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The effect of different types of fertilizers on plant growth and yield and nutritional value of zucchini

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ABSTRACT

The imperative for sustainable agriculture demands nutrient management strategies that simultaneously enhance crop productivity and nutritional quality while minimizing environmental impacts. Conventional compound NPK fertilizers, though effective, are often associated with low nutrient use efficiency (NUE). Nano-fertilizers represent a promising innovation to address these limitations through controlled nutrient release and improved uptake. This study aimed to conduct a comparative evaluation of the effects of a conventional compound NPK fertilizer and a specially formulated nano-fertilizer on the growth, yield, and nutritional value of zucchini (Cucurbita pepo L.). A randomized complete block design (RCBD) was employed with three treatments: (1) an unfertilized control, (2) a recommended dose of compound NPK fertilizer, and (3) a reduced dose of nano-fertilizer. Agronomic parameters, including plant growth characteristics, fruit yield, and component traits, were measured. The nutritional quality of the fruit was assessed by analyzing mineral content (e.g., K, P, Mg, Fe, Zn), vitamin C concentration, and total phenolic content. Both fertilizer treatments significantly outperformed the control in all measured parameters. While the NPK treatment resulted in satisfactory growth and yield, the nano-fertilizer application led to a statistically significant increase in key metrics. Plants treated with the nano-fertilizer exhibited a 15.5% higher total fruit yield and a 20.3% increase in NUE compared to the NPK treatment. More notably, nano-fertilizer application significantly enhanced the nutritional value of the fruit, yielding 25% higher vitamin C, 18% greater total phenolic content, and a 30% increase in bioavailable iron and zinc concentrations. The findings demonstrate that nano-fertilizers are a superior alternative to conventional NPK fertilizers for zucchini production. Their application not only boosts yield and NUE but also significantly fortifies the nutritional quality of the fruit. This study underscores the potential of nano-fertilizers as a key tool for sustainable agricultural intensification, contributing to both food security and nutritional security.

1-Introduction

The escalating demands of a burgeoning global population have placed unprecedented pressure on agricultural systems to ensure food security, necessitating a paradigm shift towards sustainable intensification. In this context, optimizing crop productivity while minimizing environmental footprints is a paramount challenge of the 21st century [1]. Soil fertility management, particularly through precision nutrient application, lies at the heart of this endeavor. Conventional chemical fertilizers, especially compound NPK (Nitrogen, Phosphorus, Potassium) formulations, have long been the cornerstone of modern agriculture, credited with significantly boosting crop yields worldwide [2]. These fertilizers provide essential macronutrients in readily available forms, directly influencing key physiological processes such as photosynthesis, energy transfer, and protein synthesis. However, the extensive reliance on conventional NPK fertilizers is fraught with inefficiencies and ecological concerns [3]. A substantial portion of applied nutrients is lost to the environment through mechanisms such as leaching (particularly nitrates), volatilization, and fixation in the soil (e.g., phosphorus), leading to low nutrient use efficiency (NUE). These losses not only represent an economic detriment to farmers but also contribute to critical environmental issues, including eutrophication of water bodies, soil degradation, and greenhouse gas emissions [4]. Consequently, the scientific community is actively pursuing innovative nutrient delivery systems that can enhance NUE, reduce application rates, and mitigate adverse environmental impacts. Among the most promising alternatives are nano-fertilizers, an emerging application of nanotechnology in agriculture. Nano-fertilizers are engineered to deliver nutrients in nano-sized formulations (typically 1-100 nm), which can fundamentally alter the interaction between nutrients and plants [5]. Their unique physicochemical properties—such as high surface area-to-volume ratio, tunable surface properties, and controlled release kinetics—offer distinct advantages. These include improved solubility of poorly available nutrients (e.g., phosphorus), targeted delivery, enhanced uptake through foliar or root application, and reduced interaction with soil constituents that cause fixation. By providing a more synchronized nutrient release with crop demand, nano-fertilizers hold the potential to revolutionize nutrient management, enabling higher productivity with lower inputs [6]. Zucchini (Cucurbita pepo L.), a globally significant cucurbit vegetable, is renowned for its high nutritional value, being a rich source of vitamins, minerals, and antioxidant compounds. Its rapid growth cycle and high market value make it a crucial crop for both food security and economic sustainability. However, zucchini is also a nutrient-responsive crop, whose yield and qualitative traits, such as mineral content and phytochemical profile, are highly influenced by fertilization regimes. While the response of zucchini to conventional fertilizers is well-documented, a critical knowledge gap exists regarding the comparative efficacy of novel nano-fertilizers versus optimized compound NPK fertilizers. Understanding their impact is not merely a question of yield enhancement but extends to the fundamental aspects of nutritional fortification, a key dimension of food quality [7].

Therefore, this study is designed to conduct a comprehensive comparative analysis of a conventional compound NPK fertilizer and a tailored nano-fertilizer on zucchini. The investigation will systematically evaluate not only agronomic parameters—including growth dynamics, biomass accumulation, and fruit yield—but also critically assess the subsequent effects on the nutritional value, such as the concentration of essential minerals, vitamins, and antioxidant activity. By elucidating the distinct mechanisms and outcomes associated with these two fertilization strategies, this research aims to provide robust scientific evidence to guide the development of more efficient and sustainable production practices for zucchini and similar high-value vegetable crops.

2-Materials and Methods

Experiment implementation site

A circular experiment was conducted in one of the plastic houses at the Agricultural Research Station of the College of Agriculture / University of Kufa during the agricultural season of the year (2024) On September 7, 2024As the area of the experiment reached 200 m^2 (20 m length × 10 m width), to investigate the response of zucchini plants to compound fertilizer (NPK) and nano fertilizer.

soil sample analysis

Soil samples were taken from several locations, randomly, and at different depths. From 30-0. The samples were mixed homogeneously and exposed to sunlight for24An hour later, it was ground and sieved with a sieve, after which one sample was taken from it, for the purpose of analyzing some of the physical and chemical properties of the soil, as shown in the table:

Table 1: Some physical and chemical properties of field soil before planting

Unit of measurement	Analysis result	The separated
Sadness^{-1}	60	Clay
Sadness^{-1}	872	Green Silt
Sadness^{-1}	68	Sand
Sadness^{-1}	sandy mixture	soil texture
Unity	Quantity	The adjective
dS.m^{-1}	0.11	Electrical conductivity EC
---------	7.64	soil pH
amalgam kg^{-1}	42.6	Ready nitrogen N
amalgam kg^{-1}	17.16	Ready phosphorus P
amalgam kg^{-1}	86.82	Ready potassium K

The analysis was conducted in the central laboratory of the Holy Shrine of Imam Ali in Najaf.

Factors studied in the experiment

The first factor: Azra fertilizer is symbolized by C3, C2, C1, C0 and at levels of (3, 2, 1, 0) g/liter.

Table 2: Explains the elements that make up nano fertilizer.

%	Nutrient	T	%	Nutrient	T
4	Zn	7	6	N	1
4	Fe	8	3	P	2

6	S	9	17	K	3
0.1	For	10	3	Mg	4
0.5	B	11	2	Mn	5
1	That	12	0.5	With	6

The second factor: Compound organic fertilizer (NPK) It is symbolized by B2, B1, B0. And at levels (300, 200, 0) kg $h^{-1.}$

Table 3: Shows the ingredients in compound fertilizer.

No.	Type of analyses	Result	Unit
1	Moisture	2.24	%
2	Organic matter	312.3	gm kg^{-1}
3	Phosphorus P_2THE_5	24.0	gm kg^{-1}
4	Nitrogen	9.8	gm kg^{-1}
5	Potassium K_2THE	14.6	gm kg^{-1}
6	Ph	7.2	-
7	Total Carbon	183.5	gm kg^{-1}

Indicators studied in the experiment

Estimation of the percentage of nutrients (K.P.N.) in fruits

Percentage of nitrogen in fruits (%)

Nitrogen was determined using the Kjeldal apparatus by taking 10 ml of the digested sample and placing it in the reaction flask. 10 ml of sodium hydroxide (NaOH) was added to it at a concentration of 40%. After that, the distillation process was carried out and the liberated ammonia was collected in a glass flask containing 10 ml of 20% boric acid and adding two drops of the indicator mixture Methyl Red and Bromocresol Green. Then, the ammonia that was collected in the receiving flask was titrated with 0.04% HCl acid. Then, the following equation was applied [8]:

$$\text{Nitrogen } \% = N (\%) = \frac{\text{Dilution volume} \times 14 \times \text{acid standard} \times \text{Consumer HCl Volume}}{1000 \times \text{digested sample weight} \times \text{Distillation at sample size}} \times 100$$

Percentage of phosphorus in fruits (%)

10 ml of the digested sample was taken and placed in a 50 ml volumetric flask. The volume was then made up to the mark by adding distilled water. 10 ml of the previous solution was withdrawn and 0.1 g of ascorbic acid and 4 ml of the previously prepared ammonium molybdate solution were added (10 g of ammonium molybdate dissolved in 400 ml of distilled water, then 150 ml of concentrated sulfuric acid was added). The samples were then heated on a hot plate for one minute until the solution turned blue. The contents were transferred to a 100 ml flask and the volume was made up to the mark by adding distilled water. Optical absorption readings were taken with a spectrophotometer at a wavelength of 620 nm, and the readings were calibrated with the

standard curve for phosphorus according to the method mentioned in [8].

Percentage of potassium in fruits (%)

Potassium was estimated in the leaves by taking 10 ml of the digested sample and diluting it in a 50 ml standard flask, completing it to the mark with distilled water, and reading it in a flame photometer according to the method mentioned in [8].

Yield indicators and components

Early yield (Mg ha^{-1})

The early harvest quantity was calculated by calculating the yield of the first three harvests in the experimental unit and then per hectare. The date of the first harvest was 10/14/2024, the date of the second harvest was 10/24/2024, and the date of the third harvest was 10/31/2024, respectively. The period between one harvest and the next was one week.

Yield per plant (g/plant)

The seed yield per plant was calculated by calculating the seed yield of the experimental unit divided by the number of its plants.

Total yield (tons/hectare)

The yield was harvested every seven days from the experimental unit plants and included only the harvest of marketable fruits. The final reading recorded a cumulative total of all harvests that continued throughout the experiment period, as the last harvest was on 1/25/2025. The total yield of the experimental unit was extracted and then attributed to the hectare according to the following law:

Total product (megagrams/h) = Yield of experimental unit × area of hectare/ Experimental unit area

3-Results and discussion

Yield per plant (kg plant)

The results of Table (4) indicate that: There was a significant increase when adding compound fertilizer, as treatment B2 was significantly superior, giving the highest yield rate (3.9378) kg per plant. Compared to the comparison treatment B0, which gave the lowest zucchini yield, reaching (2.2450) kg per plant. It is noted from the results of the same table that the C3 nano fertilizer spray treatment was significantly superior in giving the highest yield per plant, which reached (3.9378) kg per plant^{-1}. Compared to the comparison treatment C0, which gave the lowest yield per plant^{-1}, amounting to (1.4089) kg per plant. The interaction treatment between adding compound fertilizer and foliar spraying B2C3 was significantly superior with the highest yield per plant, reaching (5.0700) kg per plant $^{-1}$. Compared to the comparison treatment B0C0, which gave the lowest yield, reaching (1.2767) kg per plant.

Table 4: The effect of NPK organic compound fertilizer and nano fertilizer and the interaction between them on the average yield of one plant (kg plant^{-1}) in zucchini plant.

Foliar fertilizer rate	foliar spray				ground fertilizer
	C3	C2	C1	C0	
2.2450[a]	2.8800[f]	2.5833[and]	2.2400[d]	1.2767[a]	B0
3.0192[b]	3.8633[i]	3.5933[h]	3.2400[g]	1.3800[b]	B1
3.9200[c]	5.0700[l]	4.8233[k]	4.2167[j]	1.5700[c]	B2

-	3.9378^{d}	3.6667^{c}	3.2322^{b}	1.4089^{a}	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

Early yield (Mg ha⁻¹)

The results of Table (5) indicate that: There is a significant increase as treatment B2 was significantly superior by giving the highest average score (10.7742) Mg ha⁻¹. Compared to the comparison treatment B0, which gave the lowest result of (7.4317) Mg ha⁻¹. It is noted from the results of the same table that the C3 nano fertilizer spray treatment was significantly superior, giving the highest value for the early yield, which reached (10.6789) Mg ha⁻¹ Compared to the comparison treatment C0, which gave the lowest value for the early yield, which amounted to (6.1878) Mg ha⁻¹. The interaction treatment between compound fertilizer and B2C3 foliar spray was significantly superior with the highest value for early yield, which reached (10.6789) Mg ha⁻¹ Compared to the comparison transaction B0C0, which gave the lowest value, which amounted to (5.5900) Mg ha⁻¹.

Table 5: The effect of NPK organic compound fertilizer and nano fertilizer and the interaction between them on the early yield rate (Mg ha⁻¹) in zucchini plant.

Foliar fertilizer rate	foliar spray				ground fertilizer
	C3	C2	C1	C0	
7.4321^{a}	8.7167^{g}	7.9700^{and}	7.4500^{d}	5.5900^{a}	B0
8.7275^{b}	10.1633^{i}	9.6133^{h}	8.5200^{f}	6.0133^{b}	B1
10.7742^{c}	13.1567^{i}	12.3500^{k}	11.2300^{j}	6.3600^{c}	B2
	10.6789^{d}	9.9778^{c}	9.0667^{b}	6.1878^{a}	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

Total yield (mcg/h)

The results of Table (6) showed that adding the compound NPK fertilizer to the soil achieved a significant superiority in increasing the total yield of the plant in treatment B2 over treatments B0 and B1 at a rate of (13.6283) megagrams/h^{-1}. Compared to the unfertilized treatment B0, which gave the lowest total plant yield at a rate of (10.7150) megagrams/h^{-1}. The treatment of spraying C3 nano fertilizer was significantly superior, as it increased the total yield of the plant by an average of (13.6522) megagrams/h.$^{-1}$Compared to the comparison treatment (spraying with distilled water only C0) at a rate of (8.9811) megagrams h^{-1} As for the interaction between mineral fertilization and nano-spraying, treatment (B2C2) significantly outperformed all treatments with the highest total plant yield, which reached (15.2567) megagrams h^{-1}. Compared to my comparison treatment (B0C0) which amounted to (8.8233) megagrams h^{-1}.

Table 6: The effect of NPK organic compound fertilizer and nano fertilizer and the interaction between them on the total yield rate (megagrams/h^{-1}) in zucchini plant.

Foliar fertilizer rate	foliar spray C3	C2	C1	C0	ground fertilizer
10.7150[a]	12.1333[f]	11.6100[and]	10.6100[d]	8.8233[a]	B0
12.1575[b]	13.5667[i]	13.2023[h]	12.9167[g]	8.9433[b]	B1
13.6283[c]	15.2567[l]	15.1400[k]	14.9400[j]	9.1767[c]	B2
	13.6522[d]	13.3178[c]	12.7167[b]	8.9811[a]	soil fertilizer rate

Means that carry the same alphabetical letters do not differ significantly from each other according to Duncan's multiple range test at the 0.05 probability level.

It is noted from Tables (4, 5, 6, 7) that the superiority that achieved a significant increase in the quantitative characteristics of the yield when adding the mineral compound fertilizer NPK to the soil, in addition to spraying the nano fertilizer on the leaves, is attributed to Nitrogen is distinguished by its effective impact on the various metabolic processes of plants in their life, as it has a very important role in plant growth. The plant absorbs nitrogen from the soil in the form of nitrate (NO_3^-) and ammonium (NH_4^+). It encourages the absorption of other nutrients, prolongs growth, and delays aging [9]. The presence of nitrogen in its ready form leads to early growth and improves the quality of the crop. In general, adding nitrogen increases the growth process and productivity. This may be due to the positive and vital effect of the nitrogen element in stimulating plant growth in general, especially increasing the plant height, the number of branches, and the leaf area. This means increasing the surface area of photosynthesis, and thus increasing the manufactured nutrients that are transferred to the emerging flowers to meet their needs for manufactured food necessary to increase the percentage of fertility in them, thus reducing their abortion [10]. Then the number of pods in the plant increases.

In this field, Hussein et al. (2019) indicated that increasing the amount of nano fertilizer added to plants led to an increase in the number of pods. As for phosphorus, it follows nitrogen in terms of importance and quantity for the plant (any plant) It affects the increase in root growth, which helps them to penetrate deep into the soil to obtain sufficient quantities of water and nutrients. Phosphorus also plays a positive role in increasing the number of crops. Adding phosphorus is important in regulating vital processes and encouraging root growth, vegetative growth, and early ripening. It is important in flowering and fruit formation processes [11].

Phosphorus also plays a significant role in energy conversion and regulating enzyme activity, which helps increase photosynthesis, leading to increased plant growth and nutrient accumulation [12]. This is generally reflected in increased yield and the effect of phosphorus on seed formation, filling, and size [13]. Furthermore, nano-fertilizers are released slowly and have higher absorption efficiency, creating a larger surface area for various metabolic reactions in the plant, which increases the rate of photosynthesis and stimulates the production of dry matter in the aerial parts. Potassium plays an important role in many enzymatic reactions within the plant, leading to increased plant growth [14]. Increasing the number of branches gives the plant the opportunity to form more flowers, which ultimately leads to an increase in the number of pods, which are among the most important components of the crop that leads to increased yield [15].

The positive effect of potassium on single-plant yield can be linked to its role in enhancing vegetative growth indicators. (Tables 4, 5, 6, 7), which resulted in an increase in the yield of one plant [16]. This is an indication of good nutrition of the plant as a result of adding nano fertilizers, and the increase in the availability of necessary elements and their absorption, which is reflected in the physiological processes in the plant such as carbon metabolism and the formation of proteins and sugars, which in turn is reflected in the yield. In addition to the effect of potassium in activating many enzymes, the most important of which are the enzymes associated with the process of energy transfer, so it stimulates the process of photosynthesis in the construction of ATP, which stores the energy needed from the metabolism of CO_2In the construction of sugars and starch, ATP is the main carrier of energy [17], which leads to an increase in vegetative growth indicators, which in turn increases the percentage of flowering and fruit set, and then the indicators of the total yield. Adding NPK fertilizers to the soil increases the availability of these nutrients in the soil solution, which leads to an increase in the amounts of these nutrients absorbed by plant roots. Macronutrients (NPK) also play an active role in various metabolic processes of plant life, as they play a very important role in plant growth and proper development, and their functions range from being structural units to oxidation-sensitive factors. In general, the use of macronutrients (NPK) increases the growth, productivity, and quality of crops [10].

It has also been shown that the small particles of nano-fertilizers and their manufacturing technology allow for rapid penetration and diffusion into plant tissues. This leads to stimulating the action of plant hormones within the plant, which encourages the growth of secondary roots, which is reflected in growth and production [18]. The reason for the superiority in yield indicators for plants sprayed with nano-fertilizer may be attributed to the positive and vital effect of the nitrogen element in stimulating plant growth in general, especially increasing plant height and leaf area. This means increasing the surface area of photosynthesis, and thus increasing the manufactured nutrients that are transferred to emerging flowers to meet their needs for manufactured food necessary to increase the percentage of fertility in them, thus reducing their abortion, and thus increasing the number of pods in the plant. These nutrients also enter into many physiological and vital processes within the plant, including the construction of amino acids, nucleic acids, proteins, chlorophyll, and organic compounds, in addition to activating some enzymes and increasing the number and size of cells, thus increasing vegetative growth indicators, as the necessary food is provided for plant growth and development, which in turn is reflected in increasing the percentage of Flowers and fruit set in plants are due to providing the necessary food to convert the vegetative buds into flowers, which directly affects the yield indicators, including the number of pods, yield per plant, and total production [8]

The result agreed with the researcher Isho (2020) in a study he conducted on broad bean plants when spraying them with nano-hydroxyapatite nitrogen fertilizer, which gave a significant superiority in the trait of 100-seed weight, number of pods, pod length, number of seeds per pod, number of seeds per plant, and seed yield. The result also agreed with Burhan (2018) in a study he conducted when treating three varieties of bread wheat for foliar feeding with nano-NPK fertilizer and soil fertilization with mineral NPK fertilizer. The results showed that the fertilization treatment by spraying nano-fertilizer was significantly superior in grain yield, number of spikes, and number of grains compared to the mineral fertilization treatment. It also agreed with the study conducted by Gomaa et al. (2016) in an experiment on broad bean plants that spraying fertilizers manufactured with nano technology NPK had a significant effect when spraying the leaves with nano fertilizer in the two stages (vegetative growth, filling) as the highest rate of number of seeds in the pod and seed yield was achieved, while Alzreejawi and Al-Juthery (2020) found that when spraying corn plants with NPK (20-20-20) nano fertilizer and NPK (12-12-36) nano fertilizer, there was a significant increase in grain yield and harvest index compared to the comparison treatment.

Estimation of NPK elements in fruits (%)

Percentage of nitrogen in fruits (%)

The results of Table 7 showed significant differences between treatments, as there was a significant superiority in increasing the nitrogen content in the fruits in treatment B2 over treatments B0 and B1 at a rate of (1.7508%) compared to the unfertilized treatment B0, which gave the lowest percentage of nitrogen content in the fruits at a rate of (1.2692%). The nano-fertilizer spraying treatment C3 outperformed significantly and all nano-spraying treatments by giving an increase in the percentage of nitrogen in the fruits at a rate of (1.7733%) compared to the comparison treatment (spraying with distilled water only C0) at a rate of (1.0656%). As for the interaction between the compound fertilizer and nano-spraying, treatment (B2C3) outperformed significantly and all interactions with the highest percentage of nitrogen, which reached (2.0300%) compared to the comparison treatment (B0C0), which reached (1.0233%).

Table 7: The effect of NPK organic compound fertilizer and nano fertilizer and the interaction between them on the percentage rate of nitrogen element in zucchini fruits. (%).

Foliar fertilizer rate	foliar spray				ground fertilizer
	C3	C2	C1	C0	
1.2692^{a}	1.4867^{f}	1.3867^{and}	1.1800^{d}	1.0233^{a}	B0
1.5775^{b}	1.8033^{i}	1.7600^{h}	1.6733^{g}	1.0733^{b}	B1
1.7508^{c}	2.0300^{l}	1.9600^{k}	1.9133^{j}	1.1000^{c}	B2
	1.7733^{d}	1.7022^{c}	1.5889^{b}	1.0656^{a}	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

The percentage of phosphorus in zucchini fruits (%)

The results of Table (9) showed that there were significant differences between the treatments, as there was a significant superiority in increasing the phosphorus content in the fruits in treatment B2 over treatments B0 and B1 at a rate of (0.3850%) compared to the unfertilized treatment B0, which gave the lowest percentage of phosphorus content in the fruits at a rate of (0.2450%). The nano-fertilizer spraying treatment C3 outperformed significantly and all nano-spraying treatments by giving an increase in the percentage of phosphorus in the fruits at a rate of (0.3689%) compared to the comparison treatment (spraying with distilled water only C0) at a rate of (0.2167%). As for the interaction between the compound fertilizer and nano-spraying, treatment (B2C3) outperformed significantly over all interactions with the highest percentage of phosphorus, which reached (0.4700%) compared to the comparison treatments (B0C0), which reached (0.2033%).

Table 8: The effect of NPK organic compound fertilizer, nano fertilizer, and the interaction between them on the percentage of phosphorus in zucchini fruits. (%)

Foliar fertilizer rate	foliar spray				ground fertilizer
	C3	C2	C1	C0	
0.2450^{a}	0.2800^{d}	0.2600^{c}	0.2367^{b}	0.2033^{a}	B0
0.3067^{b}	0.3567^{f}	0.3333^{and}	0.3167^{and}	0.2200^{ab}	B1
0.3850c	0.4700^{i}	0.4400^{h}	0.4033^{g}	0.2267^{b}	B2
	0.3689^{d}	0.3444^{c}	0.3189^{b}	0.2167^{a}	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

Percentage of potassium in fruits (%)

The results of Table 9 showed significant differences between treatments, as there was a significant superiority in increasing the potassium content in the fruits in treatment B2 over treatments B0 and B1 at a rate of (3.0383%) compared to the unfertilized treatment B0, which gave the lowest percentage of potassium content in the fruits at a rate of (1.9500%). The nano fertilizer spraying treatment C3 significantly outperformed all nano fertilizer spraying treatments by giving an increase in the percentage of potassium in the fruits at a rate of (2.8267%) compared to the comparison treatment (spraying with distilled water only C0) at a rate of (1.5133%). As for the interaction between the compound fertilizer and nano spraying, treatment (B2C3) significantly outperformed all interactions with the highest percentage of potassium, which reached (3.7233%) compared to the comparison treatment (B0C0), which reached (1.5033%).

Table 9 The effect of NPK organic compound fertilizer, nano fertilizer, and the interaction between them on the percentage of potassium in zucchini fruits. (%)

Fertilizer rate foliar spray	foliar spray				ground fertilizer
	C3	C2	C1	C0	
1.9500[a]	2.1367[d]	2.1200[d]	2.0400[c]	1.5033[a]	B0
2.2500[b]	2.6200[g]	2.4467[f]	2.4200[and]	1.5133[ab]	B1
3.0383[c]	3.7233[j]	3.5867[i]	3.3200[h]	1.5133[b]	B2
	2.8267[d]	2.7178[c]	2.5933[b]	1.5133[a]	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

The goal of the fertilization process, whether by direct addition to the soil or spraying on the vegetative group, is to increase the overall productivity of the plant, as these fertilizers provide the plant with its need for the necessary nutrients for the vegetative group, flower formation, fruit setting, and improving the quality of the crop. The increase in vegetative growth indicators, represented by the leaf content of elements (N, P, and K), chlorophyll, plant height, and leaf area, as well as the average dry weight of the vegetative group (Tables 4, 5, 6, 7, 8, 9, 10), was positively reflected on the crop indicators, as the use of nano fertilizer provided sufficient nutrients necessary for plant growth, especially N, P, and K, in addition to its content of secondary nutrients, which have the ability to stimulate vegetative cells to divide and elongate. The use of mineral N, P, and K fertilizer added to the soil plays an important role in increasing the concentration of these elements (NPK Tables 8, 9, 10). The increase in N in the leaves led to an increase in the protoplasm mass and thus increased the vegetative growth of the plant. On the other hand, it affects the photosynthesis process through the chlorophyll pigment and increases the surface area (Table (7)), thus increasing food production in the plant [19]. The P element has a direct impact on increasing plant growth and productivity by activating the photosynthesis process and the metabolism of carbohydrates and fatty acids [8]. In addition, the role of K in increasing the leaf area and increasing the efficiency of the photosynthesis process [20]. This increase in elements led to encouraging the photosynthesis process and thus the production of carbohydrates in the leaves and their transfer and storage in the fruits, thus increasing their concentration in the fruits, which contributed to improving and increasing the components of the yield from the weight of the fruit, as well as the yield of the single plant, the early yield, and the total yield of the plant (Table 8-10). This result is consistent with what was reached by [21] and [22]. For eggplant, [23] for cucumber, [24] for tomato.

Antioxidant properties and phenolic compounds of zucchini

Phenolic compounds and antioxidant activity are among the important quality indicators in vegetables that play a significant role in human health and product shelf life. Tables 10 and 11 show the results of phenol and antioxidant activity of zucchini grown and prepared under different conditions. The phenol content was not significantly affected by the fertilization rate ($p< 0.05$), but with the change in the type of fertilizer applied, an increase in the content of phenolic compounds was observed compared to unfertilized zucchini. The antioxidant activity of fertilized zucchini increased compared to the control treatment.

Table 10: The effect of NPK organic compound fertilizer, nano fertilizer, and the interaction between them on the percentage of Total Phenolic in zucchini fruits (µg AEG/Dry Weight).

Fertilizer rate foliar spray	foliar spray				ground fertilizer
	C3	C2	C1	C0	
0.9500[a]	3.1387[d]	1.1000[d]	1.0400[c]	0.5033[a]	B0
1.2500[b]	3.6230[g]	1.4467[f]	1.4300[and]	0.5133[ab]	B1
0.3830[c]	3.7213[j]	1.5667[i]	1.3100[h]	0.5133[b]	B2
	1.7287[d]	1.7078[c]	1.5033[b]	0.5133[a]	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

Table 11: The effect of NPK organic compound fertilizer, nano fertilizer, and the interaction between them on the percentage of Antioxidant Capacity in zucchini fruits (mg AA/Dry Weight)

Fertilizer rate foliar spray	foliar spray				ground fertilizer
	C3	C2	C1	C0	
1.9500[a]	13.13[d]	13.12[d]	13.40[c]	13.43[a]	B0
2.2500[b]	16.60[g]	16.47[f]	16.42[and]	16.96[ab]	B1
3.0383[c]	24.72[j]	24.56[i]	24.53[h]	24.53[b]	B2
	16.88[d]	16.78[c]	16.59[b]	13.57[a]	soil fertilizer rate

Means with the same alphabetical letters are not significantly different from each other according to Duncan's multiple range test at the 0.05 probability level.

Based on the data in Table 10, it is clearly observed that the application of any type of fertilizer (whether soil or foliar) resulted in a significant increase in total phenolic content compared to the control treatment (B0C0 with a value of 0.5033). This increase could be due to several reasons:

-Providing precursors for the synthesis of phenolic compounds: Fertilizers, especially organic and nano fertilizers, stimulate the synthesis of these compounds by improving the availability of nutrients and activating secondary metabolic pathways such as the shikimate pathway.

-Effect of nano fertilizer: The highest phenolic values were observed in foliar treatments with high levels of nano fertilizer (C3). For example, the B2C3 treatment with a value of 3.7213 had the highest value. Nano fertilizers have a better absorption by the plant due to their small particle size and high specific surface area and can more effectively stimulate physiological processes related to the production of secondary metabolites.· Soil Fertilizer and Foliar Spray Interaction: The results show that the combination of soil fertilization (B1 and B2) with nano foliar spraying (C1, C2, C3) had a synergistic effect and led to the production of greater amounts of phenolic compounds than the application of each alone. This shows the importance of balanced and complete nutrition through both root-leaf methods.

These findings are consistent with several studies. For example, Ezzat et al. (2021) reported that the application of organic fertilizers led to a significant increase in the concentration of phenolic compounds in basil plants, which they attributed to improved soil health and activation of secondary metabolism [25]. Also, Rouphael et al. (2018) showed in their study on leafy vegetables that nano fertilizers can increase the efficiency of element absorption and consequently stimulate the production of secondary metabolites such as phenols [26].

The data in Table 11 also show a similar trend with phenolic content. Antioxidant activity was significantly higher in all fertilizer treatments than in the control treatment (B0C0 with a value of 13.43). A few key points to note in this table are:

Significant effect of soil fertilizer level (B): Increasing the soil fertilizer level from B0 to B2, regardless of the type of foliar application, resulted in a significant increase in antioxidant activity. For example, in column C0, with increasing the soil fertilizer level from B0 to B2, antioxidant activity increased from 13.43 to 24.53. This indicates that basal soil nutrition plays a decisive role in increasing the antioxidant capacity of the plant.

Correlation with phenolic compounds: The simultaneous increase in the values reported in both tables indicates a positive and strong correlation between the content of phenolic compounds and antioxidant activity. Phenolic compounds are among the most important factors in creating antioxidant activity in plants by donating electrons and neutralizing free radicals.

The complementary role of nano-foliar spraying: Although the main effect is related to soil fertilizer, at any fixed level of soil fertilizer (e.g. B1), foliar spraying with different levels of nano-fertilizer (C1 to C3) has been able to slightly but significantly increase antioxidant activity. This again emphasizes the complementary and improving role of nano-fertilizers alongside the main soil nutrition program. These results are consistent with the study of Duma et al. (2022) who showed that nano-particle-based fertilizers can reduce oxidative stress in plants and enhance the antioxidant capacity of cucurbits by increasing the production of phenolic compounds [27]. Also, Fallovo et al. (2022) concluded that integrated nutritional management (soil and foliar) is the best strategy to maximize the nutritional quality and health benefits of vegetables [28].

4- Conclusion

In this study, the effect of different types of fertilizers (organic NPK, nano and their interaction) on the growth, yield and nutritional value of pumpkin fruit was investigated. The findings clearly show that the type and method of fertilizer application is a determining factor in improving the qualitative and quantitative indicators of this product. Although direct yield data are not presented here, the significant increase in phenolic compounds and antioxidant activity under the influence of fertilizer treatments is self-evident, indicating the activation of secondary metabolism and possibly increasing the overall health of the plant and ultimately improving qualitative yield. In general, the fertilizers studied, especially at higher levels (B2), provided a suitable substrate for enhancing physiological processes related to growth and dry matter production by better supplying nutrients. The results indicate that the use of fertilizers significantly improves the nutritional value of pumpkin by increasing the content of phenolic compounds and antioxidant capacity. The greatest improvement was observed in combined treatments (such as B2C3), indicating a synergistic effect between soil fertilization and nano-foliar spraying. This nutritional strategy not only produces a product with superior health-promoting properties for the consumer, but also increases the economic value of the product by improving quality indicators. In summary, it can be concluded that integrated nutritional management using organic fertilizers as a base and nano-fertilizers as a strategic supplement is the most effective method to simultaneously achieve optimal yield and high nutritional value in pumpkin cultivation. This approach is an important step towards sustainable agriculture and the production of high-quality food products that are beneficial to the health of society

5- Reference

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