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RESEARCH ARTICLE

Effect of spraying with nano zinc and coconut milk on the growth and flowering of the petunia plant

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Abstract

This study examined the influences of spraying nano zinc and coconut milk and their interplay on growth, flowering and chemical indicators on *Petunia* grown in a lath house over the 2022 growing season. During the experiment, two factors were studied: spraying nano zinc (Z) at 10 and 20 mg L^{-1} concentrations and spraying coconut milk (C) at concentrations of 10, 20 and 30 %. Additionally, distilled water was sprayed as the control treatment for both factors. All of the traits examined were significantly impacted by nano zinc spraying, the greatest results for the attributes were obtained at a concentration of 20 mg L^{-1} (Z_2), including (plant height, number of branches, leaf area, flowers number, flower diameter, flower weight, total chlorophyll, total carbohydrates, nitrogen, Phosphorus and potassium). Conversely, the coconut milk spraying treatments significantly impacted all the attributes examined except flower weight. The highest values for the traits were obtained with the 20 % (C_2) treatment, including (plant height, number, leaf area, flowers number, flower diameter, total chlorophyll and total carbohydrates). In contrast, the concentration of 30 % (C_3) achieved the best results for the traits (nitrogen, phosphorus and potassium). These results demonstrate the potential of combining nano zinc and coconut milk as an eco-friendly biostimulant strategy for ornamental crops.

Keywords: coconut milk; flowering; growth; nano zinc; *Petunia hybrida* L.

Introduction

Petunia hybrida is one of the most widely cultivated ornamental plants in Iraq. It is an annual plant with an herbaceous or pedunculated stem; its leaves are opposite or alternate, simple in form and big, funnel-shaped, abundant and multicoloured. Autumn and springtime seeds allow petunias to grow and are deemed inappropriate to be picked. It grows well in semi-shaded and sunny areas (1). Petunias grow slowly when planted in situations with short days and the final plants are short, with a profusion of branches and very short internodes. When planted in an environment with lengthy days, the principal branch is longer and less branching, with the lengthening internodes (2, 3). Foliar application effectively supplies nutrients to plants, particularly micronutrients, which improves fertilising efficiency. It also helps to lessen the quantity of lost elements and the likelihood that they will be fixed in the soil (4). The soils' high levels of salt and lime are among the most significant factors that promote the use of foliar spraying of plants (5).

The term nanotechnology refers to precise manipulation at the nanoscale, which encompasses not only mechanical processing but also chemical, physical and biological approaches, making it broader than being limited to mechanical processing alone. Nanotechnology allows fertilisers to be used in lower, more efficient and controlled doses, enhancing plant nutrition without the need to increase application rates (6). The use of nano-fertilisers will undoubtedly contribute to a significant improvement in plant productivity and quality. This improvement is achieved through precise control of nutrient release, ensuring that plants receive the required amount at the right time. The benefits can be accurately measured by monitoring measurable parameters, such as plant growth rates, biomass accumulation of those plants and their efficiency in absorbing various nutrients (7). Whether applied to the vegetation or as part of the soils' nutrition, nano fertilisers are essential for effectively feeding plants. This is because they enhance the photosynthesis process by raising the leaves' chlorophyll content. In addition, they make crops more resilient to stress and disease, preserve the genes needed to produce various crops and enhance the amount of active substances in the plant (8, 9). Zinc is essential for growth because it helps produce the amino acid tryptophan, which is a component of the hormone auxin and directly affects the elongation and growth of plant cells (10, 11).

Zinc plays an important role in the formation of the plasma membrane of plant cells and is involved in many cellular processes that take place within the plant (12). It also contributes to the enzyme carbonic anhydrase, which is a cofactor in photosynthesis, leading to an increase in the amount of energy molecules and carbohydrates produced by photosynthesis in the leaves (13). Zinc deficiency in plants reduces food production through photosynthesis by 50-70 % depending on the plant species and the level of deficiency, which may cause an impairment in protein production as a result of a decrease in the number of formed ribosomes and the concentration of RNA (10). Zinc also enhances the ability of plant roots to absorb minerals from the soil, thus increasing the plants' mineral content. Furthermore, zinc contributes to regulating the acidity of chloroplasts, prevents changes in protein properties and activates several essential enzymes, including carbonic anhydrase and enolase (14). Zinc also has varying effects on the metabolism of produced carbohydrates and these effects are closely related to the systems that convert sugar forms (15). Zinc also controls protein synthesis in plants through its clear effect on ribonucleic acid (RNA) (16). This may be because zinc is important for phosphorylation and glucose formation during starch synthesis in plants (17). Zinc is also necessary for RNA synthesis and protein synthesis and it contributes to nitrogen transformations (18). Zinc also plays a role in cell membrane growth and function, which contributes to influencing various parts of the plant, such as growing roots (19). Zinc deficiency clearly affects cell membranes and also impacts the movement and transport of many chemicals within developing roots, including phenols, sugars and various amino acids. This, in turn, affects plant growth and reproduction (20).

Modern research has increasingly focused on using plant extracts as a safe and sustainable alternative to industrial materials. These natural extracts are biodegradable and environmentally friendly, leaving minimal or no adverse effects on humans and ecosystems. By evaluating measurable parameters such as toxicity levels, biodegradability rate and ecological impact, the benefits of plant-based materials can be accurately quantified, as well as increasing the plants' resistance to disease and insect infection (21). The liquid endosperm of *Cocos nucifera* L. is known as coconut milk. It has a variety of physiologically active substances in it, particularly growth regulators like auxin, gibberellin, cytokinins and salicylic acid, as well as the compounds' natural regulators and inhibitors, including ethylene, abscisic acid, flavonols and phenols. Additionally, it has many minerals and free amino acids, which help the development of plant vegetative and flowering (22). Research indicates that foliar application (of coconut milk) improves plant growth parameters (23). Coconut milk contains reduced nitrogenous compounds, including amino acids and amides (24). Research indicates that many components of coconut milk have been isolated, the most important of which are cytokinins (25). This study aims to investigate the effect of nano zinc and coconut milk on enhancing Petunia plant traits, including vegetative growth, flowering and chemical composition. It also aims to reveal the ability of these treatments to improve measurable parameters such as the number of flowers, total leaf area, chlorophyll content of developing leaves and accumulation of nutrients within plant organs. Nano zinc activates photosynthesis and enzymes important for growth, while the milk in coconut fruit contributes to providing many minerals and organic compounds that activate metabolic processes taking place within plants. The interaction of the two study factors differs from previous studies that investigated the effect of nano-fertilisers alone or in combination with separate natural stimulants, which positively affect growth and increase plant productivity. Our study also aims to investigate the effect of the two study factors on specific aspects, such as plant growth, increasing the number of flowers and improving the resistance of the plants under study to various stresses, an aspect that has not been adequately addressed by researchers in their previous studies. Therefore, this research largely represents a distinctive scientific contribution to understanding the interaction between nano-fertilisers and natural plant stimulants and their impact on improving various sustainable agriculture strategies. This study hypothesises that foliar application of nano zinc and coconut milk, individually and in combination, enhances the growth, flowering and biochemical properties of *Petunia hybrida* through synergistic physiological effects.

Materials and Methods

Soil properties

The experiment was carried out in the lath house belonging to the Department of Horticulture & Landscape Gardening at College of Agriculture, University of Anbar, which is situated in the city of Ramadi, Anbar Governorate, Iraq, at nearly latitude 33.35 °N and longitude 43.79 °E to study the impact of spraying with nano zinc, coconut milk and their interplay on the parameters of growth, flowering and chemical content of Petunia plant. Table 1 shows some of the properties of the soil.

Treatments

Spraying with the nano zinc (Z) at three concentrations: Z_0 (spraying with distilled water), Z_1 (10 mg L^{-1}) and Z_2 (20 mg L^{-1}). The experiment used nano-zinc manufactured by Sigma-Aldrich (Saint -Louis, MO, USA) with a particle size of approximately 40 nm. To facilitate the dissolution of nano-zinc when preparing the required concentrations. Spraying with the coconut milk (C) at four levels: C_0 (spraying with deionized water), C_1 (10 %), C_2 (20 %) and C_3 (30 %). The milk was extracted from mature coconuts and then diluted with distilled water according to the concentrations established in the experiment. The plants were sprayed with a 2 L sprayer until they were thoroughly covered. In order to minimise the surface tension of the spray solution molecules and enable the plants to absorb most of the sprayed solutions, liquid soap was added as a dispersant at a rate of 0.1 ml L^{-1}. The research components were sprayed on the plants four times (5 Dec 2021, 5 Jan 2022, 5 Feb 2022 and 5 Mar 2022), ensuring an interval of 48 hours between consecutive spraying applications.

Experimental design

A randomised complete block design was used to conduct a two-factor study. The experiment was divided into three blocks, with twelve treatments per block. Five plants were used per experimental unit, making a total of 180 plants used in the experimental study. The data were calculated at the repeater level by taking the average of the five values within each experimental

Table 1. Some chemical and physical properties of soil

P Av. mg Kg^{-1}	Total N %	$CaCO_3$ g Kg^{-1}	Bulk density g cm^{-3}	O.M %	EC ds m^{-1}	pH
1.25	0.04	148.56	1.24	1.31	1.46	7.82
Cl^-	$HCO_3^=$	$CO_3^=$	Na^+	Mg^{++}	Ca^{++}	K Av.
Mq L^{-1}	Mq L^{-1}	Mq L^{-1}	Mq L^{-1}	Mq L^{-1}	Mq L^{-1}	mg Kg^{-1}
1.53	1.68	ND	0.20	4.64	5.36	63.49
		Texture	Clay	Silt	Sand	$SO_4^=$
			g Kg^{-1}	g Kg^{-1}	g Kg^{-1}	Mq L^{-1}
		Sandy	25.0	184.7	790.3	2.90

unit.

Plant parameters

Plant height (cm) was determined from the base of the stem to the maximum level of the plant using a measuring scale. For No. of branches (branches plant $^{-1}$), the lateral branches formed on each plant were recorded. Leaf area was measured using a LI-COR LI-3100 C Leaf Area Meter. Ten fresh leaves were randomly taken from each plant and passed individually through the meter. The average was taken and the values recorded. The total leaf area was then calculated by multiplying the number of leaves per plant by the average leaf area for that plant. The values were fixed in cm^2.

The number of flowers that opened on each plant was recorded from the onset of flowering until the end of the experiment. Flower diameter (cm) was measured at the widest point of the flower using a digital vernier calliper. Measurements were taken on five flowers per plant and the mean value was recorded. The weight of the whole flower, including the stalk, was gauged using a sensitive electronic balance with an precision of 0.001 g. Five flowers per plant were gauged and the mean weight was registered.

Total chlorophyll content in leaves

Nearly 0.1 g of fresh leaf tissue was crushed in a ceramic mortar with a appropriate amount of 80 % acetone until a light green extract was acquired, as per the standard procedure (26). The extract was strained and the volume modified to 10 mL. Absorbance was assessed at 645 and 663 nm using a spectrophotometer. Total chlorophyll was estimated as per the formula in Equation 1. The results were administered in mg per 100 g fresh weight.

$$\text{Total chlorophyll} = (20.2 \times A645) + (8.02 \times A663) \qquad \text{(Eqn. 1)}$$

Total carbohydrate content in leaves

Roughly 0.5 g of dried, crushed leaf sample (oven-dried at 65 °C) was extracted with 100 mL of deionized water, stirred for 24 h and clarified. A 1 mL aliquot of the extract was blended with 5 mL of 5 % phenol solution and 5 mL of undiluted H_2SO_4, then placed in a heated water at boiling point bath for 30 mint. Absorbance was assessed at 485 nm using a spectrophotometer and carbohydrate content was assessed using a glucose standard calibration curve (27).

Macroelements content in leaves

Leaf samples were cleaned with water to eliminate dust and desiccated in an oven at 65 °C until stable weight. Samples were crushed and sieved through a 0.2 mm mesh. About 0.2 g of desiccated sample was digested with 5 mL of 98 % concentrated sulfuric acid. After collecting a clear solution, the samples were tempered and adulterated to 50 mL with deionized water. Nitrogen was determined using the semi-micro Kjeldahl method, phosphorus was calculated spectrophotometrically and potassium was measured using a flame photometer (28-30).

Statistical analysis

The Genstat version 12 software was used to statistically analyse the data and means were compared at a significance level of 0.05 by using the least significant difference (LSD) test (31).

Results

Growth traits

Height of the plant

The findings show that nano zinc spraying was a significant factor in the variations in plant height (Fig. 1). The spray treatment (Z_2) achieved the highest plant height, reaching 17.37 cm, while the treatment (Z_0) showed the lowest height at 13.35 cm. Furthermore, spraying coconut milk on the foliage improved plant growth characteristics, particularly with a 20 % concentration (C_2) of the extract, which increased the height to 16.61 cm. The height decreased with the non-spraying treatment (C_0), which recorded the lowest plant height at 14.67 cm. Table 2 shows the significant effect of the interaction of the two study factors, as the treatment (Z_2C_2) achieved the highest height of 19.24 cm, while the treatment without spraying with both study factors (Z_0C_0) achieved the lowest value of the studied trait, reaching 11.74 cm.

Number of branches

The results of the statistical analysis in Fig. 2 show that spraying zinc in nano-form significantly affected the number of branches in plants; the treatment (Z_2) showed a value that reached the highest level of 6.19 branches plant^{-1}, while the treatment without spraying with nano-zinc (Z_0) recorded the lowest value for the number of branches, which reached 5.40 branches plant^{-1}. Spraying the second study factor, which is coconut milk, showed a clear significant effect, as the highest value appeared in the treatment (Z_2), reaching 6.11 branches plant^{-1}, while the non-spraying treatment (Z_0) recorded the lowest number of branches, reaching 5.64 branches plant^{-1}. The results of Table 2 show a statistically significant interaction trend between the two study factors, with the highest value occurring with treatment (Z_2C_2) and achieving 6.82 branches plant^{-1}, whereas the treatment without spraying

Table 2. Interaction effects of nano zinc (Z) and coconut milk (C) on growth and flowering traits of *Petunia hybrida* L.

Nano Zinc (Z)	Coconut Milk (C)	Height of plant (cm)	Number of branches (branch plant^{-1})	Leaves area (cm^2 plant^{-1})	Number of flowers (flower plant^{-1})	Flower diameter (cm)	Flower weight (g)
	C_0 (0 %)	11.74	5.28	635.49	134.82	7.46	2.57
Z_0	C_1 (10 %)	12.43	5.40	642.78	135.66	8.69	3.06
(0 mg L^{-1})	C_2 (20 %)	13.87	5.44	667.26	137.35	8.87	3.34
	C_3 (30 %)	15.35	5.71	689.70	135.47	7.53	2.92
	C_0 (0 %)	15.45	5.47	695.54	139.12	8.17	3.43
Z_1	C_1 (10 %)	15.36	6.14	692.63	143.41	8.72	3.58
(10 mg L^{-1})	C_2 (20 %)	16.72	6.05	703.81	142.50	8.56	3.25
	C_3 (30 %)	17.74	6.27	722.03	144.68	8.79	3.34
	C_0 (0 %)	16.82	5.93	694.56	141.27	7.84	3.74
Z_2	C_1 (10 %)	17.30	6.30	718.16	144.98	8.43	3.48
(20 mg L^{-1})	C_2 (20 %)	19.24	6.82	752.73	149.85	9.20	3.85
	C_3 (30 %)	16.13	5.69	701.97	138.16	10.02	3.60
LSD 5 %		1.92	0.48	34.18	4.73	1.12	N.S

LSD: Least significant difference; NS: Non-significant

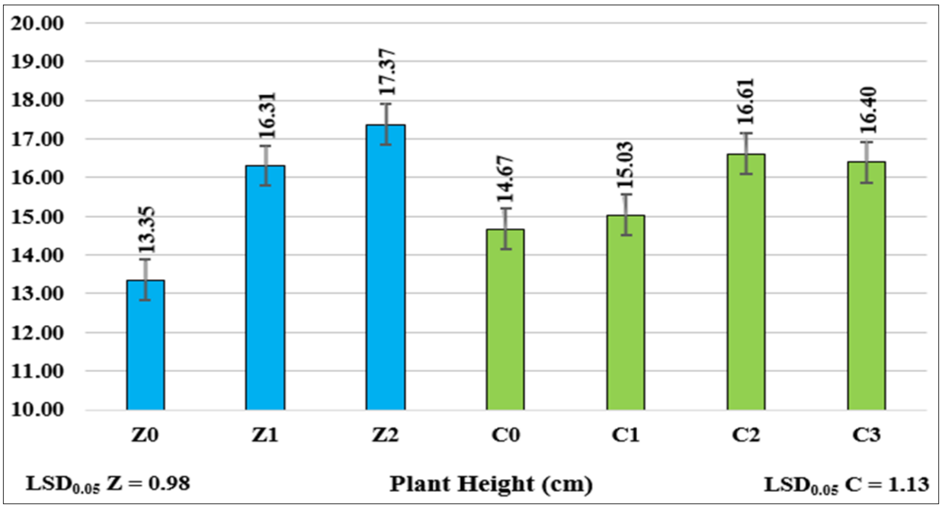

Fig. 1. Effect of nano zinc (Z) and the coconut milk (C) on the height of plants of *Petunia hybrida* L.

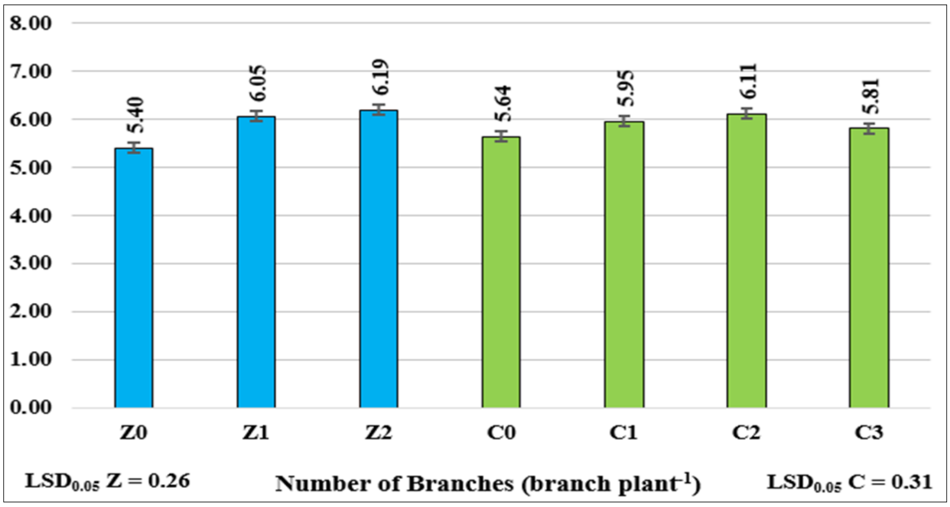

Fig. 2. Effect of nano zinc (Z) and coconut milk (C) on the number of branches of *Petunia hybrida* L.

with the two study factors (Z_0C_0) recorded the least value of 5.28 branches plant^{-1}.

Leaves area

The Leaves area exhibited a notable advantage with the foliar spraying of nano zinc (Z_2), reaching a maximum value of 716.61cm^2 plant^{-1}, while the non-sprayed treatment (Z_0) saw a fall in value to 658.81 cm^2 plant^{-1} (Fig. 3). Moreover, the coconut milk foliar spraying considerably impacted on the characteristic under study, C_2 and C_3 treatments yielded the highest value of 707.93 and 704.56 cm^2 plant^{-1}, respectively, while the treatment (C0) showed the lowest rate, at 675.19 cm^2 plant^{-1}. The treatment (Z_2C_2) stood out with the highest value of 752.73 cm^2 plant^{-1}, while the control treatment (Z_0C_0) had the lowest value at 635.49 cm^2 plant^{-1}, indicating that the interplay between the study traits had a substantial influence (Table 2).

Flowering traits

Number of flowers

As shown in Fig. 4, the results show that foliar spraying with nano zinc significantly affected the number of flowers; treatment (Z_2) had the maximum content, recording 143.81 flowers plant^{-1}, while treatment (Z_0) had the lowest value, 135.82 flowers plant^{-1}. Reaching 142.90 flower plant^{-1}, treatment (C_2) had the highest value for spraying coconut milk and treatment (C_0) had the lowest value, with 138.40 flower plant^{-1}. The results indicate that there was a two-way interaction between the nano zinc and coconut milk at treatments (Z_2C_2) of 149.85 flower plant^{-1}, whereas treatment (Z_0C_0) produced the minimal flowers at 134.82 flower plant^{-1} (Table 2).

Flower diameter

Fig. 5 illustrates the considerable impact of nano zinc spraying treatments on flower diameter; treatment (Z_2) exhibited the maximum value of 8.87 cm, whereas treatment (Z_0) displayed the lowest value of 8.14 cm. Coconut milk spraying on plants showed a significant effect, with treatment (C_2) giving the largest flower diameter of 8.89 cm, while treatment (C_0) not spray the extract on plants, showed the lowest diameter, which decreased to 7.83 cm. A statistically significant two-factor interaction was found between nano zinc and coconut milk; treatment (Z_2C_3) significantly increased the plant height, measuring 10.02 cm, whereas treatment (Z_0C_0) produced the lowest value, measuring 7.46 cm (Table 2).

Flower weight

The studied trait was significantly affected by nano zinc spraying; according to the data, treatment (Z_2) had the highest levels of influence, reaching 3.67 g, while treatment (Z_0) had the lowest value, 2.97 cm (Fig. 6). On the other hand, the result showed no significant effects in the flower weight by spraying with coconut milk and the interaction between the two factors of the study (Table 2).

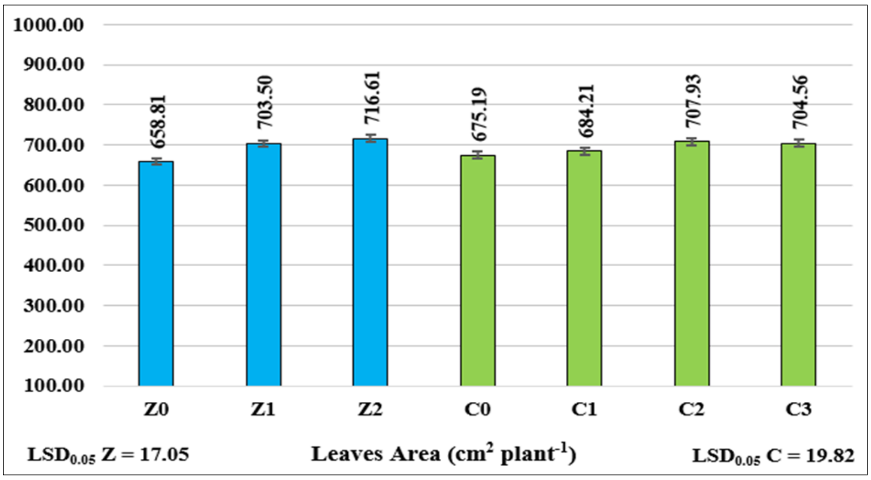

Fig. 3. Effect of nano zinc (Z) and coconut milk (C) on leaf area of *Petunia hybrida* L.

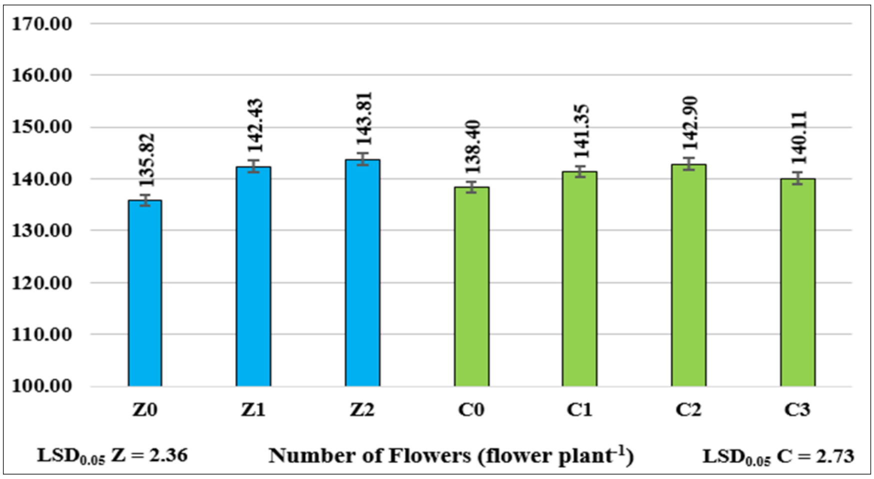

Fig. 4. Effect of nano zinc (Z) and coconut milk (C) on the number of flowers of *Petunia hybrida* L.

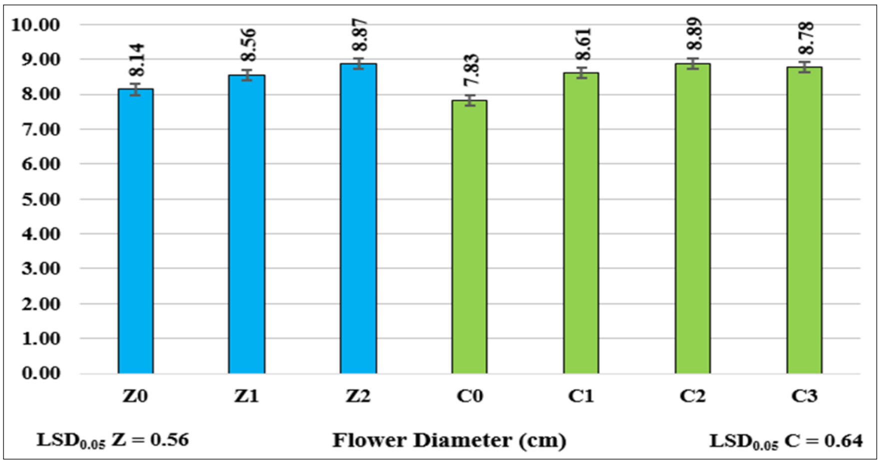

Fig. 5. Effect of nano zinc (Z) and coconut milk (C) on flower diameter of *Petunia hybrida* L.

Table 3. Interaction effects of nano zinc (Z) and coconut milk spray (C) on the chemical traits of *Petunia hybrida* L.

Nano zinc (Z)	Coconut Milk (C)	Total chlorophyll (mg100 g^{-1})	Total carbohydrate (%)	Nitrogen (%)	Phosphorus (%)	Potassium (%)
	C_0 (0 %)	11.42	9.02	2.46	0.27	1.73
Z_0	C_1 (10 %)	11.86	10.21	2.45	0.31	1.69
(0 mg L^{-1})	C_2 (20 %)	12.45	10.82	2.43	0.33	1.75
	C_3 (30 %)	11.52	9.46	2.48	0.30	1.77
	C_0 (0 %)	13.11	9.67	2.43	0.34	1.74
Z_1	C_1 (10 %)	13.50	10.44	2.52	0.42	1.81
(10 mg L^{-1})	C_2 (20 %)	13.91	10.78	2.46	0.39	1.85
	C_3 (30 %)	12.37	10.30	2.49	0.35	1.83
	C_0 (0 %)	12.25	9.32	2.44	0.35	1.87
Z_2	C_1 (10 %)	12.07	9.98	2.56	0.46	1.92
(20 mg L^{-1})	C_2 (20 %)	14.53	10.67	2.47	0.36	1.79
	C_3 (30 %)	14.42	11.71	2.68	0.57	1.94
LSD 5 %		1.64	0.87	N.S	0.10	0.08

LSD: Least significant difference; NS: Non-significant

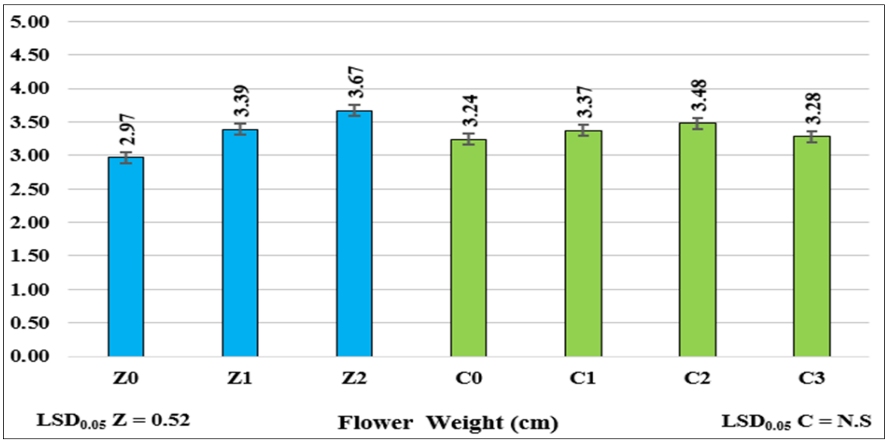

Fig. 6. Effect of nano zinc (Z) and coconut milk (C) on flower weight of *Petunia hybrida* L.

Chemical traits

Total chlorophyll

The results show that nano zinc spraying substantially impacted total chlorophyll; treatment (Z_2) had the highest levels, reaching 13.31 mg100 g^{-1}, while treatment (Z_0) had the lowest values, 11.81 mg100 g^{-1}(Fig. 7). Conversely, foliar spraying with coconut milk significantly impacted this trait; treatment (C_2) had the highest value, 13.63 mg100 g^{-1}, while treatment (C_0) had the lowest value, 12.26 mg100 g^{-1}. The two study components' interaction had a substantial impact, with treatment (Z_2C_2) showing the highest values at 14.53 mg 100 g^{-1} and treatment (Z_0C_0) showing the lowest values at 11.42 mg 100 g^{-1} (Table 3).

Total carbohydrates

Foliar spraying with the nano zinc significantly increased the total carbohydrates in the leaves (Fig. 8), with a maximum content of 10.42 %, which was seen in the treatment (Z_2), which significantly differed from the treatment (Z_0) and produced the lowest percentage of 9.88 %. However, foliar spraying with coconut milk substantially impacted the characteristic under study; treatment (C_2) had the highest percentage, 10.76 %, while treatment (C_0) had the lowest percentage, 9.33 %. The two study components exhibited a similar pattern of substantial effect in their interaction, with the treatment (Z_2C_3) achieving the maximum percentage of 11.71 % and the control therapy (Z0C0)

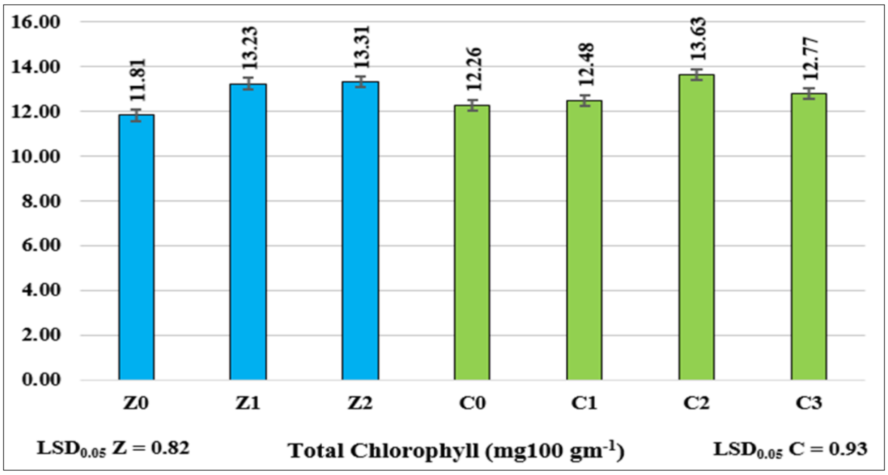

Fig. 7. Effect of nano zinc (Z) and coconut milk (C) on total chlorophyll of *Petunia hybrida* L.

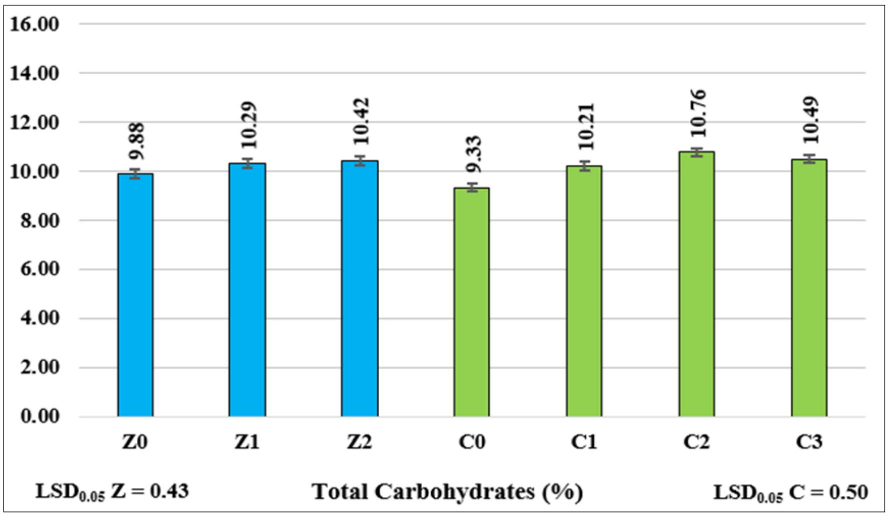

Fig. 8. Effect of nano zinc (Z) and coconut milk (C) on total carbohydrates of *Petunia hybrida* L.

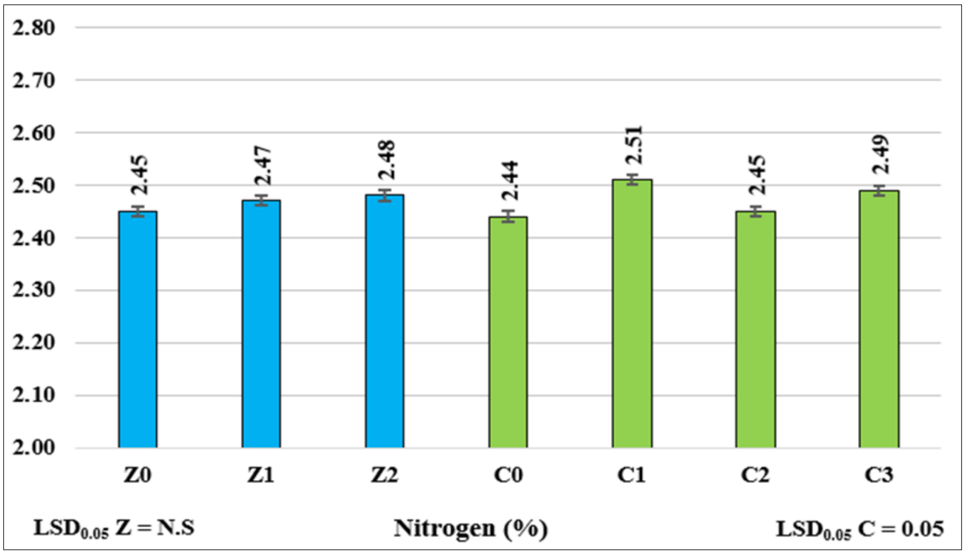

Fig. 9. Effect of nano zinc (Z) and coconut milk (C) on Nitrogen of *Petunia hybrida* L.

having the lowest percentage of 9.02 % (Table 3).

Nitrogen content in leaves

The result showed that no significant effects on the nitrogen content of the leaves due to the spraying with nano zinc (Fig. 9). However, the coconut milk foliar spraying considerably impacted the characteristic under study; treatment C_1 yielded the highest percentage of 2.51 %, while the treatment C_0showed the lowest rate, at 2.44 %. (Table 3). On the other hand, the result showed no significant effects in the nitrogen content of the leaves due to the interaction between the two factors of the study.

Phosphorous content in leaves

According to the results shown in (Fig. 10), foliar spraying with the nano zinc significantly enhanced the phosphorus content of the leaves, attaining a peak of 0.43 % in treatment (Z_2), while treatment (Z_0) showed the lowest percentage at 0.30 %. However, spraying onto leaves with coconut milk had a considerable influence, particularly in treatments (C_3 and C_1), which produced the highest percentage at 0.41 and 0.40 %, respectively, while the treatment (C0) had the lowest value, 0.32 %. On the other side, the relationship between the two research components had a significant path of effect, particularly in treatment (Z_2C_3), which attained the maximum phosphorus content in the leaves at 0.57 %, while treatment (Z_0C_0) obtained the lowest percentage at 0.27 % (Table 3).

Potassium content in leaves

Based on the data presented in Fig. 11, it is evident that the nano zinc treatment (Z_2) had a significant impact and the highest potassium percentage in the leaves, 1.88 %, whereas the non-sprayed treatment (Z_0) had the lowest percentage, 1.74 %. The coconut milk foliar spraying significantly impacted the trait under study, particularly in treatment C_3, which produced the highest percentage of 1.85 (treatment C_0); on the other hand, it had the lowest percentage, 1.62 %. The studys' two components interacted significantly, with treatment (Z_2C_3) exhibiting the highest percentage of potassium in the leaves 1.94 %, on the other side, the treatment (Z_0C_0) exhibiting the lowest value, 1.73 % (Table 3).

Discussion

The improvement in the growth of petunia plants when sprayed with nano-zinc may be due to the basic physiological role that zinc plays in different plants, as it stimulates many processes that take place inside the cells, including cell elongation and division and the formation of cell membranes, which in turn contributes to improving the vegetative growth of those plants and

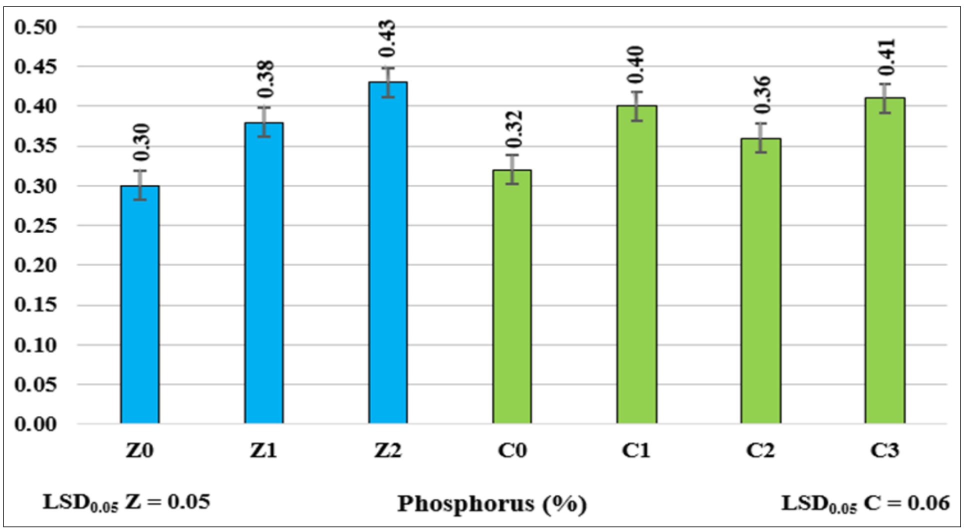

Fig. 10. Effect of nano zinc (Z) and coconut milk (C) on phosphorus of *Petunia hybrida* L.

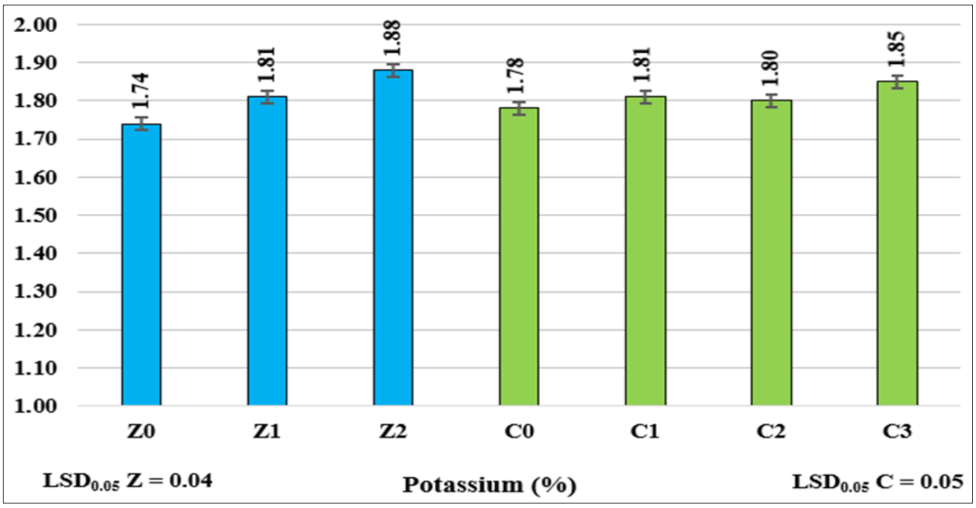

Fig. 11. Effect of nano zinc (Z) and coconut milk (C) spray on the percentage of Potassium of *Petunia hybrida* L.

improving the growth of their root system (32). Zinc also contributes to maintaining the functional and structural integrity of the cell plasma membrane, while balancing various cellular activities (33, 34). Furthermore, zinc has an enzymatic role, acting as a cofactor for carbonic anhydrase, which is essential for photosynthesis. Zinc contributes to enhancing carbon uptake, which indirectly stimulates the synthesis of energy units such as ATP and NADPH, as well as carbohydrates manufactured within the plant (35, 36). When zinc is deficient in the plant, these activities it performs will decrease significantly, by up to 70 % or more, with reduced protein synthesis due to decreased ribosome activity and reduced concentrations of ribonucleic acid (37, 38). Zinc also supports the regulation of acidity in plant chloroplasts and activates the action of many oxidation and decomposition enzymes, which significantly increases the absorption of mineral elements and contributes to increased plant growth by improving the nutrition of those plants (14, 19).

A study was conducted in India to demonstrate the effect of spraying coconut milk extract and it was observed that its effectiveness lies in its unique biochemical content of essential mineral elements and plant growth regulators such as auxins (IAA) that stimulate the growth of plant roots and the elongation of their cells. In addition to its content of cytokinins, which stimulate plant cell division, delay ageing and promote the differentiation of plant chloroplasts (39, 40). Coconut milk also contains micronutrients, amino acids and soluble sugars as shown in Table 2, all of which act as a balanced nutrient medium to activate metabolic pathways within the plant, increase the synthesis of proteins and plant pigments such as chlorophyll, as well as improve growth and reproduction characteristics in plants (41). The biochemical components of coconut milk extract are similar in effect to synthetic plant growth regulators, but more naturally and holistically, making this plant extract a promising and environmentally friendly biostimulant. The experiment was carried out during only one growing season, which contributes to the inability to generalise the results obtained to other growing seasons, in which climatic factors will certainly differ, which greatly affects the results. The study also did not include an analysis of the long-term effects of the two study factors on environmental characteristics, including soil, which calls for the need in the future to conduct studies over several seasons to evaluate the cumulative effect of using coconut milk extract and nano-zinc and to demonstrate its effect on the vegetative growth of plants and their flowering more comprehensively and accurately.

The study results demonstrate the superior performance of the nano-zinc spray interaction with coconut milk compared to the individual treatments. This effect cannot be explained as a mere additive response, but rather represents a complex interactive mechanism. It can be explained that coconut milk extract may contribute as a biotransporter or effective chelating matrix that helps stabilise zinc nanoparticles and prevent their accumulation and contributes to their easy transfer within plant tissues. The presence of organic matter and functionally active compounds in coconut milk extract can improve the solubility and bioavailability of nano-zinc, making it easier for plants to absorb it more efficiently. Furthermore, zinc nanoparticles may enhance cellular signalling pathways as well as enzyme systems that lead to increased absorption of the mineral elements found in coconut milk extract. It is worth noting that there are still similar studies on the interaction between nanomaterials and natural extracts, which opens the door for our results to form the basis for future studies in the molecular, biochemical and microscopic fields to explain the underlying pathways resulting from these shared bio-reactions.

Our results are of practical importance and reflect light on the attempt to compare them with traditional fertilization systems, especially chemical ones, as these fertilizers have always been considered a basic pillar for the cultivation of ornamental plants, but they are marred by many concerns, especially when added directly to the soil, which contributes to soil degradation, nutrient leaching and increased amounts of carbon emitted during. On the other hand, the combined addition of nano-zinc and coconut milk extract has several advantages, the most important of which are: Efficacy, environmental sustainability and Economic feasibility.

Spraying with very low concentrations of nano-zinc showed vegetative growth responses in plants similar to, or perhaps even exceeding, those caused by spraying with much larger quantities of conventional fertiliser. This efficiency demonstrates the high efficacy of nano-delivery systems and natural plant stimulants. Avoiding or reducing the use of heavy chemical fertilisers helps prevent the transfer of nutrients into water bodies, thus reducing the risk of food poisoning in both humans and animals. Furthermore, using natural, organic fertilisers such as coconut milk extract and nano-zinc in small concentrations effectively contributes to environmental conservation. Recent studies indicate that spraying nano-zinc at appropriate concentrations in agricultural practices does not have a harmful cumulative effect on groundwater or soil and that the levels of absorption of this element by plants are sufficient to minimise any potential negative impact on the environment. Adherence to the recommended concentrations is also advised to avoid potential environmental risks and to ensure the sustainability of its use (42, 43).

While the cost of a unit of nano-zinc formulations or coconut milk extract may seem higher at first glance than the costs of chemical fertilisers of all kinds, the great effectiveness of each gives a clear idea in the end of the low costs and the effective role in stimulating plant growth and the quality of its flowers. This is of great importance in the cultivation and production of ornamental plants, as competitiveness in the market depends mainly on producing high-quality plants at low costs. An important concern is the potential for phytotoxicity caused by high doses of nano-zinc or other biologically active compounds. Although our study clearly showed significant responses within the concentrations used, exceeding these levels of the element can cause oxidative stress, damage to cell membranes and lead to symptoms such as yellowing, leaf burn and reduced root elongation. These results are consistent with previous research, which has shown the need to take into account adherence to zinc toxicity limits to avoid adverse effects on plant health (44).

The combined results confirm beyond any doubt that the combined use of nano-zinc and coconut milk extract contributes to providing a vital and effective stimulating strategy that improves plant growth through multifaceted physiological, biochemical and environmental mechanisms. Through the combined effect of nutrient efficiency, hormonal balance and environmental sustainability, this can serve as a promising model for research into diverse future innovations in ornamental plant nutrition, contributing to sound planning for future research. This includes conducting detailed studies into the molecular basis of the combined effect of nutrients, agricultural research to compare with a wider range of traditional fertilisers and biostimulants and developing in-depth economic evaluation studies to demonstrate the long-term viability of those nutrients. These guidelines will not only show an improvement in our current results but will also contribute to reinforcing the great practical importance of sustainable gardening practices.

The results obtained through our study showed that the effects of nano-zinc and coconut milk extract were closely related to their physiological mechanisms in stimulating plant growth. Spraying with nano-zinc contributes to a clear activation of the enzymes responsible for photosynthesis and chlorophyll production, which contributes to increasing plant characteristics such as increasing their length, number of leaves and branches. This also improves the absorption of nutrients, especially macronutrients. The presence of stimulating substances in coconut milk extract, such as auxins, cytokinins and various natural vitamins, contributes to cell division and elongation, increasing vegetative and floral growth in plants. This clearly explains the significant increase in the number, weight, diameter and other characteristics of flowers. On the other hand, the combination of adding both nano zinc and coconut milk extract contributed to activating the metabolic and physiological processes of the plants, which in turn had a positive effect on all or most of the studied traits.

Conclusion

Spraying with nano-zinc showed a clear positive effect on all aspects of vegetative growth and floral characteristics, as well as the chemical content of petunia plants, except for the nitrogen content of the leaves, which did not reach a significant level. The best results appeared when spraying at a concentration of 20 ml L^{-1}. Regarding the spraying of coconut milk extract, the level of effect reached a significant level in all vegetative and flowering growth characteristics except for flower weight, which was not significantly affected. It also showed a significant and noticeable effect on all chemical content characteristics of the plants. The 20 % concentration showed the best values for most of the studied characteristics, while the 30 % concentration showed the highest values for the leaf content of nutrients. From an applied perspective, the results obtained reflect significant economic and environmental impacts. The high performance at relatively low application rates for both study factors indicates that farmers can reduce their use of high-concentration synthetic fertilisers, positively impacting nutrient manufacturing costs and minimising nutrient loss through leaching. It also reduces the likelihood of environmental pollution. All of this aligns with current trends in sustainable horticulture, with a strong emphasis on producing high-quality ornamental plants and implementing sound and efficient, environmentally friendly nutrient management strategies.

This study lays the foundation for future studies, as the synergistic interactions that are clearly observed necessitate molecular and physiological studies to search for the underlying mechanisms of interactions between different nutrients and hormones. Furthermore, comparative trials with conventional fertilisers, studies on appropriate fertiliser dosages and long-term economic evaluations of these fertilisers can demonstrate the feasibility of implementing these results on a wider agricultural scale and their potential for scaling up in all directions. On the other hand, the results highlight the importance of precise nutrient concentrations. Using either nano -zinc or coconut milk in high concentrations may lead to toxicity in treated plants, which underscores the need to use the recommended concentrations to avoid stunted growth or damage to plant tissues. All of this confirms that the effectiveness of biostimulants depends primarily on the appropriate formulation and concentrations used, which are factors of great importance for safe and effective application in horticultural practices.

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Authors' contributions

HEA was responsible for creating the initial research idea and collecting the literature review to achieve the final idea for this research, as well as performing statistical analysis after collecting data to investigate the effect of individual factors solely or the interaction between them, and moreover comprehensive reading for the final manuscript. AFZA carried out the experiment, data collection, and interpretation of results; moreover, the initial writing of the manuscript also compared the findings with the literature and made the conclusions built into the output of this research.

Compliance with ethical standards

Conflict of interest: The authors have stated that there are no conflicts of interest.

Ethical issues: None

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