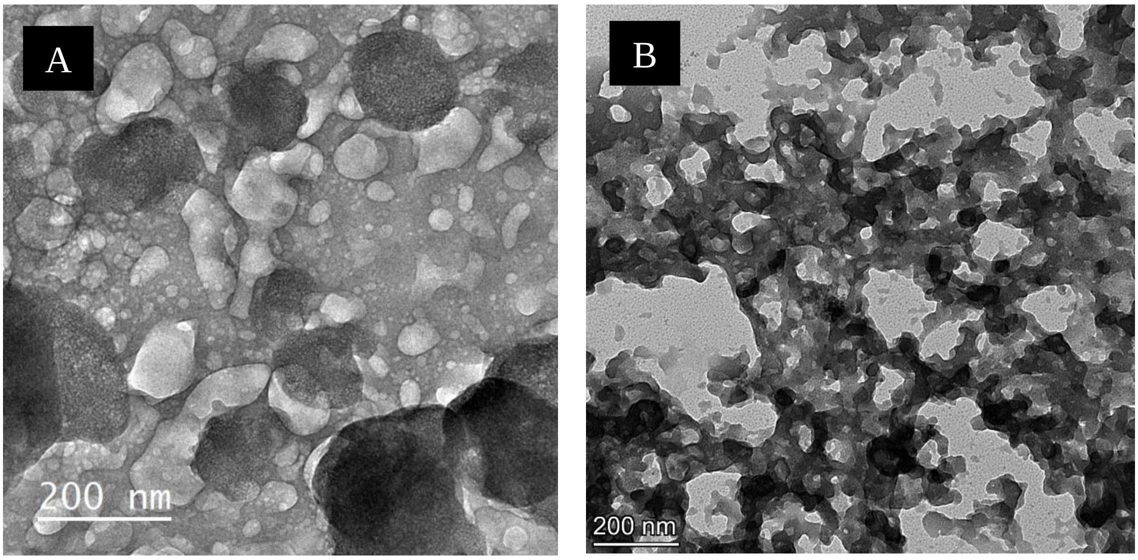


Fig. 3. TEM imaging of nano- NPK (A) and nano-micronutrients (B).

2.3 Vegetation parameters

The following data was recorded in the first week of July during the both seasons of 2021 and 2022, at the end of the experimental seasons including plant height, branches number/plant, fresh and dry of aerial parts/plant, leaves number/plant, leaf area. Root growth traits as root length, fresh and dry weight. Flowering parameters such as days to flowering, inflorescences number and florets number / inflorescences.

The leaf disc method was used to determine the leaf area. Twenty leaf discs per replicate were collected using a volumetric ring with an internal diameter of 2.5 cm (4.9 cm^2). After being placed in paper bags, the replicated leaf discs were dried in a forced-air oven set at 65°C until they reached a consistent weight. The area of the plant's leaves was calculated using the leaf disc area and the dry weight values, according to Equation:

$$Leaf\ area = \frac{DA\ \times LDW}{DDW/N}$$

Where:

LA: leaf area, cm^2

DA: leaf disc area, cm^2

LDW: leaf dry weight, g

DDW: leaf disc dry weight, g

N: number of discs used in the replicate.

2.4 Chlorophyll content estimation

The chlorophyll concentration was determined by adding 20 ml of 80% acetone, 1 g of leaf tissue, and 0.5 gram of ($MgCO_3$) powder, all of which were gently ground. For 3 h, the mixture was kept at 4ºC for incubation. The centrifugation at 2500 rpm for 5 minutes, the supernatant was transferred to a 100 ml volumetric flask, and the volume was brought up to 100 ml with the addition of 80% acetone. The solution was used to estimate chlorophyll a and b (Chl. a and Chl. b), as per the following equation according to (Rajalakshmi and Banu 2015):

Chlorophyll a (mg/g f.w.): [12.7 (A 663) −2.69 (A.645)] * V/ 1000*W

Chlorophyll b (mg/g f.w.): [22.9 (A 645)-4.68 (A663)] * V/1000* W

A = Absorbance of specific wavelength.

V = final volume of chlorophyll extract in 80% acetone.

W = fresh weight of leaves extract.

2.5. Total carotenoids estimation

Following the methodology outlined by Sumanta et al. (2014), the total concentration of carotenoids was determined using the same chlorophyll extract as measured at 470 nm in a spectrophotometer (Jenway 6405, the UK), as follows:

Total carotenoids (mg/g fw) = (1000A470 - 1.82 Chl. a – 85.02Chl. b)/198

Flowers' total carotenoids were extracted using Ranganna (1986) technique. A known weight of fresh Tecoma flowers, were weighed and then finely pulverized in acetone using a mill and pestle until the residue was colorless. A conical flask was used to collect the acetone extract. The carotenoid pigments were separated using a separating funnel. After moving the carotenoid extract to a separating funnel, 10% Na_2SO_4 was added along with petroleum ether. To separate the carotenoid layer, swirl the funnel. Volumetric flasks held the collected separated carotenoids. The procedure was repeated until the extract had no more color. The absorbance was measured spectrophotometrically at 452 nm. The following formula was used to estimate the total carotenoids.

$$\textbf{Total carotenoids } (\boldsymbol{mg/100g\ F.W\ basis}) = \frac{3.87\ x\ absorbance\ (452\ nm)\ x\ volume\ make\ up\ x\ dilution\ factor\ x\ 100}{weight\ of\ sample\ (g)\ x\ 1000}$$

2.6 Membrane stability index

In accordance with Sairam et al. (1997), the membrane stability index was ascertained. Two sets of test tubes, each containing 10 ml of distilled water, were used to collect 200 mg of leaf disks. The electrical conductivity (C1) of one pair was measured after 30 minutes of being heated in a water bath to 40ºC. The electrical conductivity (C2) of the second group was measured after incubation at 100ºC for 15 minutes. membrane stability index was determined using the following formula:

Membrane stability index (%) = (1- C1/C2) ×100

2.7 Leaf water status (RWC)

After the fresh weight of the young leaves (FW) was determined, they were submerged in distilled water for 24 hours in Petri dishes. Following the leaves' water saturation, the turgid weight (TW) was determined. The leaves were weighted after being dried at 70°C to a consistent weight (DW). The following formula, published by (Hanson AD 1982), was used to compute the relative water contents (RWC) of leaves:

RWC= (FW.DW) / (TW.DW) × 100.

2.8 Leaf chemical composition

Nitrogen (N), phosphorus (P), and potassium (K) content of the dried leaves were determined by digesting 0.2 gm of the leaves according to (Peterburgski 1968). Then, the Kjeldahl device, a spectrophotometer (Jenway 6405), and a flame photometer (Jenway PFP7, Staffordshire, UK) were used to measure the N, P, and K, respectively (Mertens 2005).

2.9. Ascertaining the activity of enzymes

Leaves (0.3 g) were soaked in liquid nitrogen, 2 mL of homogenized medium was added, and the mixture was centrifuged at 12,000×g for 15 minutes at 4 °C to prepare the crude enzymatic extracts used to evaluate catalase and peroxidase activity. The following items made up the homogenization media: For the enzymes CAT, POX: 50 mM potassium phosphate buffer, pH 7.0, 1 mM ascorbate, and 1 mM EDTA (Nakano and Asada 1981), (Peixoto et al. 1999)

A reaction solution containing 50 mM potassium phosphate buffer at pH 7.0 and 12.5 mM H2O2 was mixed with 2.9 mL of enzymatic extract to measure the catalase (EC 1.11.1.6) activity (Havir and McHale 1987). At 25 °C, the absorbance began to decrease at 240 nm after one minute of reaction. According to (Anderson et al. 1995), the enzymatic activity was determined by utilizing a molar extinction value of 36 mol L^{-1} cm^{-1} and expressed as μmol of H_2O_2 min^{-1} mg^{-1} Fw. Using a spectrophotometer (Jenway 6405).

The purpurogallin production rate at 420 nm was used to measure the POX activity (EC 1.11.1.7) using the molar extinction coefficient of 2.47 $mmol^{-1}$ L cm^{-1}, as suggested by Nakano and Asada (1981). The measure used to express the enzymatic activity was μmol purpurogallin $min^{-1}g^{-1}$ Fw (Chance and Maehly 1955).

2.10 Statistical analyses

ANOVA was used to statically analyze the data using the Costate program (Version 6.303, Co Hort, USA, 1998–2004)]. The mean was compared at the P ≤ 0.05% probability level using Duncan's multiple range test (Duncan 1955). according to

(Gomez and Gomez 1984), the average mean of the two independent seasons ±SE was displayed as the result.

3. Results

3.1 Vegetative characteristics

Table (1) shows that compared to the control treatment (traditional NPK 3 g/l), all nano-NPK and nano-NPK plus nano-micronutrient treatments considerably increased vegetative growth traits such as plant height, branches number/plant, fresh and dry weights of aerial parts, leaf number/plant, and leaf area. Treatment with 2 ml/l of nano-NPK plus 1.5 ml/l of nano mix micro-nutrients produced the most statistically significant results for the aforementioned parameters, followed by treatment with 2 ml/l of nano-NPK plus 1 ml/l of nano mix micro-elements. While there were no statistically significant changes in the number of branches number/plant, the other treatments often produced much lower results.

Table 1. Effect of foliar application of nano NPK and nano micronutrients fertilizer on vegetative growth traits of *Tecoma stans* (average of 2021 and 2022 seasons).

Treatments	Plant height (cm)	Branches number plant^{-1}	Aerial parts/plant (g)		Leaf area, cm^2	Leaves number plant^{-1}
			Fresh weight	Dry weight		
T1: Control (NPK at 3 g L^{-1})	168.69f	6.17b	187.56g	58.38g	438.78g	81.17d
T2: Nano- NPK (1 ppm)	186.69e	6.50b	216.11f	67.74f	450.98f	91.00cd
T3: Nano- NPK (2 ppm)	190.73d	6.67b	228.37e	73.20e	466.75e	101.67bcd
T4: Nano- NPK (3 ppm)	193.63d	6.83b	246.74d	81.98d	477.22d	105.17bcd
T5: Nano-NPK (2 ppm) + n-MNs (0.5 ppm)	202.36c	7.33b	276.30c	92.27c	507.35c	126.17bc
T6: Nano-NPK (2 ppm) + n-MNs (1.0 ppm)	215.26b	7.83ab	305.58b	105.16b	533.12b	132.83ab
T7: Nano-NPK (2 ppm) + n-MNs (1.5 ppm)	250.82a	10.00a	414.94a	130.54a	601.63a	168.50a
F-test	**	*	**	**	**	**

Mean followed by the same letter in the same column had no significantly by Duncan's multiple (p<5%)
Nano-micronutrients (n-MNs).

3.2 Root growth characteristics

Data in **Table (2)** revealed that all nano NPK and nano NPK plus nano-micronutrients treatments significantly increased root length and fresh and dry weights of roots compared to the control treatment which listed the least parameters for these traits. The highest values of root length and fresh and dry weights of roots were resulted from the treatment of nano NPK at 2 ml/l plus nano-micronutrients at 1.5 ml/l, followed by treatment nano NPK at 2 ml plus nano-micronutrient at 1 ml/l. However, the remainder nano fertilizer treatments scored significantly less values. Also, the results cleared that adding nano-micronutrients at the different rates to nano NPK at 2 ml/l led to an increase in the root parameters, the highest increase rates in these traits were resulted from treatment of nano NPK at 2 ml/l plus nano-micronutrients at rate 1.5 ml/l as listed 56.590/% for root length; 129.67% for root fresh weight and 197.09% for dry weight as compared to the control treatment.

Table 2. Effect of foliar application of NPK-NPs and nano-micronutrients fertilizer on root growth parameters of *Tecoma stans* (average of 2021 and 2022 seasons).

Treatments	Root length (cm)	Root fresh weight (g)	Roots dry weight (g)
T1: Control (NPK at 3 g L^{-1})	26.47g	62.61g	18.24g
T2: Nano- NPK (1 ppm)	28.11f	65.93f	21.55f
T3: Nano- NPK (2 ppm)	29.28e	71.95e	23.56e
T4: Nano- NPK (3 ppm)	30.65d	85.54d	27.47d
T5: Nano-NPK (2 ppm) + n-MNs (0.5 ppm)	32.28c	94.55c	32.11c
T6: Nano-NPK (2 ppm) + n-MNs (1.0 ppm)	34.11b	98.40b	35.30b
T7: Nano-NPK (2 ppm) + n-MNs (1.5 ppm)	41.45a	143.80a	54.19a
F-test	**	**	**

Mean followed by the same letter in the same column had no significantly by Duncan's multiple (p<5%)
Nano-micronutrients (**n-MNs)**

3.3 Flowering parameters

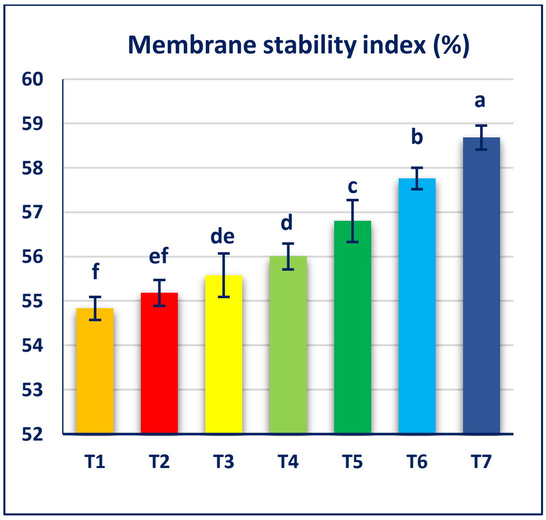
The data displayed in **Table (3)** unmistakably demonstrate that spraying Tecoma plants with nano-NPK and nano-micronutrients fertilizers improved the flowering characteristics (number of days from planting to flowering, inflorescences number/plant, and florets number/ inflorescences) in comparison to the control treatment.

comparing days to Flowering with the control treatment, which was listed as 154 days, the treatment of nano-NPK at 2 ml/l plus nano-micronutrients at 1.5 ml/l resulted in the highest reduction in the time from the planting date until the appearance of the first inflorescences, at 138.83 and 146 days, respectively. The results of the other treatments were moderate. The highest mean values for the two traits were obtained by foliar applying nano NPK at a rate of 2 ml/l with nano-micronutrients at 1.5 ml/l. This was observed in the mean of inflorescence number / plant and florets number / inflorescence. Using nano-NPK at 2 ml/l plus nano-micronutrients at 1 ml/l produced the next significant values, while the other treatments showed intermediate results for the number of inflorescences per plant and the number of florets per inflorescence. The findings demonstrated that these parameters were increased with using NPK at 2 ml/l plus nano-micronutrients at 1.5 ml/l. Specifically, there was an increase in the number of inflorescences per plant of 114.88% and in the number of florets per inflorescence of 60.82% as compared to the control treatment.

Table 3. Effect of foliar application of NPK NPs and nano-micronutrients fertilizer on flowering parameters of *Tecoma stans* (average of 2021 and 2022 seasons).

Treatments	Days to flowering	No. of inflorescences	No. of florets per inflorescence
T1: Control (NPK at 3 g L^{-1})	154.00a	4.50c	8.50e
T2: Nano- NPK (1 ppm)	151.83ab	5.00c	8.83de
T3: Nano- NPK (2 ppm)	151.33ab	5.50c	9.50de
T4: Nano- NPK (3 ppm)	150.83ab	5.33c	10.00cd
T5: Nano-NPK (2 ppm) + n-MNs (0.5 ppm)	148.33ab	6.83b	11.00bc
T6: Nano-NPK (2 ppm) + n-MNs (1.0 ppm)	146.00b	7.17b	11.67b
T7: Nano-NPK (2 ppm) + n-MNs (1.5 ppm)	138.83c	9.67a	13.67a
F-test	*	*	**

Mean followed by the same letter in the same column had no significantly by Duncan's multiple (p<5%)
Nano-micronutrents (n-MNs).



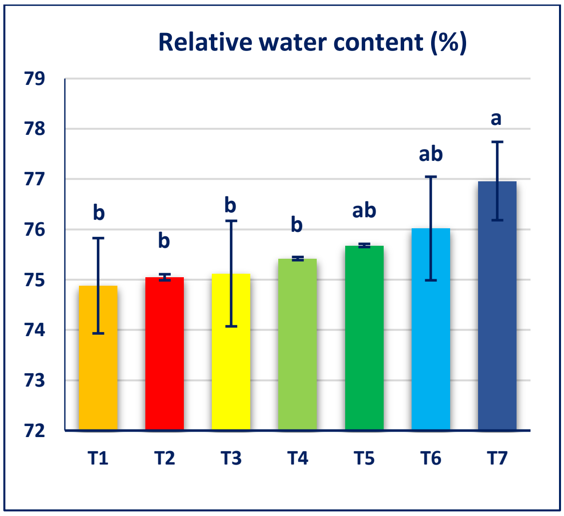


Fig. 4. Effect of foliar application of NPK NPs and nano-micronutrients fertilizer on membrane stability index% (A), relative water content% (B) Bars represented as mean ± SE (average of 2021 and 2022).

T1: Control; T2: Nano-NPK 1 ppm; T3: Nano-NPK 2 ppm; T4: Nano-NPK 3 ppm; T5: Nano-NPK 2 ppm + nMNs 0.5 ppm; T6: nano-NPK 2 ppm + n-MNs 1 ppm and T7: Nano-NPK 2 ppm + n-MNs 1.5 ppm

3.4 Membrane stability index and relative water content

The obtained data in **Figure (4)** cleared that all used nano fertilizer treatments increased the traits of membrane stability index and RWC parameters compared the control treatment. The highest significant values for these traits were resulted from the treatment of nano NPK at rate 2 ml/l plus nano-micronutrients at 1.5 ml/l, while the lowest value was observed with the control treatment.

3.5 Photosynthetic pigments

Figure (5) demonstrats that, with exception for the low level of nano NPK 3 ml/l which listed lowest value of leaves chlorophyll a, b, total carotenoids and total carotenoids in the flowers, all nano NPK levels and nano NPK at 2 ml/l plus nano-micronutrients treatment significantly increased mentioned parameters compared to the control treatment. Resulted from the treatment of nano NPK at rate of 2 ml/l plus nano-micronutrients at 1.5 ml/l followed by treatment of nano NPK at 2 ml/l plus nano-micronutrients at 1 ml/l scored the highest significant for these traits. The other treatments recorded significantly less values. The highest increase rates in these traits were 35.55% for chlorophyll a; 45.24 for chlorophyll b; 52.90% for total carotenoids of leaves and 14.81% for total carotenoids in the flowers as compared to the control treatment**.**

3.6 Leaf chemical composition

All of the nano fertilizer treatments considerably raised the content nitrogen, phosphorus, and potassium in the Tecoma leaves compared to the control treatment or conventional NPK fertilizer (Table 4). The control treatment had the lowest percentage of all three mineral elements, while treatments involving 2 ml/l of nano-NPK plus 1.5 ml/l of nano-micronutrients yielded the highest percentages. Then came treatments involving 2 ml/l of nano NPK plus 1 ml/l of nano-micronutrients. There was a marked decrease in values for the other treatments.

3.7 Antioxidant activity

The results shown in **Figure (6)** for catalase and peroxidase activities show that all applied treatments improved the up-regulation of enzyme activities in Tecoma plant leaves. When comparing the treatment of nano NPK at 2 ml/l plus nano-micronutrients at 1.5 ml/l to the control treatment, the treatment of nano NPK at 2 ml/l plus nano-micronutrients at 1 ml/l produced the significantly highest activity. There was noticeably less action with the other treatments listed. The rate of increase in the activities were seen for peroxidase (34.88%) and catalase (53.25%) with the treatment of nano NPK at 2 ml/l plus nano-micronutrients at 1.5 ml/l.

4. Discussion

Tecoma, with its yearly bright yellow trumpet-shaped blooms and year-round attractive leaves, is often utilized for landscape beautification as a hedge, specimen shrub, and over highway road dividers because of its drought-tolerant and robust nature (Singh et al. 2024).

Because of their tiny size and huge surface area, nano-fertilizers improve the absorption surface, which in turn increases the rate of photosynthesis and the creation of active compounds in plants. This is only one of many advantages of utilizing these fertilizers (Singh and Prasad 2017; Shalaby et al. 2022a). One possible explanation for this could be that its small particle size gives it a wide surface area, which in turn expands the effective area of the reaction and boosts enzyme efficiency. This, in turn, increases the number of biochemical reactions, which in turn increases the number of cell divisions (Zhao et al. 2023; Haydar et al. 2024).

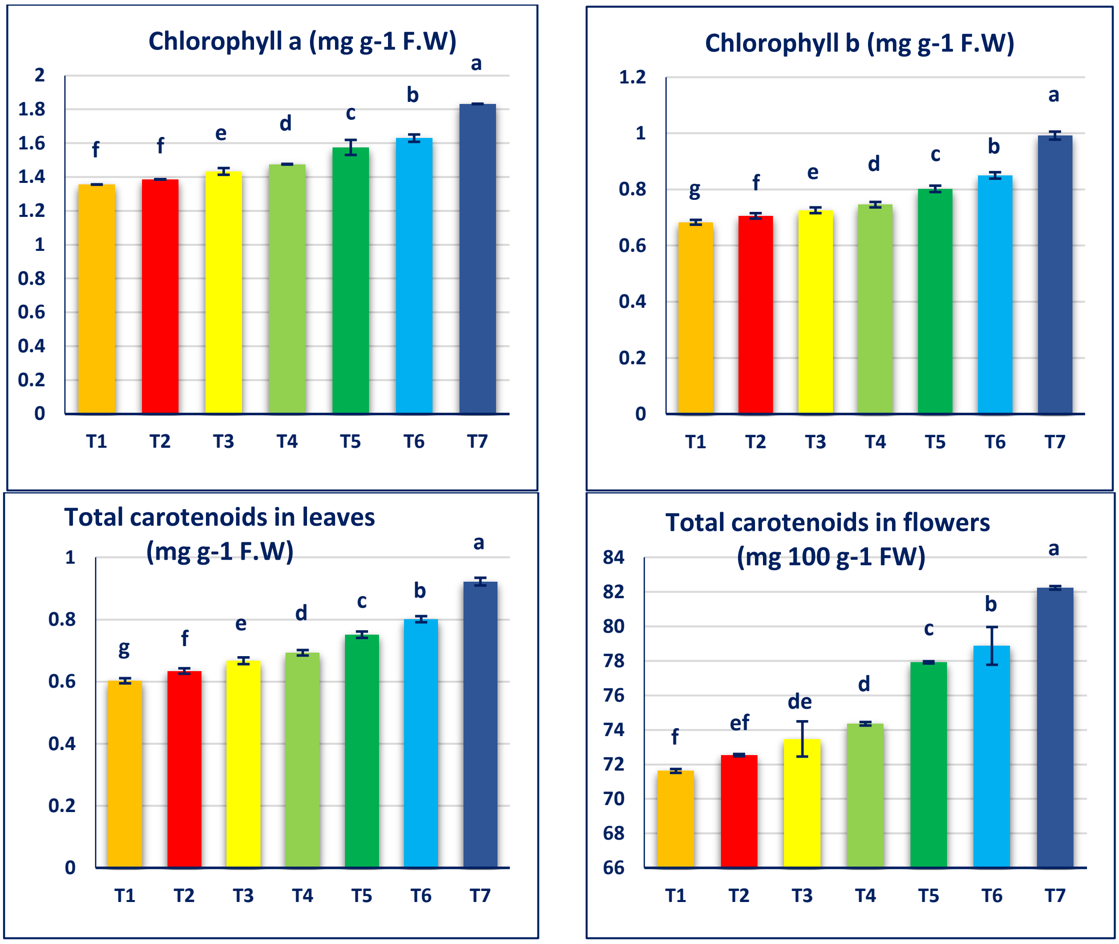


Fig. 5. Effect of foliar application of NPK NPs and nano-micronutrients fertilizer on pigment contents mg/g. f.w. of *Tecoma stans* plants as chl a (a), chl b (b), carotenoids (c) and total carotenoids in the flowers (D) Bars represented as mean ± SE (average of 2021 and 2022)

T1: Control; T2: Nano-NPK 1 ppm; T3: Nano-NPK 2 ppm; T4: Nano-NPK 3 ppm; T5: Nano-NPK 2 ppm + nMNs 0.5 ppm; T6: nano-NPK 2 ppm + n-MNs 1 ppm and T7: Nano-NPK 2 ppm + n-MNs 1.5 ppm

Table 4. Effect of foliar application of NPK NPs and nano-micronutrients fertilizer on leaves mineral N, P and K (%) of *Tecoma stans* (average of 2021 and 2022 seasons).

Treatments	N (%)	P (%)	K (%)
T1: Control (NPK at 3 g L^{-1})	3.19f	0.435f	2.34f
T2: Nano- NPK (1 ppm)	3.26e	0.442e	2.40e
T3: Nano- NPK (2 ppm)	3.32d	0.446e	2.44de
T4: Nano- NPK (3 ppm)	3.35d	0.452d	2.50d
T5: Nano-NPK (2 ppm) + n-MNs (0.5 ppm)	3.45c	0.463c	2.62c
T6: Nano-NPK (2 ppm) + n-MNs (1.0 ppm)	3.55b	0.471b	2.72b
T7: Nano-NPK (2 ppm) + n-MNs (1.5 ppm)	3.82a	0.497a	2.95a
F-test	**	**	**

Mean followed by the same letter in the same column had no significantly by Duncan's multiple (p<5%)
Nano-micronutrients (**n-MNs)**

The present investigation found that all treatments with nano fertilizer had a positive impact on the growth of Tecoma as well as on chemical and physiological parameters. The stimulative effect on the various vegetative growth metrics may be the primary explanation for the beneficial effects of NPK-fertilizer treatments. When there is an improvement in vegetative development, it should be evident in the different components of flowering. One possible interpretation is that nitrogen plays a crucial role in the synthesis of numerous critical plant chemicals and molecules, including RNA, DNA, enzymes, amino acids, chlorophyll, and necessary for plant growth (Liu et al. 2014; Khalil et al. 2016). Numerous plant physiological activities rely on phosphorus, including energy storage, photosynthesis, cell expansion, and cell division. Phosphorus is an essential building block of numerous biochemicals, including nucleotides, phospholipids, sugar phosphate, nucleic acids (DNA, RNA), and coenzymes as well as promotes root growth (Nofal et al. 2021). Potassium plays a crucial role in several biological processes, including photosynthesis, nitrogen metabolism, sugar translocation, enzyme activation, stomatal opening, and meristatic tissue growth (Sarhan et al. 2022).

Plants can't expand or mature without micronutrients. Micronutrients perform an essential function in many plant processes, including metabolism, nutrition, reproductive growth regulation, chlorophyll synthesis, carbohydrate biosynthesis, and more (Rahman et al. 2020). Micronutrients nanoparticles such as (6% Fe, 6% Zn, 2% B, 5% Mn, 1% Cu, and 0.01% Mo 0.1%) caused a significant increase in the fennel plant's total phosphorus and chlorophyll content (Abdelkader et al. 2019). According to Singh et al. (2023), the increased production and translocation of photosynthates to various plant parts by these nanoparticles results in a higher rate of photosynthesis and chlorophyll content. Additionally, because of their larger surface area than traditional fertilizers, nanoparticles are absorbed more efficiently, improving the vegetative as well as other flowering and fruiting attributes of the plant. Al-Hamad et al. (2022) reported that spraying broccoli with nano-microelements (1% zinc, 9% iron, and 1% manganese) at 1.5 ml L^{-1} significantly and favorably affected the protein, carbs, NPK (%) and overall plant yield in addition to the active chemicals, which include flavonoids and phenols. Furthermore, 150 mg L^{-1} of Fe-NPs produced the highest result of carotenoid and total chlorophyll content, according to El-Shawa et al. (2022) research on philodendron plants. Additionally, the greatest findings for enzyme activity (catalase and peroxidase) were obtained with Zinc-NPs at 200 mg L^{-1}.

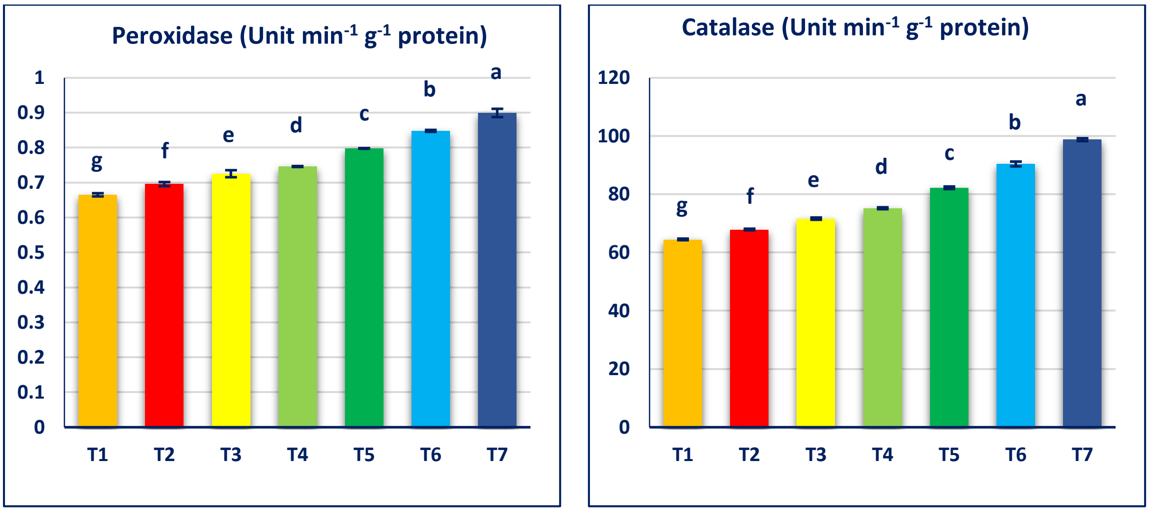


Fig. 6. Effect of foliar application of NPK-NPs and nano-micronutrients fertilizer on antioxidant activity of *Tecoma stans* plants as peroxidase (A) and catalase activity (B). Bars as mean ± SE (average of 2021 and 2022)

T1: Control; T2: Nano-NPK 1 ppm; T3: Nano-NPK 2 ppm; T4: Nano-NPK 3 ppm; T5: Nano-NPK 2 ppm + nMNs 0.5 ppm; T6: nano-NPK 2 ppm + n-MNs 1 ppm and T7: Nano-NPK 2 ppm + n-MNs 1.5 ppm

By applying nanotechnology and nano-fertilizers (NFs), the agricultural industry has seen the introduction of healthier alternatives. These novel NFs increase the effectiveness of nutrient consumption by utilizing the extraordinary qualities of nanoparticles, which vary in size from 1 to 100 nm. NFs, in contrast to their traditional equivalents, have a number of benefits, such as variable solubility, reliable and efficient performance, regulated release mechanisms, improved targeted activity, less ecotoxicity, and simple, secure delivery and disposal processes (**Figure 7**). NFs effectively save nutrients that might otherwise go to waste by allowing rapid and thorough plant absorption, hence reducing possible environmental harm (Channab et al. 2024).

Applied nano-NPK fertilizers were investigated on different ornamental seedlings under different stresses like soil salinity or normal (non-stressful) conditions. The main factors are controlling this impact can be presented in **Table 5**. Salinity stress can reduce many physiological parameters, but applied nano-NPK can promote this effect. It could notice from **Table 5** that improving studied parameters by increasing applied dose of nano-NPK fertilizer under both stressful and nno-stressfull conditions.

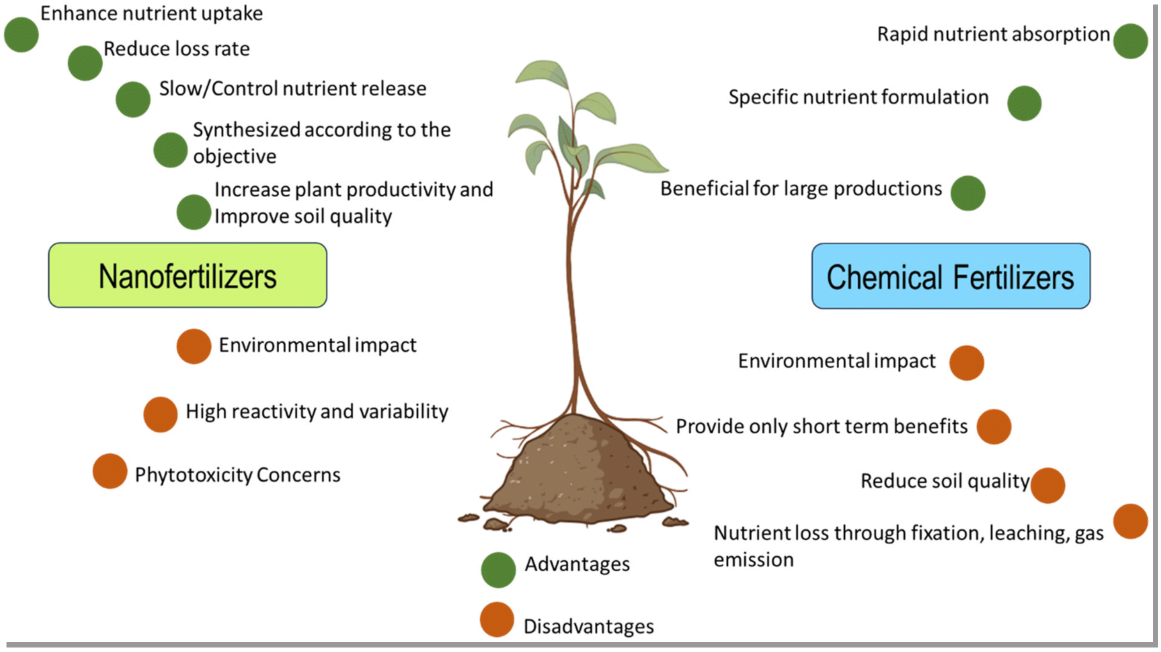


Fig. 7. A comparison between chemical and nano-fertilizers.

Table 5. Impacts of applied nano-NPK on ornamental seedlings under different conditions.

Seedling species	Nano-NPK dose	N, P, K content in leaves (%)	Ch.a ($mg\ g^{-1}$)	Ch. b ($mg\ g^{-1}$)	Carot. ($mg\ g^{-1}$)	POX (unit)	CAT (unit)	Ref.
I. Under non-saline soil conditions (1.75 dS m^{-1}); nano-NPK fertilizer size was 317.9 and 274.2 nm, resp.								
Tecoma stans L.	1.0 ppm	3.26, 0.43, 2.40	1.386	0.706	0.634f	0.696	67.88	[1]
	2.0 ppm	3.32, 0.44, 2.44	1.433	0.726	0.667	0.725	71.64	
	3.0 ppm	3.35, 0.45, 2.50	1.475	0.746	0.693	0.746	75.21	
Phyllodendron	1.0 ppm	3.55, 0.49, 2.45	1.198	0.572	0.352	0.738	74.46	[2]
sellum L.	2.0 ppm	3.75, 0.51, 2.60	1.368	0.639	0.377	0.809	81.47	
	3.0 ppm	3.92, 0.53, 2.73	1.539	0.708	0.406	0.925	93.72	
II. Under soil salinity stress (4.5 dS m^{-1}); size of nano-NPK fertilizer was 308 nm								
Khaya	1.0 ppm	2.12, 0.49, 1.33	1.03	0.41	0.28	0.69	25.19	[3]
senegalensis L.	2.0 ppm	2.27, 0.51, 1.46	1.07	0.43	0.31	0.75	26.12	
	3.0 ppm	2.21, 0.50, 1.42	1.07	0.42	0.30	0.71	25.60	
Kigelia africana	1.0 ppm	3.1, 0.52, 2.8	1.73	0.81	0.25	0.65	25.22	[4]
(Lam.) Benth	2.0 ppm	3.8, 0.54, 3.5	1.79	0.98	0.26	0.85	27.12	
	3.0 ppm	3.5, 0.53, 3.3	1.74	0.83	0.28	0.73	25.69	

Refs. [1] Current study, [2] Nofal et al. (2024c), [3] Nofal et al. (2024a), [4] Nofal et al. (2024b). Carotenoids: Cart.; Catalase (CAT, µmol of H_2O_2 min^{-1} mg^{-1} fw), Peroxidase (POX, µmol of H_2O_2 min^{-1} mg^{-1} fw)

5. Conclusion

Its attractive foliage and recurrent, trumpet-shaped flowers make Tecoma a popular choice for hedges, shrub specimens, and even as a road divider over highways. The most favorable results in terms of morphological, biochemical, and physiological parameters were achieved when a mixture of nano-NPK fertilizer (2 ml L^{-1}) and nano-micronutrient (1.5 ml L^{-1}) was applied at intervals of 15 days during the growth season. Among these factors were the leaf's nutrient content, photosynthetic pigments, catalase, and peroxidase activity. Enzymatic antioxidants and nutrients that were bioavailable helped this system be oxidatively resistant. To fill in the gaps in our understanding of this significant ornamental crop, additional researches is required.

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