RESEARCH PAPER

Effect of Plant Growth Regulators and Micro-Elements (Nano-Oxides) on The Growth, Chemical Content, and Active Compounds of Aloe vera L. Plants

Israa Jameel Yaseen[1], Hiba Ezzat Hamed[2], Assist. Prof Awatif Abed Ibrahim Al-Ani[3], Zainab Riadh Abduljabbar Al-Sharea[4], Khalid Ibrahim Adwan[5], Abdelhadi Adam Salih Denei[1], Reem Mohammed Azeez[6], Aws Abdulhussein Shakir[7], Prof Dr. Firas Aziz Rahi[8], Shailaja Pashikanti[1], Prof. Dr. Jameel Yaseen Ali Altememy[9*]

[1]Department of Pharmaceutical Technology, A.U. College of Pharmaceutical Sciences, Andhra University, Visakhapatnam, 530003, India.
[2]Department of Pharmaceutical Chemistry, College of Pharmacy, Al-Nisour University, Baghdad,10001, Iraq.
[3]Department of Pharmaceutical Chemistry, College of Pharmacy, Al-Iraqia Science University, Baghdad,10001, Iraq.
[4]College of Pharmacy, Al-Nisour University, Baghdad,10001, Iraq.
[5]Department of Pharmacology and Toxicology, College of Pharmacy, Al-Nisour University, Baghdad,10001, Iraq.
[6]Department of Biochemistry, College of Pharmacy, Al-Nisour University, Baghdad,10001, Iraq.
[7]Department of Pharmacognosy, College of Pharmacy, Al-Nisour University, Baghdad,10001, Iraq.
[8]Head of Department, College of pharmacy, Al-Mansour University College, Baghdad,10001, Iraq.
[9*]Professor of Medicinal Plant Physiology, Head of Department Pharmaceutical Chemistry and Pharmacognosy, College of Pharmacy, Al-Nisour University, Baghdad,10001, Iraq, Email: jameelyaseenalialtememy@gmail.com

Abstract

This study was conducted in the wooden canopy at Tikrit University, Salahaddin Governorate, Iraq, on Aloe vera plants. It aimed to show the effect of spraying the plant with plant growth regulators and micronutrients (nano-oxides) on the growth, chemical content, and active compounds of Aloe vera L. plants over a 2024 season.

A factorial experiment was carried out included two factors: The first was a plant growth regulation at three treatments (PO with no spraying, Pi spraying, of 100 mg.L-1 IAA, P2 spray of 100 mg.L-1 GA3). The second factor is spraying Micro-element Nono-oxides mixture at 3 levels (To with no nano oxide, T1 spraying the mixture at a low concentration of 50 mg.L-1 Fe, 25 mg.L-1 Cu, 25 mg.L-1 Zn, 5 mg.L-1 B) and T2 spraying Nano oxide with a high mixture concentration of 100 mg.L-1 Fe, 50 mg.L-1 Cu, 50 mg.L-1 Zn, 10 mg.L-1 B).

The experiment was carried out according to the Randomized Complete Block Design (RCBD) with three replications and the treatments were compared according to Duncan's Multiple Range Test at a probability level of 5%. The most important results were summarized as follows:

A. The vegetative growth characteristics of Aloe vera plants which were sprayed with plant growth regulators or nano-oxides differed significantly and positively from those of unsprayed plants. The interaction between plant growth regulators and micro-element nano-oxides was significant. The Aloe vera plants sprayed with 100 mg. L-1 GA3+ high concentration of Nano-Oxide mixtur of Fe, Cu, Zn and B produced the highest values of vegetative growth characteristics. Therefore, the plant had the highest leaves No. (2.59), leaf thickness (2.71 cm), plant height (38.1 cm), chlorophyll concentration (46.24 SPAD), dry weight (14.39 gm) and carbohydrate percentage (11.87%) compared to the lowest values for the above-mentioned traits for the control plants.

B. When plant growth regulator and nano-oxides of micro-nutrients were sprayed, the highest significant differences in the means of all macro and micro elements content trait in the leaves appeared compared to the lowest values for the a bove mentioned trails of the control plants for the interaction treatments p2T2 (spraying with 100 mg/L-1 of GA3+ high concentration of nano-oxide mixture of Fe, Cu, Zn, B). The highest concentration of N (2.16%), P (0.360%), K (2.13%), Fe (48.60 mg.kg-1), Cu (8.30 mg/kg), Zn (11.50 mg.kg-1), and B (7.60 mg.kg-1). Compare to the lowest concentration of the above-mentioned traits of the control treatment.

C. The interaction between plant growth regulator and nano-oxide was significant. Aloe vera plants sprayed with 100 GA3+ high concentration of nano-oxide produced a high concentration of phenolic compounds (cinnam 0.094 µg.mg-1 and Aloin 0.379 $^{-10}$ µg.mg-1). Plants sprayed with high concentration of nano-oxide produced only the highest concentration of Aloenodin (0.132 µg.mg-1). A plants sprayed with 100 mg.L-1 GA3+ produced only the highest concentration of barbolin compound (0.350 µg.mg^{-1}) and anthnanol phenolic compound (0.213 µg.mg^{-1}). Compared to the lowest concentration of these 5 phenolic compounds in the control plants.

Keywords: Aloe vera, nano zinc oxide, alkaline, flavonoid, vegetative growth characteristics

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Introduction

Aloe vera L. is a plant belonging to the Amaryllidaceae family (Abu Zaid, 2000). It grows in Africa and spreads to many regions of the world. It is also characterized by large, fleshy, succulent, lanceolate leaves with serrated margins.

Historical records indicate that humans have known the therapeutic properties of Aloe vera for 5,000 years, and it has been used to maintain health. It is a glycoside, and Aloe is used to stimulate the production of fibrous cells in the skin, which are responsible for collagen production (Heggers et al., 1996).

It is known that ancient civilizations used Aloe vera 4,000 years ago, and this is confirmed by medical documents (Atherton, 1998). It is also known as a medicinal plant, and it is widely used in treating skin diseases (Grover, 2001) in treating burns and inflammation (Jyotsan et al., 2009) and it is used to help in cancer treatment (Fenig et al., 2004) and liver cancer (Kuo et al., 2002). There are different types of Aloe; some are used as food, and others are used as antibacterial, for treating skin, burns, and acne, and for treating skin abrasions and burns. Aloe is also used in the production of creams and cosmetics to moisturize the skin and treat many skin problems. The therapeutic and industrial uses of medicinal plants require high quality of essential oils and their active ingredients. Plants need micronutrients, whether in their natural state or nano-state, as they are chemically rich. In particular, micronutrients improve the growth and development of medicinal plants, and their deficiency leads to a lack of necessary micronutrients for plant cells, which affects the plant's health and growth and helps in overcoming plant difficulties, improving their properties, and increasing the production of essential oils and medicinal compounds (Al-Bayati et al., 2012). The mechanism of action of micronutrients is due to their chemical and physical properties. They differ from other elements in terms of surface area and effect (Naghibi et al., 2022). Their small size increases their efficiency as they are absorbed by the plant. They lead to an increase in the rate of chemical reactions (Habib et al., 2022). New studies on nanotechnology have shown positive changes in medicinal plants, such as increasing the size and concentration of active compounds, which is reflected in increased efficacy and increased production of essential oils (Khodakovskaya et al., 2012). A study by (Habib et al., 2022) dealt with the interaction between nanotechnology and medicinal plants, leading to a change in the plant's chemical composition. This leads to biological pathways that affect the growth and capability of the plant. Researchers are studying the effect of nano-elements on plants, as it is considered one of the important methods for increasing the active compounds and components in plants. They play a role in the synthesis of carbohydrates and proteins, which are important for plant cells and are involved in the processes of metabolism and secondary plant processes (Al-Sahaf et al., 1989). Regarding copper, it is one of the important chemical elements. Sulfides, mineral carbonates, and chelates are the best mineral sources that can be easily absorbed by the plant. It is used as a cofactor for enzymes and helps in the synthesis of plant nutrients and improving the main properties of the plant (Abu Naqta, 2004). Copper also acts as an activator for enzymes (Al-Sahaf et al., 1989). It is essential in the synthesis of indole acetic acid (IAA) (Al-Tememe and Al-Douri et al., 2012). Studies have shown that micronutrients interact with plant cells by acting as catalysts for various reactions within the plant, directly contributing to the synthesis of medicinal compounds in these plants. Most studies on nano-elements confirm their importance in plant growth and chemical composition (Abbass and Abu Qumra, 2010). A study by (Aldujaili, 1996) stated that adding iron helps improve the content of growth regulators and increase the nutritional elements. Talaat and (Al-Tememe, 1998) stated that adding micronutrients to plants has a positive effect on the plant's chemical content, which is reflected in improvement of growth traits. This leads to an increase in the absorption of elements and their accumulation within the plants. Active materials are some of the natural plant products (secondary compounds).

(Abu-Nuqta et al., 2004) showed that iron leads to an increase in active compounds in plants. Also, (Al-Tememe and Aldouri, 2012) found an increase in active compounds in Apium graveolens L. plants. Adding micronutrients also affects plant growth of plants, their chemical content, and active ingredients (Al-Tememe and Al-dulaimi, 2014). Plants were treated with a mixture of IAA and GA3, and a mixture of micronutrients (Fe, Zn, Cu, B), where there was a positive effect of all these treatments on growth traits and increased chemical content. The addition of these elements and growth regulators helps in improving the plant's growth and increasing its chemical and active content.

2. Materials and Methods:

This study was conducted in Alath house in the Department of Horticulture, College of Agriculture, Tikrit University/ Iraq, during the 2022 season on Aloe vera plant as a plastic pots experiment with a diameter of 30cm filled with a soil mixture (peatmoss and sandy soil) in a 1:3 ratio. The plant seedling 10 cm high were planted in the pots.

The experiment followed a Randomized Complete Block Design (RCBD) with a factorial experiment consisting of two factors:

Nano-nutrients (T) three levels were used:

- T0 (sprayed with distilled water),
- T1 (low concentration of a mixture of nano-oxides of Fe50mg.L-1, Cu25mg.L-1, Zn25mg.L-1, and B5mg.L-1).
- T2 (High concentration of Mixture of Nano-oxides of Fe100mg.L-1, Cu50mg.L-1, Zn50mg.L-1, B10mg.L-1).

. Plant growth regulators (P) Three treatments were used:

- P0 (sprayed with distilled water).
- P1 (sprayed with 100mg.L-1 of IAA).
- P2 (sprayed with 100mg.L-1 of GA3).

There are 9 treatments from the factorial Combination-ion (Txp):

P0T0, POT1, P0T2, P1T0, P1T1, P1T2, P2T0, P2T0, P2T1, P2T2.
All data were subjected to statistical analysis and treatment means were compared using Duncuan's Multiple Range Test at the probability level of 5%.
The measurements were taken one month after the second spray expiration and at the end of the experiment.

2.1. Growth characteristics:

2.1.1 Leaf Number, plant-1.
2.1.2. Leaf Width (thickness) cm.
2.1.3. Plant height cm.
2.1.4. Chlorophyll Content (SPAD).
2.1.5. Plant Dry weight gm.
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2.1.6. Carbohydrate's percent in leaves.

2.2. Chemical Content:

2.2.1. Nitrogen concentration (N%) using Micro Kjeldahl apparatus.
2.2.2. Phosphorus concentration (P%) using spectrophotometer apparatus.
2.2.3. Potassium concentration (K%) using Flame photometer apparatus.
2.2.4. Micro Nutrient Concentration (Fe, Cu, Zn, B mg.kg-1) using Atomic absorption spectrophotometer apparatus (Al-Sahaf, 1989).

Samples prepared for chemical analysis recording to (Al-Sahaf, 1989), plant samples were dried in an oven. at 65-70°C for 48-72 hours and ground into fine powder and 0.2gm was placed in apyrex tube, 2ml of concentrated sulfuric acid was added. Samples were left overnight. A mixture of 2 ml + 2 ml of sulfuric acid and perochloric acid was prepared. The samples were then placed in a digestion hood at 450°C for 1.5-2 hours until the sample turned clear. Next, the samples were placed in a conical flask (100 ml) and the volume was completed with a distilled water. Analysis was then performed using the apparatus.
Active compounds:

Samples were prepared by taking 10 g of fresh Aloe vera matter and measured in a college of Medicine laboratory using an HPLC apparatus to measure a phenolic active compound concentration

Table (1): Chromatographic separation conditions (HPLC)

Column	**Condition / parameter**
Column	HD Reversed-phase column (50 * 4.6 mm)
Mobile Phase	70: 30 Ethanol : water (v/v)
Mobile Phase Flow Rate	2 mL/min
Injection Volume	3ml
Detector Type	UV detector at a wavelength of 280 nm
Temperature	30 C°
Chart Speed	2 cm/min

Results and Discussion:
Table (2): Effect of plant growth regulators and Nano-Oxides of Micro element and their interaction on the Vegetative Growth of Aloe vera L. Plant.

Vegetative Characteristic / Treatments	**Leaves no. plant-1**	**Leaf thickness cm**	**Plant high cm**	**Chlorophyll concentration (SPAD)**	**Dry weight**	**% Carbohydrates**

P0	C 13.3	B 1.60	bM 26.9	B 36.36	B 12.62	B 7.31
P1	B 19.3	A 2.17	A 32.4	A 41.27	Ab 13.35	B 8.31
P2	A 2.27	A 2.48	A 35.8	A 43.32	A 13.74	B 10.36
T0	B 1.57	B 1.66	B 26.6	B 35.66	C 12.03	B 7.33
T1	Ab 1.85	A 2.13	A 32.7	A 41.25	B 13.51	B 8.99
T2	A 2.11	A 2.46	A 35.9	A 44.04	A 14.17	A 9.66
P0T0	H 1.16	F 2.22	H 22.4	H 31.40	F 11.25	G 6.38
P0T1	G 1.30	E 1.49	G 26.1	F 37.15	D 12.65	E 7.67
P0T2	Fe 1.52	Bc 2.10	E 32.3	D 40.55	C 13.97	E 7.89
P1T0	C 1.71	E 1.69	g 27.5	G 36.20	E 12.10	F 7.10
P1T1	D 1.85	B 2.24	D 34.0	C 42.26	C 13.80	D 8.61
P1T2	C 2.22	A 2.59	C 35.9	A 45.35	B 14.15	C 9.22
P2T0	D 1.84	C 2.06	F 24.9	E 39.40	D 12.75	D 8.52
P2T1	B 2.39	A 2.67	B 34.5	B 44.34	B 14.09	B 10.71
P2T2	A 2.59	A 2.71	A 38.1	A 46.24	A 14.39	A 11.87

* The letter above the numbers means No. significant differences between them upon experimental Duncun's multiple range test on probability level 5%.

Table (2) shows that spraying with plant growth regulators and a nano-element mixture caused significant increases in all vegetative growth compared with the characteristics of Aloe vera plants not sprayed with these substances. Table (2) also shows that the interaction between plant growth regulators and nano-elements was significant. Aloe plants sprayed with 100 mg.L-1 of GA3 + the highest concentration of nano-oxide of microelements (100 mg.L-1 Fe + 50mg.L-1 Cu + 50mg.L-1 Zn + 10 mg.L-1 B) produced higher values of all vegetative growth of Aloe plants (leaf height No. 25.9), (leaf thickness 2.71 cm), (plant height, 38.1 cm), (chlorophyll concentration, 46.24 SPAD), (Dry weight, 14.39 gm), and (carbohydrate percentage, 11.57%) compared with other treatment and control plants which alowes values of All these Vegetative Growth Characteristics (11.6 leaf plant), (lowest leaf thickness, 2.22 cm), (lowest plant height, 22.4 cm), (lowest chlorophyll concentration, 31.40 SPAD), (dry weight, 11.5 gm), and carbohydrate percentage (6.38%).

Table (3): Effect of plant growth regulators and Nano-Elements and their interactions on the content of macro and micro elements in Aloe vera L. plant.

Vegetative Characteristics / Treatments	N%	P%	K%	Fe mg.kg-1	Cu mg.kg-1	Zn mg.kg-1	B mg.kg-1
P0	C 1.55	B 0.230	C 1.59	C 30.53	C 4.36	C 6.76	B 5.52
P1	B 1.87	A 0.280	B 1.83	B 34.90	B 6.07	B 8.18	A 6.67
P2	A 2.07	A 0.320	A 2.02	A 41.46	A 7.46	A 10.46	A 6.90
T0	B 1.58	B 0.240	B 1.65	C 30.56	B 4.76	B 7.50	B 5.50
T1	A 1.87	B 0.270	A 1.84	B 35.50	A 6.24	Ab 8.60	A 6.65
T2	A 2.03	A 0.310	A 1.95	A 40.83	A 6.90	A 9.32	A 6.94
P0T0	F 1.25	G 0.190	F 1.45	E 28.10	H 3.30	E 6.50	D 4.72
P0T1	E 1.60	F 0.230	E 1.61	D 30.20	G 4.20	E 6.80	C 5.82
P0T2	D 1.80	D 0.280	D 1.72	C 33.30	E 5.60	E 7.00	C 6.04
P1T0	E 1.65	E 0.260	E 1.62	D 29.40	F 4.80	E 6.80	C 5.90
P1T1	C 1.91	C 0.290	C 1.89	C 34.70	C 6.63	D 8.30	B 6.45
P1T2	B 2.05	B 0.300	Bc1.99	B 40.60	C 6.80	C 9.46	B 7.16
P2T0	D 1.86	C 0.290	C 1.89	C 34.20	D 6.20	C 9.20	C 5.90
P2T1	B 2.11	B 0.310	B 2.04	B 41.60	B 7.90	B10.70	B 7.20
P2T2	A 2.16	A 0.360	A 2.13	A 48.60	A 8.30	a11.50	A 7.62

The letter above the numbers means No. significant differences between them upon excremental Duncun's multiple range test on probability level 5%.

Table (3) shows the effect of plant growth regulators and non-oxidants of (Fe, Cu, Zn, B) and their effects on the concentration of macro and micro elements in Aloe vera. Spraying with plant growth regulators caused a significant effect on the content of these elements compared with no spraying treatment. Non-oxidants of micro elements also caused appositive significant effects on the concentration of these elements compared with no-sprayed plants.

Table (3) shows that the interaction between these two factors is significant. The plant Sprayed with 100mg.L-1 of GA3+ the highest concentration of nano-oxides mixture (Fe, Cu, Zn, B) + gave the highest concentrations of (N, 2.167%), (P, 0.360%), (K, 2.13%), (Fe, 48.60 mg.kg-1)
(Cu 8.30 mg.kg-1), (Zn 11.50 mg.kg-1), (B 7.62 mg/kg-1). Compared with the lowest concentration of the seven (Macro and Micro nutrients), (N, 1.25%), (P, 0.190%), (K, 145%) and (Fe, 28.16mg.kg-1), (Cu, 3.30 mg.kg-1), (Zn, 6.50 mg.kg-1), and (B, 4.72 mg.kg-1).

Factors	%P
P0	0.23
P1	0.28
P2	0.32
T0	0.24
T1	0.27
T2	0.31
P0T0	0.19
P0T1	0.23
P0T2	0.28
P1T0	0.26
P1T1	0.29
P1T2	0.3
P2T0	0.29
P2T1	0.31
P2T2	0.36

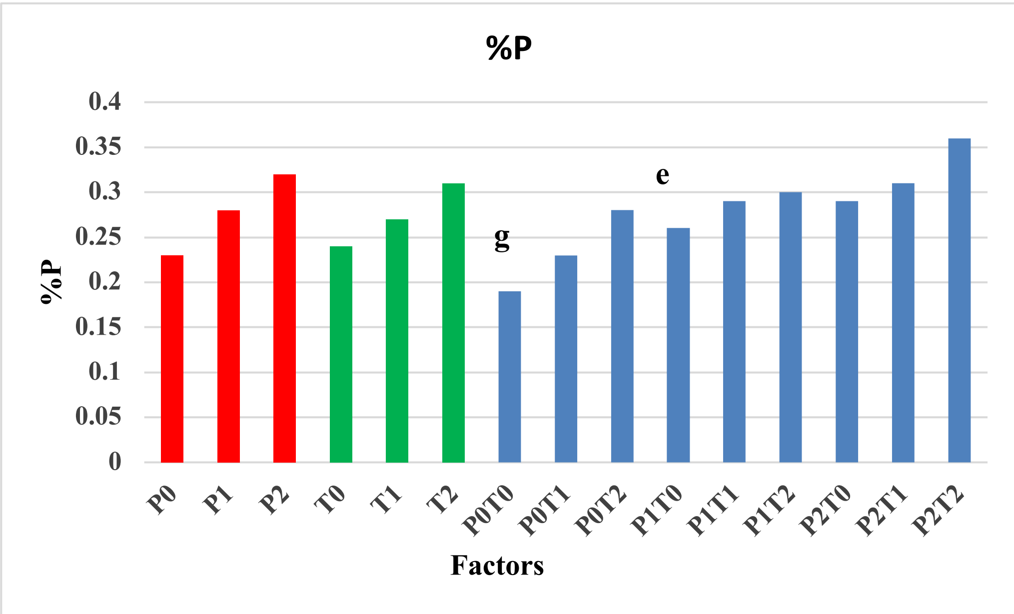
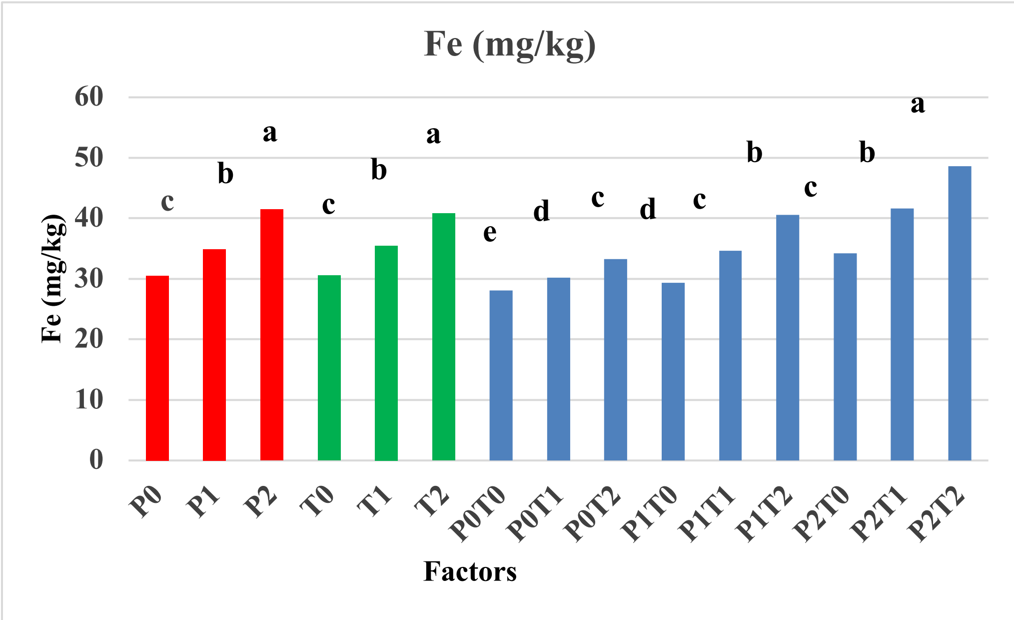


Fig. (1) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro elements (Fe, Cu, Zn, B) and their interactions on phosphorous concentration (%P) of Aloe vera plants.

*The letters above the columns means there are No. significant variation as Duncun's Multiple range test at 5% probability.

Factors	Fe (mg/kg)
P0	30.53
P1	34.9
P2	41.46
T0	30.56
T1	35.5
T2	40.83
P0T0	28.1
P0T1	30.2
P0T2	33.3
P1T0	29.4
P1T1	34.7
P1T2	40.6
P2T0	34.2
P2T1	41.6

P2T2	48.6



*The letters above the columns means there are No. significant variation as Duncun's Multiple range test at 5% probability.

Fig. (2) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro eleme (Fe, Cu, Zn, B) and their interactions on Iron concentration (%Fe) of Aloe vera plants.

Factors	Cu (mg/kg)
P0	4.36
P1	6.07
P2	7.46
T0	4.76
T1	6.24
T2	6.9
P0T0	3.3
P0T1	4.2
P0T2	5.6
P1T0	4.8
P1T1	6.63
P1T2	6.8
P2T0	6.2
P2T1	7.9
P2T2	8.3

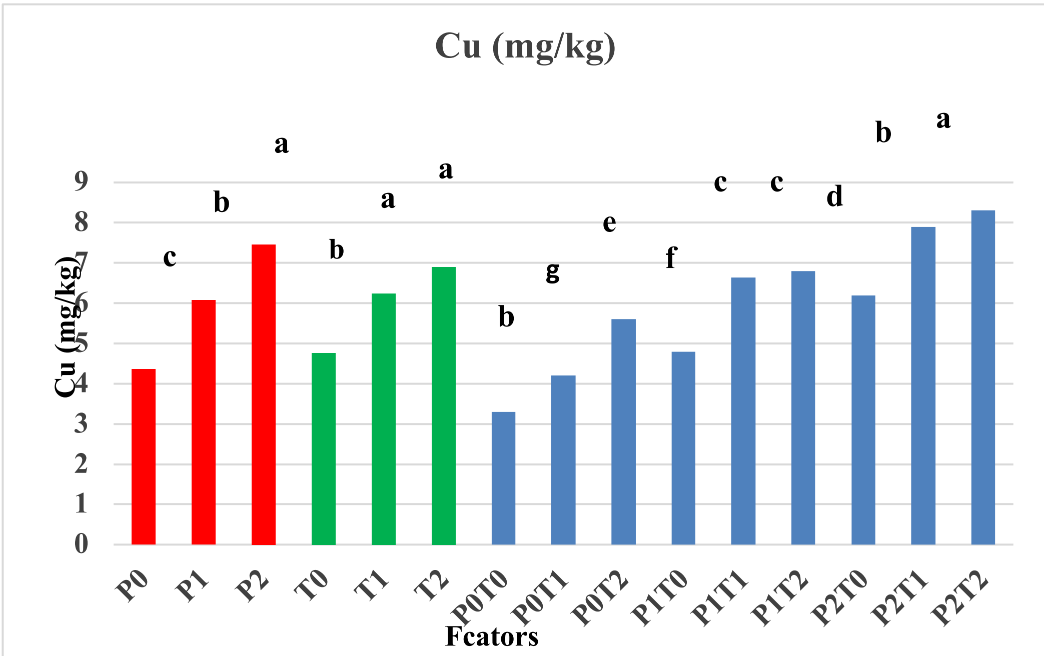


Fig. (3) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro elements (Fe, Cu, Zn, B) and their interactions on copper concentration (%Cu) of Aloe vera plants.

The letters above the columns

means there are No. significant variation as Duncun's Multiple range test at 5% probability.

Factors	Zn (mg/kg)
P0	6.76
P1	8.18
P2	10.46
T0	7.5
T1	8.6
T2	9.32
P0T0	6.5
P0T1	6.8
P0T2	7
P1T0	6.8
P1T1	8.3
P1T2	9.46
P2T0	9.2
P2T1	10.7
P2T2	11.5

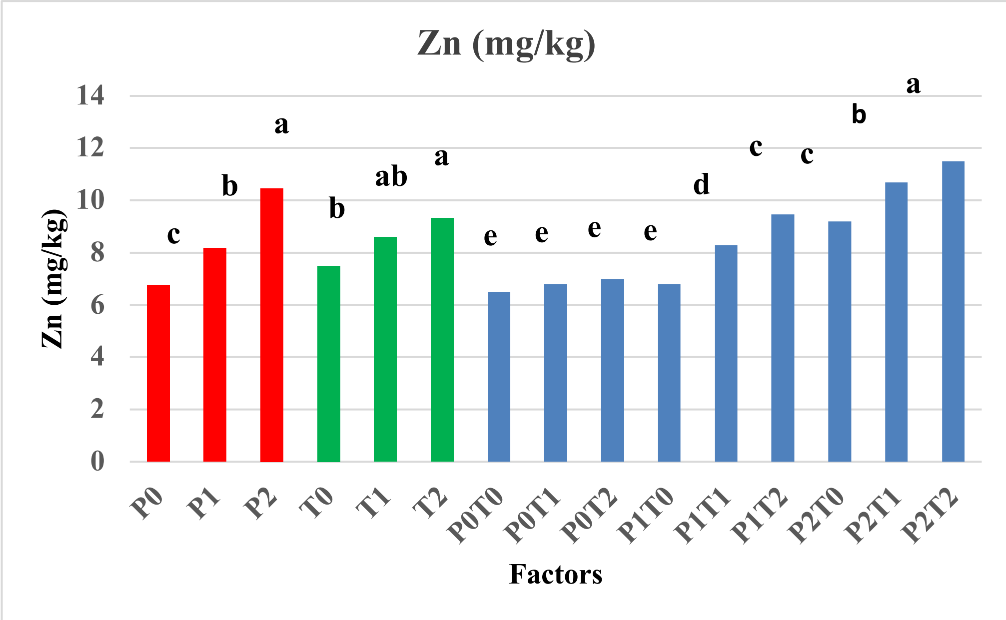


Fig. (4) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro elements (Fe, Cu, Zn, B) and their interactions on Zinc concentration (%Zn) of Aloe vera plants.

*The letters above the columns means there are No. significant variation as Duncun's Multiple range test at 5% probability.

Factors	B (mg/kg)
P0	5.52
P1	6.67
P2	6.9
T0	5.5
T1	6.65
T2	6.94
P0T0	4.72
P0T1	5.02
P0T2	6.04
P1T0	5.9
P1T1	6.45
P1T2	7.16
P2T0	5.9
P2T1	7.2
P0	1.59
P2T2	7.62

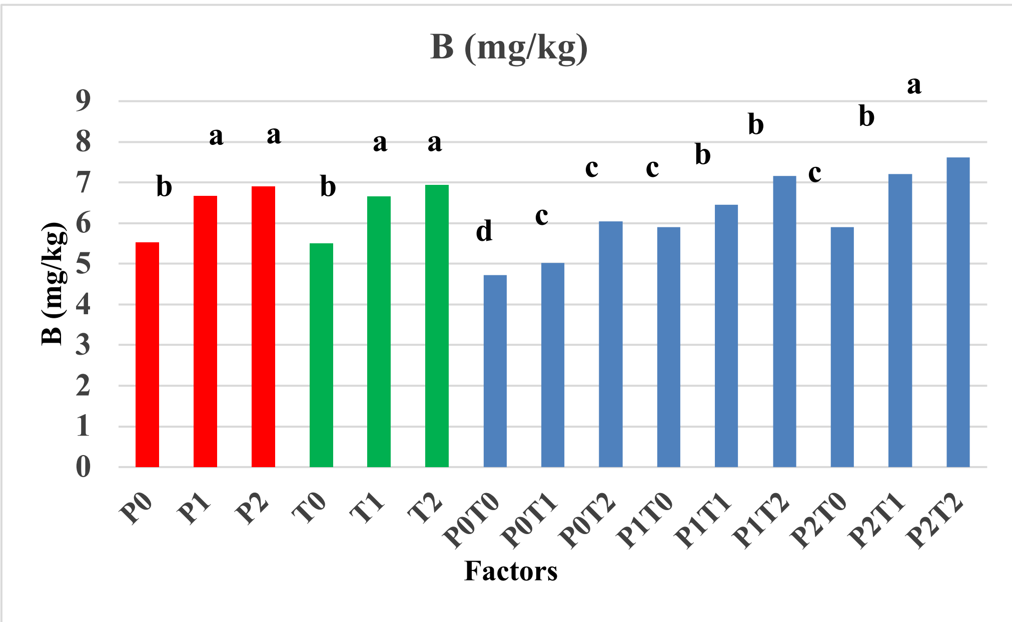
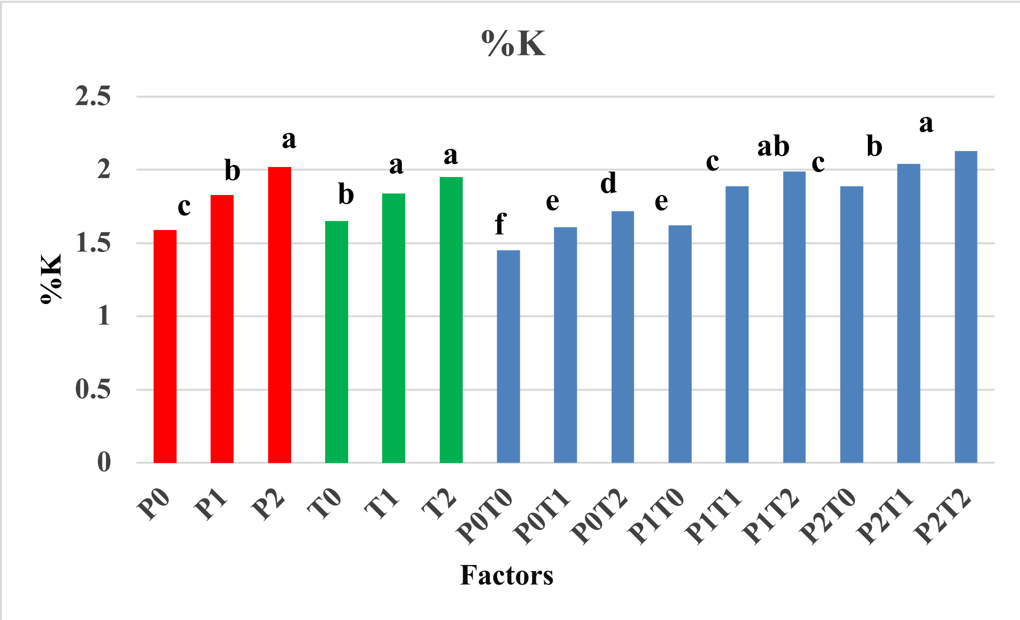


Fig. (5) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro elements (Fe, Cu, Zn, B) and their interactions on Boron concentration (%B) of Aloe vera plants.

Factors	%K

*The letters above the columns means there are No. significant variation as Duncun's Multiple range test at 5% probability

P1	1.83
P2	2.02
T0	1.65
T1	1.84
T2	1.95
P0T0	1.45
P0T1	1.61
P0T2	1.72
P1T0	1.62
P1T1	1.89
P1T2	1.99
P2T0	1.89
P2T1	2.04
P2T2	2.13



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probability.

Fig. (6) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro elements (Fe, Cu, Zn, B) and their interactions on Potassium concentration (%K) of Aloe vera plants.

Factors	N%
P0	1.55
P1	1.87
P2	2.07
T0	1.58
T1	1.87
T2	2.03
P0T0	1.25
P0T1	1.6
P0T2	1.8
P1T0	1.65
P1T1	1.91
P1T2	2.05
P2T0	1.86
P2T1	2.11
P2T2	2.26

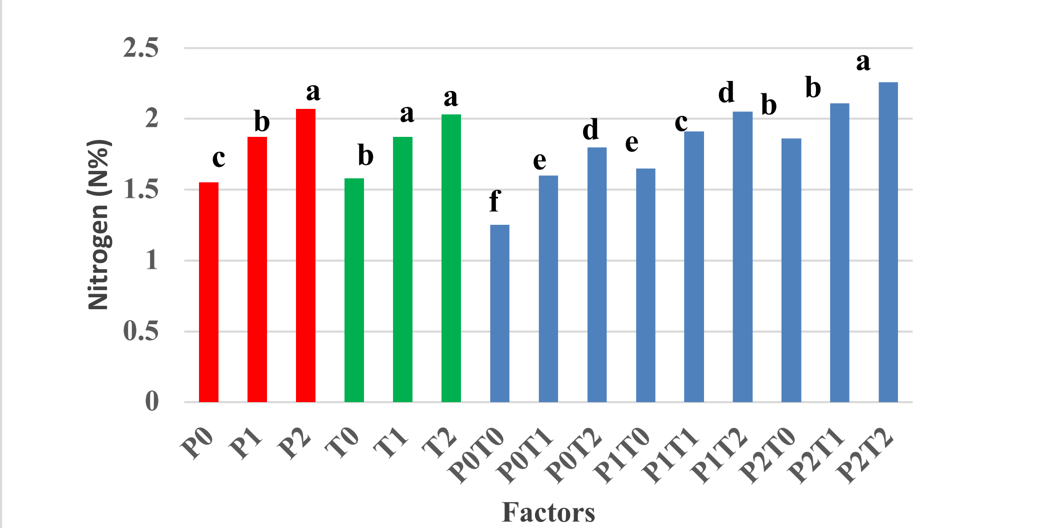


Fig. (7) Effect of plant growth regulators (IAA, GA3) and mixture of Nano-Micro elements (Fe, Cu, Zn, B) and their interactions on Nitrogen concentration (%N) of Aloe vera plants.

* The letters above the columns means there are No. significant variation as Duncun's Multiple range test at 5% probability.

Table (4): Effect of plant growth regulator (IAA, GA3) and Nano-Elements (Fe, Cu, Zn and B) on the concentration of phenolic compounds of Alo vera L. plant.

Active Compounds / Treatments	Apigenin	Crocin	Caffeine
P0T0	0.001	0.515	0.005
P0T1	0.032	0.298	0.144
P0T2	0.264	0.616	0.264
P1T0	0.039	0.160	0.200
P1T1	0.414	1.205	0.252
P1T2	0.522	56.326	0.241
P2T0	-	-	1.212
P2T1	0.051	1.269	0.041
P2T2	0.419	146.424	1.138

Tab. (4) Shows the interactive effect of foliar application of a mixture of secondary oxide nanoparticles of micronutrients and plant growth regulators on the concentration of active alkaloid compounds in Alo vera. The result indicate that plants treated with IAA at a concentration of (100mg.L-1) combined with the high concentration of the nano-micronutrient oxide mixture (P1T1) produced the highest concentration of the alkaloid compound Apogenin (0.522 µg.mg-1) compared with all other treatments. In contrast, the control treatment (without spraying) recorded the lowest concentration of this compound (0.001 µg.mg-1).

Treatment P2T2 resulted in the highest concentrations of the alkaloid compounds Crocin (146.424 µg.mg-1) and Caffeine (1.138 µg.mg-1) compared with the other treatment. Conversely, treatment P1T0 recorded the lowest concentration of Crocin (0.160 µg.mg-1, while the control treatment showed the lowest concentration of Caffeine (0.005 µg.mg-1).

Table (5): Effect of interaction treatment between Nano-oxides and plant growth regulators of the flavonoid compound of Aloe vera plant.

Vegetative Characteristics / Treatments	Tannic acid	Safron	Quercetin	Rutin	Kaempferol	Gallic acid	3-4 Dimethoxy benzyl alcohol
P0	0.290	0.127	6.001	5.853	1.288	0.076	0.003
P1	1.064	2.657	0.357	3.267	1.915	0.122	0.022

P2	1.185	4.253	0.608	0.082	-	-	-
T0	0.014	0.078	0.878	2.709	10.121	1.786	0.165
T1	0.093	0.052	0.018	1.751	0.009	8.33	
T2	0.074	0.220	0.536	3.707	1.425	0.176	0.021
P0T0	0.006	0.193	5.873	4.114	12.980	0.316	0.023
P0T1	0.008	0.450	0.113	0.622	0.451	0.173	0.498
P0T2	0.482	0.142	1.515	12.247	20.297	4.452	0.752

Table (5) illustrates the interactive effect of nano-oxide treatment and plant growth regulators on the concentration of flavonoid compounds in Alo vera. The results demonstrate that treatment P0T2 produced the highest concentration of the flavonoid Tannic acid, reaching (1.185 µg.mg-1).

Treatment P0T2 also recorded a concentration of (4.253Mfg.mg), compared with the other treatment. Meanwhile, the control treatment outperformed all other treatment by recording the highest concentration of the flavonoid compound Quercetin (6.001 µg.mg-1), indicating a negative effect of the interaction between the treatments on reducing the concentration of this compound in the plant.

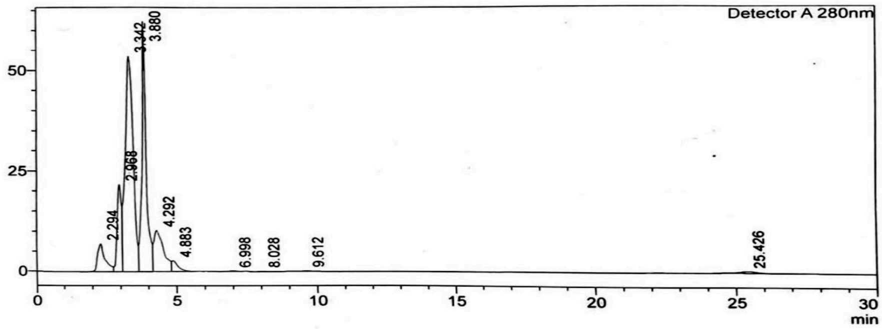
Treatment P2T2 resulted in the highest concentration of the flavonoid compounds Rutin (12.247Mg.mg-1), Kaempferol (20.297 µg.mg-1), and Dimethoxybenzyl alcohol (0.752 µg.mg-1), compared with the other treatments. In contrast, treatment P1T1 recorded the highest concentration of Gallic acid (8.33 µg.mg-1) compared with the other treatments.

These results indicate the positive effect of nano-oxides and plant growth regulators on the accumulation and concentration of flavonoid compounds in Aloe vera plants.

Fig. (8): Aleo vera plants used in the experiment

Tables Showing Retention Time, Peak Area, Concentration, and Dilution Factor of Some Bioactive Compounds in Interacted Aloe vera L. Treatments.

Factor P0T0:

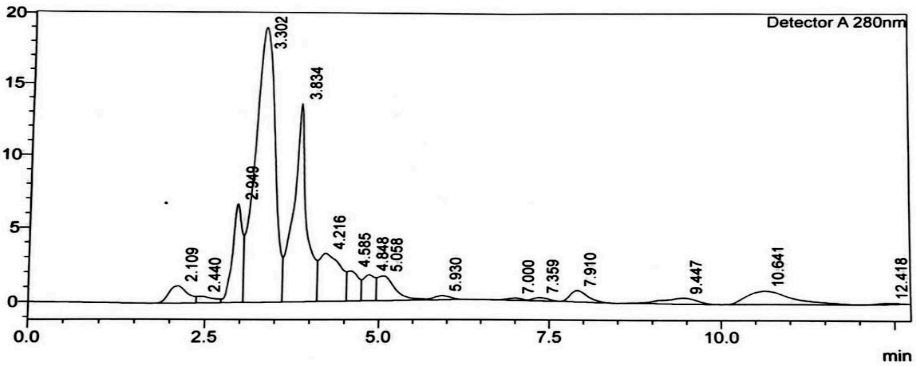


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1.	2.294	133795	25	2		Tannic acid
2.	2.968	241075	25	2	V	Safron
3.	3.342	1073926	25	2	V	Quercetin
4.	3.880	661407	25	2	V	Rutin
5.	4.292	252668	25	2	V	Kaempferol
6.	4.883	43146	25	2	V	Gallic acid
7.	6.998	3364	25	2		3.4 Dimethoxybenzyl alcohol
8.	8.028	1646	25	2		Caffeine
9.	9.612	3545	25	2		Crocin
10.	25.426	16125	25	2		Apigenin
Total		2430698				

Factor P0T1:

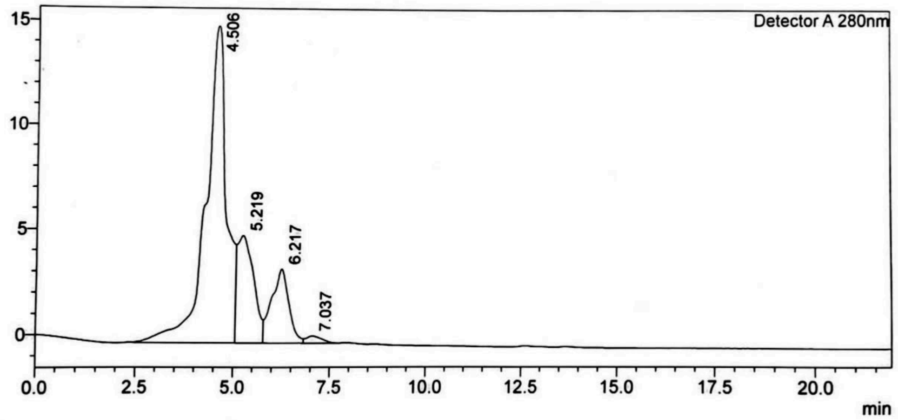


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	2.109	21572	25	2		Tannic acid
2	2.440	7230	25	2	V	Safron
3	2.949	64006	25	2	V	Quercetin
4	3.302	369183	25	2	V	Rutin
5	3.834	179498	25	2	V	Kaempferol
6	4.216	69799	25	2	V	Gallic acid
7	4.585	23355	25	2	V	3.4 Dimethoxybenzyl alcohol
8	4.848	20904	25	2	V	Caffeine
9	5.058	29540	25	2	V	Crocin
10	5.930	4670	25	2	V	Apigenin
Total		789757				

Factor P0T2:

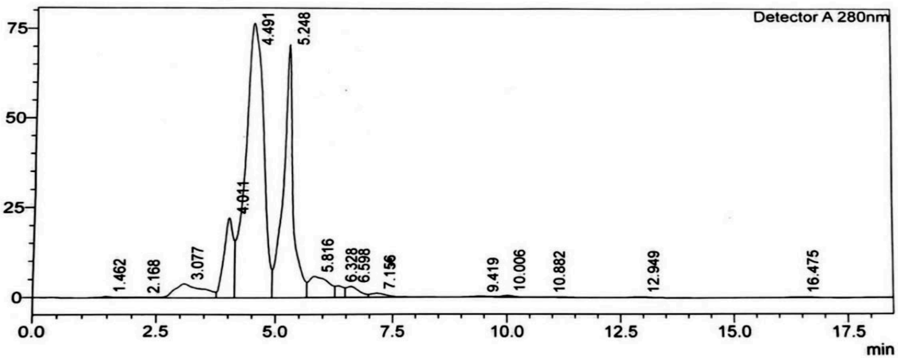


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	4.506	546300	25	2	V	Tannic acid
2	5.219	150654	25	2	V	Safron
3	6.217	108898	25	2	V	Quercetin
4	7.037	9312	25	2	V	Rutin
Total		815165				

Factor P1T0:

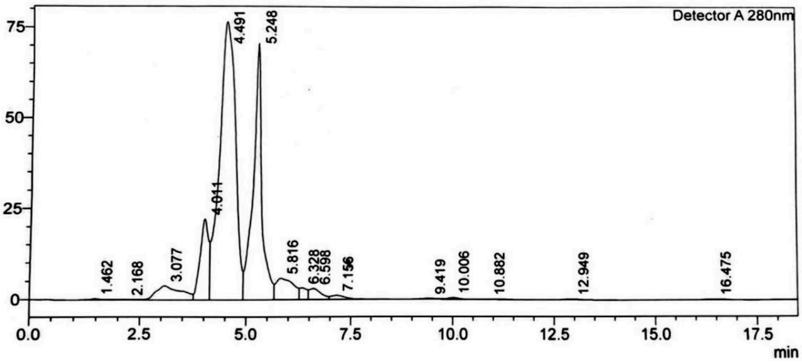


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	1.462	6708	25	2		Tannic acid
2	2.168	4445	25	2	V	Safron
3	3.077	157162	25	2	V	Quercetin
4	4.011	306155	25	2	V	Rutin
5	4.491	1983935	25	2	V	Kaempferol
6	5.248	1014334	25	2	V	Gallic acid
7	5.816	168605	25	2	V	3.4 Dimethoxybenzyl alcohol
8	6.328	38278	25	2	V	Caffeine
9	6.598	59214	25	2	V	Crocin
10	7.156	26584	25	2	V	Apigenin
Total		3712130				

Factor P1T1:



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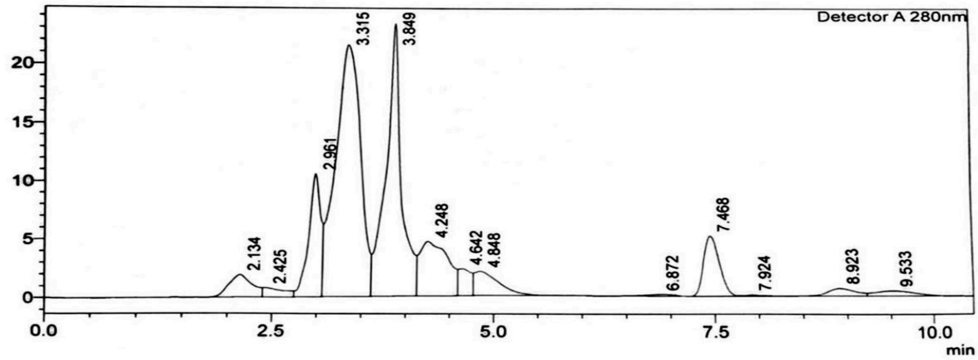
Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	1.462	6708	25	2		Tannic acid
2	2.168	4445	25	2	V	Safron
3	3.077	157162	25	2	V	Quercetin
4	4.011	306155	25	2	V	Rutin
5	4.491	1983935	25	2	V	Kaempferol
6	5.248	1014334	25	2	V	Gallic acid
7	5.816	168605	25	2	V	3.4 Dimethoxybenzyl alcohol
8	6.328	38278	25	2	V	Caffeine
9	6.598	59214	25	2	V	Crocin
10	7.156	26584	25	2	V	Apigenin
Total		3712130				

Factor P1T2:

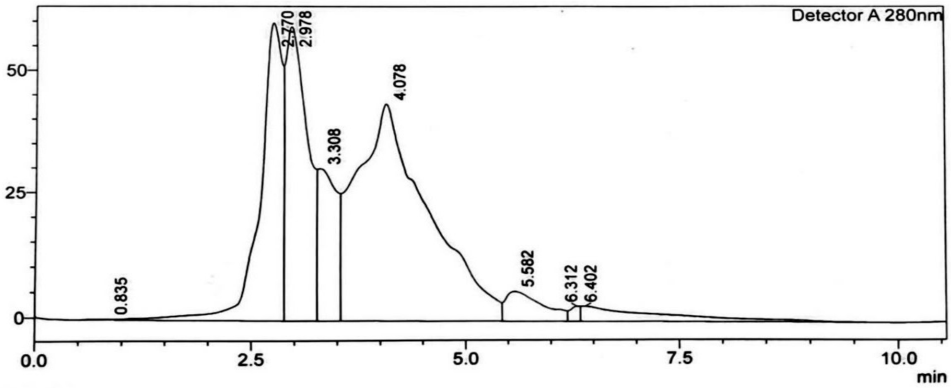


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	2.134	34244	25	2		Tannic acid
2	2.425	12514	25	2	V	Safron
3	2.961	95930	25	2	V	Quercetin
4	3.315	418871	25	2	V	Rutin
5	3.849	279379	25	2	V	Kaempferol
6	4.248	100120	25	2	V	Gallic acid
7	4.642	21593	25	2	V	3.4 Dimethoxybenzyl alcohol
8	4.848	37963	25	2	V	Caffeine
9	6.872	2958	25	2		Crocin
10	7.468	61033	25	2		Apigenin
Total		1064605				

Factor P2T0:

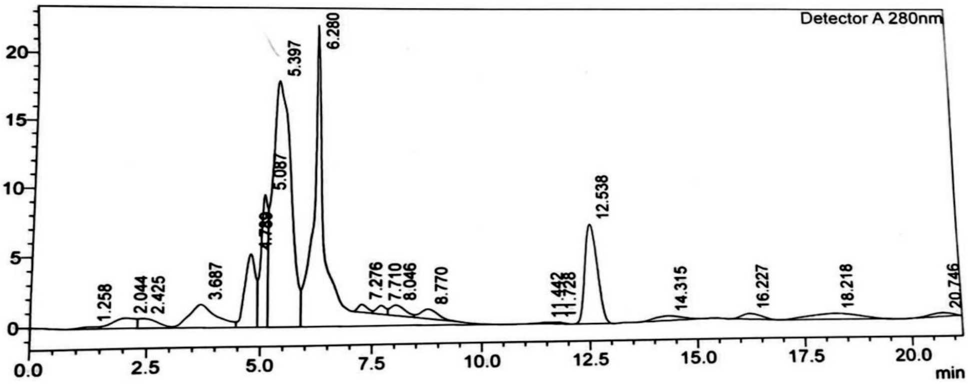


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	0.835	2933	25	2		Tannic acid
2	2.770	1098215	25	2	V	Safron
3	2.978	1050633	25	2	V	Quercetin
4	3.308	464833	25	2	V	Rutin
5	4.078	2546069	25	2	V	Kaempferol
6	5.582	179431	25	2	V	Gallic acid
7	6.312	24312	25	2	V	3.4 Dimethoxybenzyl alcohol
8	6.402	198594	25	2	V	Caffeine
Total		5565020				

Factor P2T1:

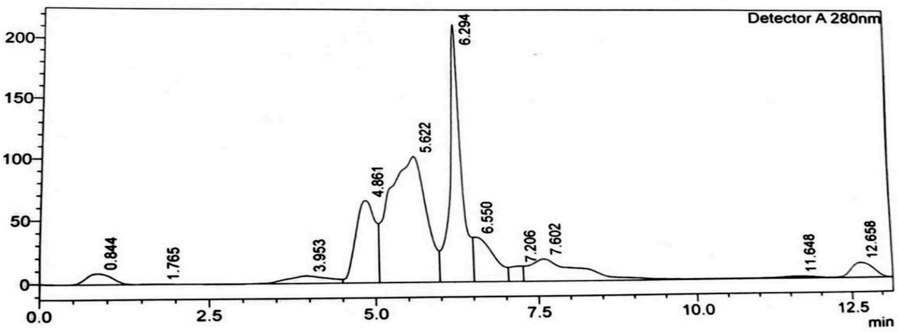


<Peak Table >

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	1.258	4015	25	2		Tannic acid
2	2.044	25547	25	2	V	Safron
3	2.425	20390	25	2	V	Quercetin
4	3.687	70278	25	2	V	Rutin
5	4.789	88532	25	2	V	Kaempferol
6	5.087	98253	25	2	V	Gallic acid
7	5.397	508491	25	2	V	3.4 Dimethoxybenzyl alcohol
8	6.280	454539	25	2	SV	Caffeine
9	7.276	8723	25	2	T	Crocin
10	7.710	9220	25	2	TV	Apigenin
Total		1287988				

Factor P2T2:



<peak table>

Detector A 280nm

Peak#	Rat. Time	Area	Conc.	Dilution Factor	Mark	Name
1	0.844	222585	25	2		Tannic acid
2	1.765	8082	25	2	V	Safron
3	3.953	271221	25	2		Quercetin
4	4.861	1383766	25	2	V	Rutin
5	5.622	3978616	25	2	V	Kaempferol
6	6.294	2527458	25	2	V	Gallic acid
7	6.550	767798	25	2	V	3.4 Dimethoxybenzyl alcohol
8	7.206	165025	25	2	V	Caffeine
9	7.602	1006228	25	2	V	Crocin
10	11.648	75522	25	2	V	Apigenin
Total		19879779				

The reason for the increase in vegetative growth of plants may be attributed to the improvement of the main physiological traits and the increase in the concentration of hormones responsible for it, such as growth regulators like Auxins (IAA) and Gibberellins (GA_3), which help in seed formation, development, and control of plant size, as well as the regulation of chemical composition, cell elongation, increasing cell wall elasticity, and cell division (Attia, 1999).

It may also be due to the increase in the concentration of micronutrients, as they play a role in the secondary processes of plant metabolism, the permeability of cell membranes, and the activation of enzymes, which leads to an increase in their absorption by the plant and reflects positively on vegetative growth and the increase in yield components of the plant (Al-Sahaf, 1989).

These increases in plant content of nutrients and compounds responsible for vegetative growth may also be attributed to the efficiency of the photosynthesis process, which provides the plant with carbohydrates necessary for its growth, improves its content, and thus increases the absorption of more essential elements for balanced plant nutrition (Al-Tememe, 1998).

Conclusion:

It is concluded from this study that the use of Gibberellic acid (GA3) at a concentration of 100 mg/L had a significant effect on the vegetative growth traits of the plant, due to its role as an active compound that stimulates growth. Additionally, the use of secondary microelements at higher concentration led to significant increases. Furthermore, the interaction between GA3 and IAA at higher concentration, such as 40 mg/L, proved to be significantly superior in all traits.

It is recommended to use higher concentrations of microelements and to add other elements such as magnesium, cobalt, and molybdenum. It is also recommended to interact GA3 with IAA and increase its concentration in treating plants. Furthermore, it is recommended to conduct such experiments on other plants.

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