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Effect of nano phosphorus and garlic extract *Allium Sativum* on growth, yield of pepper plant *Capsicum annuum* L.

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Abstract:

This study was conducted with the aim of investigating the effect of foliar application of nano fertilizer (phosphorus) at different concentrations of the nano fertilizer and varying concentrations of garlic extract, and their interactions on the vegetative growth traits, chemical content, and active substances of the pepper plant Capsicum annuum. This study was done in the fields belonging to the College of Science at Al-Qadisiyah University during the spring agricultural season of 2024/2025 from the period of 20/9/2024 to 25/11/2024. The experiment was designed including 36 experimental units with three replications. The first factor consisted of four concentrations (0, 2, 4, 6 g/L) of nano phosphorus fertilizer, in addition to a control treatment, while the second factor involved concentrations of the extract (0, 15, 20 g/L). The results showed that the use of nano fertilizers and garlic plant extracts, and the interaction between them at different concentrations, led to a significant increase in most of the studied vegetative growth traits of the plants, and the increase was greater with the increase in the concentration of the nano fertilizer, such as plant height. Foliar application of the nano fertilizer resulted in a significant increase in the average plant height, stem diameter (cm) of the plant, number of leaves (leaves/plant), average fresh yield of leaves (g/plant), leaf area (cm), average dry yield of leaves (g/plant).

Keywords: *nano fertilizer, garlic extract, Allium Sativum, Capsicum annuum.*

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تأثير الفوسفور النانوي ومستخلص الثوم *Allium Sativum* على نمو وإنتاجية نبات الفلفل *Capsicum annuum*

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الخلاصة

أُجريت هذه الدراسة بهدف دراسة تأثير التسميد الورقي بالسماد النانوي (الفوسفور) بتراكيز مختلفة من السماد النانوي وتراكيز مختلفة من مستخلص الثوم، وتفاعلاتهما في صفات النمو الخضري والمحتوى الكيميائي والمواد الفعالة لنبات الفلفل *Capsicum annuum*. أُجريت هذه الدراسة في حقول كلية العلوم بجامعة القادسية خلال الموسم الزراعي الربيعي 2025/2024، للفترة من 2024/9/20 إلى 2024/11/25. صُممت التجربة متضمنة 36 وحدة تجريبية بثلاثة مكررات. تضمن العامل الأول أربعة تراكيز (0، 2، 4، 6 غم/لتر) من السماد النانوي الفوسفوري، بالإضافة إلى معاملة مقارنة، بينما تضمن العامل الثاني تراكيز المستخلص (0، 15، 20 غم/لتر). أظهرت النتائج أن استخدام الأسمدة النانوية ومستخلصات نبات الثوم، والتفاعل بينهما بتركيزات مختلفة، أدى إلى زيادة معنوية في معظم صفات النمو الخضري المدروسة للنباتات، وازدادت هذه الزيادة بزيادة تركيز السماد النانوي، مثل ارتفاع النبات. أدى الرش الورقي للسماد النانوي إلى زيادة معنوية في متوسط ارتفاع النبات، وقطر ساقه (سم)، وعدد الأوراق (أوراق/نبات)، ومتوسط المحصول الطازج للأوراق (غم/نبات)، ومساحة الورقة (سم)، ومتوسط المحصول الجاف للأوراق (غم/نبات).

الكلمات المفتاحية: *الفسفور النانوي، مستخلص الثوم، الفلفل الحار*

1. Introduction

Pepper *Capsicum annuum* is a major and economically profitable vegetable for farmers in most countries around the world. It originated in the Americas and is now widely cultivated in most tropical and subtropical regions of the world (Díaz-Pérez, 2010). Capsicum annum, one of the chemical compounds in pepper, can stimulate the immune system, prevent cardiovascular disease and cancer, and delay the aging process. It is a rich source of vitamins A and C and is primarily used to add flavor and pungency to cooked vegetables and other dishes. Continuous monoculture of peppers has led to a decline in the yield. Therefore, intercropping is a better option to avoid these harmful effects of continuous cropping. It is a crop management system that involves co-cultivating two or more economically beneficial species for at least part of their respective production cycle and growing them close enough to induce interspecific competition (Salami, 2002).

Nanofertilizers are more effective and efficient than conventional fertilizers, due to their positive effects on crop nutrition quality, reduced stress on plants, and reduced application costs due to their rapid uptake by roots. This is due to their large surface area relative to their volume, rapid penetration into plant cells and tissues, smart targeting, slow release, and rapid transport (Singh et al., 2021). Add nanofertilizers to various types of crops leads to an increase in the rate of photosynthesis and plant growth, treatment of some diseases, and a 30% increase in yield (Al-Juthery et al., 2018). They also play an effective role in the overall growth processes of plants. Nanofertilizers are essential for stem growth, cell elongation, and increased leaf area. They are also beneficial elements for plants to reach maturity with increased bud size (Thakur et al., 2018).

Garlic is one of the most important herbaceous plants rich in nutrients, as it contains selenium, sucrose, vitamin A, minerals, and others. When dried and then rehydrated, it contains oil, polysaccharides, saponins, and proteins (Londhe et al., 2011). Spraying garlic extract on some plants, such as pepper and bean, significantly affects plant height and dry weight of crops. The extracts also play an important role in the germination process of many important crops, including pepper. Spraying garlic extract also helped in early flowering and increased the total yield (Shang et al., 2019). Garlic extract also affects the dry matter percentage, moisture content, ash content, crude protein, fat, fiber, and carbohydrates in leaves (Kuete, 2017). Therefore, the aim of study was to estimate the effect of nano fertilizer and garlic extract on growth, yield of *Capsicum annuum*.

2. Materials and Methods

Experimental Site

The study was done in one of the fields of the College of Science, University of Al-Qadisiyah, Diwaniyah Province, during the spring season of 2024 in sandy soil.

Agriculture and Crop Service

Pepper (*Capsicum annuum* L.) seeds (local variety) were planted on September 20, 2024, obtained from approved agricultural offices for the sale and purchase of seeds in Diwaniyah Province. Planting was carried out at a depth of 10 cm in each anvil. Weeding was done manually whenever necessary to remove weeds growing with the crop.

Some characteristics of the fertilizers used in the experiment

The chelated nano fertilizers were obtained from Fanavar Seperhr Parmis Company for the production of nano fertilizers. Phosphorus 25% N (Tehran, Iran).

Preparation of Experimental factors

Two opaque plastic pots (anvils) with a capacity of 20 kg each and dimensions of 20 x 30 cm were prepared and filled with 15 kg of a soil mixture (sandy soil + animal manure). Pepper seeds (a local variety) were obtained from approved agricultural offices for the sale and purchase of seeds in Diwaniyah Province. Nano-phosphorus fertilizer produced by the Iranian company Fanavar Seperhr Parmis was also obtained, according to information available from the manufacturer.

To prepare the garlic, the garlic was dried and ground using an electric grinder. Ethyl alcohol (70%) was then added to a 500 ml glass beaker. Next, 200 g of dried garlic was weighed, and 200 ml of alcohol was added. The mixture was stirred for two hours. Two or three layers of gauze were then used to filter the mixture. The filtrate was then poured into Petri dishes and stored in an oven for one day at 40°C to obtain the extract. The extract was then stored in sterile bags until use.

Vegetative Growth Indicators

Vegetative growth indicators were measured on November 25, 2024, before flowering for all pepper plants. The average was calculated by dividing the trait value by the number of plants within each treatment, as follows:

Plant Height (cm)

Plant height was measured using a measuring tape from the soil surface to the highest point of the plant for all plants.

Stem Diameter (cm)

Stem diameter was measured from the midrib of the plant using a vernie caliper (made in China) for all plants.

Number of Leaves (leaf/plant)

The number of leaves per plant was calculated, with three plants selected for each treatment.

Leaf Area

Leaf area was calculated using the following equation:

Leaf area (cm2/plant-1) = leaf length × leaf width (Al-Sahouki, 1990).

Number of branches/plant

The number of branches was calculated for each plant and for all plants.

Fresh and dry weight of the vegetative system (g/plant^{-1})

Three plants were taken from each replicate for each treatment and thoroughly cleaned of dirt and dust using distilled water. The root system was separated from the vegetative system and each was weighed using a sensitive balance. All parts were then air-dried, then the dry vegetative and root parts were placed individually in perforated paper bags and placed in an electric oven at (70)°C for (48) hours until the weight was constant. They were then weighed using a sensitive balance to estimate the dry weight.

Statistical analysis

A Randomized Complete Block Design (RCBD) was employed according to the factorial experiment organization consisting of two factors and three replications. Means were compared when significant differences were found using the Least Significant Differences (LSD) test at a probability level of (0.05).

3. Results and Discussion

The results indicated that foliar spraying with nanofertilizer led to a significant increase in plant height, with the highest rate reaching (80.00) cm when using the nanofertilizer at a concentration of 6 g/L compared to untreated plants which recorded an average height of (44.66) cm. The concentration of 2 g/L gave an average height of 53.33 cm, while the concentration of 4 g/L resulted in an average of 61.33 cm. The results also indicated a significant effect of using garlic extract combined with the foliar spraying on plant height, which resulted in a significant increase; the highest recorded height was (64.75) cm when adding the extract at a concentration of 20 g/L. Meanwhile, the concentration of 15 g/L gave an average height of 57.75 cm, while the concentration of 0 g/L yielded the lowest height averaging 57 cm. The highest recorded height from the combination of nanofertilizer and extract was 88 cm at a concentration of 6 g/L with an extract concentration of 20 g/L, compared to the control treatment which recorded 41 cm. The results from the current study showed that the response of pepper plants to the nanofertilizer exhibited a significant increase in most vegetative growth traits and the active compounds studied in the plant (Table 1).

The superiority of plants treated with nano fertilizer was particularly noted at the concentration of (6 g/L^{-1}) in most of the studied traits represented by plant height (cm) (Table 1). This confirms the importance of nano fertilizer in producing strong-growing plants that are resistant to external conditions, and this may be attributed to the fact that nano compounds possess unique qualitative properties such as their large surface area and small particle size. As a result, their absorption by pepper plants is increased. The reason for the increase in plant height may be due to the role of spraying with nano fertilizer, as these materials have a very large surface area that leads to stimulating growth, increasing photosynthesis, enhancing the plant's tolerance to biotic and abiotic stresses, and also by reducing or inhibiting the formation of reactive oxygen species, which reduces oxidative damage, delays aging, and encourages vegetative growth of the plant (Mushtaq et al., 2024).

While the highest height of the interaction between the nano fertilizer and the extract reached 88 cm at a concentration of 6 g/L with an extract concentration of 20 g/L, compared to the control treatment which reached 41 cm. The results of the current study indicated that the response of the pepper plant to the nano fertilizer showed a significant increase in most of the growth traits

and the active substances studied in the plant. The plants treated with the nano fertilizer, especially at the concentration of (6 g/L), showed superiority in most of the studied traits represented by plant height (cm). This confirms the importance of nano fertilizers in producing robust plants that are resistant to external conditions. This could be attributed to the unique specific properties of nano compounds such as their large surface area and small particle size, which enhance their absorption by the pepper plant. The increase in plant height may be due to the role of applying the nano fertilizer, as these materials have a very large surface area that stimulates growth, increases photosynthesis, enhances the plant's tolerance to biotic and abiotic stresses, and reduces or inhibits the formation of reactive oxygen species.

This is consistent with the findings of Gerami et al. (2024), which confirmed that the addition of nanofertilizer contributed to stimulating the plant to produce plant hormones, particularly auxins, and their important role in increasing the plant's height. The results are also consistent with Abdel-Aziz et al. (2012), which confirmed an increase in the height of the pepper plant *C. annuum* using nanofertilizers, in addition to an increase in leaf area, which enhances the rate of photosynthesis and increases the efficiency of leaf function. These results are also in agreement with what Al-Musawi (2023) concluded in his study on the effects of nanofertilizers on the pepper plant *C. annuum*. The results are also consistent with Gajc-Wolska et al. (2014), which showed that the use of nanofertilizer had a clear effect on the height of *C. annuum*.

Table (1) Effect of nano fertilizer and garlic extract and their interactions on the height rate of pepper plants (cm)

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	41	44	49	44.66
2	53	52	55	53.33
4	56	61	67	61.33
6	78	74	88	80.00
average	86.73	94.77	103.49	
LSD	Fertilizer= 5.38	Extract= 6.22	Combined= 10.77	

Stem Diameter Rate (cm)

The results showed that foliar spraying with nano fertilizer led to a significant increase in the stem diameter rate, reaching a maximum of 1.45 cm when using the nano fertilizer at a concentration of 6 g/L compared to untreated plants which recorded a diameter rate of 1.23 cm. The results also indicated a significant effect of using garlic extract added and the interaction between them on the stem diameter rate, as the highest rate of the stem diameter reached 1.43 cm with the addition of extract at a concentration of 20 g/L, while the concentration of 0 g/L gave the lowest recorded diameter of 1.27 cm. In addition, the concentration of 15 g/L resulted in a rate of 1.32 cm. As for the interactions between the use of concentrations of nano fertilizer with concentrations of garlic extract, the highest stem diameter rate reached 1.65 cm when using the nano fertilizer at a concentration of 6 g/L with 20 g/L of extract, while the interaction consisting of adding garlic extract at a concentration of 0 g/L without adding it to the nano fertilizer resulted in the lowest stem diameter rate of 1.11 g (Table 2).

The results indicated that the stem diameter (cm) (Table 2) is affected by the use of nano fertilizer which provided significant results. The use of nano fertilizer on pepper plants affects the rate the stem diameter in plants. The results indicated that the use of foliar spraying with nano-fertilizer had a significant effect on increasing the stem diameter (cm) (Table 2). The increase in the average diameter is attributed to the role of spraying with nanomaterials due to their growth stimulants and increase in photosynthesis, as well as reducing or inhibiting the formation of reactive oxygen species, which reduces oxidative damage, delays aging, and promotes vegetative

growth in plants (Ahmed and Abdelkader, 2020). The results are consistent with the findings of Helaly and EL-Bauome (2020) in the hot pepper plant *C. annuum*. Consequently, this leads to an increase in the metabolic rate, which results in increased synthesis and accumulation of dry matter and, thus, an overall increase in plant growth rate (Amini et al., 2024). The results also align with Matthews and Siddiqui (2025), who found that the use of nano-fertilizer significantly affected the stem diameter of *C. annuum* plants. Additionally, the results are consistent with Hussein and Alwan (2022), who indicated that the nano-fertilizer affected most growth traits of pepper plants under greenhouse conditions. This is in line with the results from Ahmed and Abdelkader, 2020.

The reason for the increase in stem diameter in pepper plants due to the effect of nano-fertilizer on the activity of the enzymes involved in photosynthesis is attributed to the fact that the active compounds in garlic reduce oxidative stress within plant cells, thereby increasing the efficiency of physiological processes such as photosynthesis (Pacurar and Krejci, 2010). The results are consistent with those of Hussein and Al-Rakabi (2006), who showed that garlic extract significantly affected the stem diameter of cucumber plants *C. sativus*.

Table (2) Effect of nano fertilizer and garlic extract and their interactions on the stem diameter of pepper plants (cm)

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	1.11	1.27	1.31	1.23
2	1.14	1.24	1.34	1.24
4	1.32	1.33	1.43	1.36
6	1.54	1.45	1.65	1.45
average	1.27	1.32	1.43	
LSD	Fertilizer= 0.080	Extract= 0.093	Combined= 0.161	

Number of Leaves (Leaf/Plant)

The results indicated that foliar spraying with nanofertilizer led to a significant increase in the rate of the number of leaves for pepper plants, with the highest rate reaching 60.33 leaves/plant when using the nanofertilizer at a concentration of 6 g/L compared to untreated plants which recorded a rate of 43.66 leaves/plant. The concentration of 2 g/L recorded 43.66 leaves/plant, while the treatment at 4 g/L yielded a rate of 54.00 leaves/plant. The results also indicated a significant effect of using garlic extract on the rate of the number of leaves for pepper plants, with the highest rate reaching 57.50 leaves/plant when adding the extract at a concentration of 20 g/L compared to the control treatment which recorded 43.50 leaves/plant, while the treatment of 15 g/L yielded a rate of 50.25 leaves/plant (Table 3).

The interactions between using concentrations of nanofertilizer with concentrations of garlic extract, the highest rate of leaves per plant was 62 leaves/plant when using nanofertilizer at a concentration of 6 g/L with a concentration of 20 g/L of garlic extract, while the interaction of adding nanofertilizer at a concentration of 2 g/L with 0 g/L of garlic extract gave the lowest rate of number of leaves.

The number of leaves reached 33 leaves/plant compared to the untreated plants, which reached 34 leaves/plant. It is observed from Table (3) a significant increase in growth indicators, including the number of leaves, due to the increased concentrations of nano-fertilizers and garlic extract that stimulated the plant to increase the rate of auxins, which have a significant effect on enhancing the activity of the meristematic tips and increasing cell division and elongation. This is attributed to the availability of materials that the plant needs in the process of photosynthesis,

such as amino acids and others (Manas et al., 2014). The results agree with Assi et al. (2020) that the nano-fertilizer significantly affected the leaf count of the pepper plant C. annuum. The results also align with those reached by Helaly and El-Bauome (2020) that the nano-phosphorus increased the leaf count of the hot pepper plant *C. annuum*. The effect of garlic extract is also attributed to the role of auxins present in the garlic extract, which enhance the metabolic activities that encourage cell division and increase the number of leaves (Pacurar and Krejci, 2010). It also helps the plant to better absorb nutrients (N, P, K), which reflects in the increase of vegetative growth, such as the number of leaves. The results are consistent with Leone.

The results are consistent with those of Leonel et al. (2015) in their study on the effect of three levels of garlic extract on the leaf count of fig trees. The results also align with what Armanious (2014) found regarding the effect of spraying garlic extract on the leaf count of grape plants. The results concur with the findings of Maaitiq and Harous (2012), who found that garlic extract had a significant effect on the leaf count of basil plants (*O. basilicum*). This result is also consistent with what Bozorgi (2012) discovered in eggplant (*Solanum melongena*).

Table (3) Effect of nano fertilizer and garlic extract and their interactions on the number of leaves of plants

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	34	41	56	43.66
2	33	48	50	43.66
4	46	54	62	54.00
6	61	58	62	60.33
average	43.50	50.25	57.50	
LSD	Fertilizer= 7.070	Extract= 8.160	Combined= 14.130	

Leaf Area (cm^2)

The results in Table (4) showed that foliar spraying with nanofertilizer led to a significant increase in the leaf area rate of pepper plants, with the highest average leaf area reaching 870.80 cm^2 when using a nanofertilizer concentration of 6 g/L compared to the untreated plants, which recorded an average of 784.16 cm^2. The treatment with 2 g/L of fertilizer resulted in an average of 805.53 cm^2, while the treatment with 4 g/L gave an average of 822.83 cm^2.

The results also indicated a significant effect of using garlic extract on the leaf area rate of pepper plants, with the highest average reaching 852.37 cm^2 when adding the extract at a concentration of 20 g/L compared to the addition of 15 g/L, which reached 799.72 cm^2, while the treatment with 0 g/L of the extract gave an average of 810.40 cm^2.As for the interactions between using concentrations of nanofertilizer with concentrations of garlic extract, the highest leaf area rate of 889.10 cm^2 was observed when using nanofertilizer at a concentration of 6 g/L combined with a concentration of 20 g/L of garlic extract, while the interaction involving the addition of garlic extract at a concentration of 0 g/L without adding it to nanofertilizer resulted in the lowest rate. The leaf area reached 764.10 cm^2, while the treatment with a fertilizer concentration of 0 g/L alongside 20 g/L of extract concentration resulted in an average of 799.20 cm^2. The treatment with an addition of 15 g/L of extract showed similar results in terms of leaf area. The results indicated that the use of foliar spraying with nano-fertilizer was significantly effective in increasing the average leaf area of pepper plants (cm^2) (Table 4). The increase in average leaf area is attributed to the role of spraying nanomaterials, due to their growth-promoting properties and increased photosynthesis, which reduces oxidative damage and encourages vegetative growth of the plant (Assi et al., 2020). Consequently, an increase in metabolic rate leads to an

increase in the average leaf area of pepper plants in general (Al-Musawi, 2023). These results align with those of Al-Salami and Abbass (2021), who found that the use of nano-fertilizer significantly affected the average leaf area of pepper plants.

The results also concur with Gajc-Wolska et al. (2018), which showed that nano-fertilizer affected most growth traits of pepper plants, including leaf area, as the use of nano-phosphorus fertilizer led to this effect There is a clear significant increase in the leaf area. The effect of garlic extract is related to certain sulfur compounds in garlic that may influence the balance of auxins and cytokinins, leading to the stimulation or inhibition of vegetative growth depending on concentration. Additionally, the effect of garlic extract is linked to an increase in metabolic activities, consequently increasing the leaf area (Pacurar and Krejci, 2010). The results are consistent with those of Maaitiq and Hrous (2012), who showed that garlic plant extract increased the leaf area rate of basil *O. bacilicum*.

Table (4) Effect of nano fertilizer and garlic extract and their interactions on the leaf area of plants (cm)

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	764.10	789.20	799.20	784.16
2	767.20	795.40	854.01	805.53
4	799.20	802.10	867.20	822.83
6	911.10	812.20	889.10	870.80
average	810.40	799.72	852.37	
LSD	Fertilizer= 3.010	Extract= 4.580	Combined= 7.010	

The number of branches

The results indicated that foliar spraying with nanofertilizer led to a significant increase in the average number of branches for pepper plants, where the highest average number of branches reached 6.16 branches/plant when using the nanofertilizer at a concentration of 6 g/L compared to untreated plants which recorded an average of 5.20 branches/plant. The treatments with 2 g/L and 4 g/L recorded 5.13 and 5.66 branches/plant, respectively (Table 5).

The results also indicated a significant effect of using added garlic extract on the average number of branches for pepper plants, with the highest average reaching 6.30 branches/plant when adding the extract at a concentration of 20 g/L compared to the control treatment which recorded 4.65 branches/plant, while the treatment of adding 15 g/L of the extract gave an average of 5.67 branches/plant. Regarding the interactions between using concentrations of nanofertilizer with concentrations of garlic extract, the highest average number of branches reached 6.9 branches/plant when using the nanofertilizer at a concentration of 6 g/L combined with 20 g/L of garlic extract, while the interaction involving adding garlic extract at a concentration of 0 g/L without addition with the nanofertilizer resulted in the lowest average number of branches which was 4.1 branches/plant.

The lowest average number of branches reached 4.1 branches/plant. The results indicate that the effect of nano-phosphorus was also observed in calculating the average number of branches, due to its role in the formation of the important amino acid tryptophan, which is essential in the production of IAA necessary for increasing cell division and enhancing the activity and divisions of meristematic cells. Additionally, it is involved in the structure of the plasma membrane and participates in many functions of plant cells, playing a key role in protecting plant cells from oxidation as well as contributing to the synthesis of enzymes, peptides, and proteins. The results are consistent with the findings of Assi et al. (2020) that nano-fertilizer significantly affected the average number of branches for the pepper plant *C. annuum*. The results also with what Helaly

and El-Bauome (2020) found, that nano-phosphorus increased the average number of branches for the chili pepper plant *C. annuum*.

Table (5) Effect of nano fertilizer and garlic extract and their interactions on the number of branches of plants

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	4.1	5.4	6.1	5.20
2	4.2	5.3	5.9	5.13
4	5.1	5.6	6.3	5.66
6	5.2	6.4	6.9	6.16
average	4.65	5.67	6.30	
LSD	Fertilizer= 0.437	Extract= 0.504	Combined= 0.870	

The fresh weight (g/plant)

The results of Table (6) indicate that foliar spraying with nano fertilizer led to a significant increase in the average fresh weight of pepper plants, reaching a maximum average of 196.22 g/plant when using nano fertilizer at a concentration of 6 g/L compared to the untreated plants which recorded an average fresh weight of 188.19 g/plant. The results also showed that the concentrations of 2 and 4 g/L produced averages of 182.54 and 191.93 g/plant, respectively. The results indicated a significant effect of using garlic extract on the average fresh weight of pepper plants, with the highest average reaching 194.17 g/plant when the extract was added at a concentration of 20 g/L. In contrast, the concentration of 15 g/L provided an average of 188.96 g/plant, while the concentration of 0 g/L resulted in an average of 183.02 g/plant.

The interactions between using concentrations of nano fertilizer with concentrations of garlic extract, the highest average fresh weight of the vegetative mass was 199.01 g/plant when using nano fertilizer at a concentration of 6 g/L combined with 20 g/liter of garlic extract, whereas the interaction of adding nano fertilizer at 2 g/L with 0 g/liter of garlic extract showed an average of Garlic extract resulted in the lowest average fresh weight of the vegetative total at 174.23 g/plant, while the control treatment yielded an average of 187.20 g/plant.

The results showed that the concentration of the extract at 20 g/L with fertilizer concentrations of 0, 2, 4, and 6 g/l yielded similar results, recording averages of 191.40, 192.60, 193.69, and 199.01 g/plant respectively. The results indicated that the use of foliar spraying with nano-fertilizers was significantly effective in increasing the average fresh yield of the vegetative total (g/plant) (Table 6). The increase in the average fresh yield is attributed to the role of spraying nano materials, as they possess substances that reduce oxidative damage and thus encourage the vegetative growth of the plant (Sajyan et al., 2020). The impact is due to the fact that phosphorus fertilizer is part of the molecular structure of important compounds, including ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). It also plays a crucial role in the processes of photosynthesis and cell division (Marshner, 1995). Khan et al. (2002) confirmed that nano phosphorus enhanced the activities of key enzymes and improved its transport in leaves, which increases plant growth and development, as it increased fresh weight compared to non-treated plants.

The results are consistent with what Assi et al. (2020) found regarding pepper plants, which indicated that the use of foliar spraying of nano fertilizers had a clear effect on most vegetative growth traits, including the yield of fresh biomass, which leads to an increase in the rate of photosynthesis in the plant and an increase in dry matter accumulation. The results are also

consistent with Prakashraj et al. (2021), who concluded that the use of nano fertilizer clearly affected the fresh weight of pepper plants. Furthermore, the results align with Ajil and Jaafar et al. (2022), who showed that nano fertilizer affected the yield of fresh biomass in pepper plants. Garlic extract improved metabolic activities, which encourage cell division processes and increase the fresh weight of the plant; it also limits the growth of harmful fungi and bacteria in the root area (rhizosphere), thereby improving nutrient absorption, reducing plant diseases, and positively impacting vegetative growth. The effect of garlic extract is also attributed to the role of macro and micronutrients it contains, which enhance metabolic activities, as well as the presence of auxins that promote cell division processes and growth increase.

Table (6) Effect of nano fertilizer and garlic extract and their interactions on the fresh weight of plants (g/plant)

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	187.20	185.98	191.40	188.19
2	174.23	180.78	192.60	182.54
4	189.43	192.67	193.69	191.93
6	193.22	196.44	199.01	196.22
average	183.02	188.96	194.17	
LSD	Fertilizer= 24.080	Extract= 27.800	Combined= 48.150	

The dry weight (g/plant)

The foliar spraying with nanofertilizer led to a significant increase in the average dry weight of pepper plants, reaching a highest average of 87.90 g/plant when using nanofertilizer at a concentration of 6 g/l compared to untreated plants which recorded an average dry weight of 76.80 g/plant. Concentrations of 2 and 4 g/l recorded averages of 78.73 and 81.80 g/plant, respectively. The results also indicated a significant effect of adding garlic extract on the average dry weight of pepper plants, with the highest average being 94.85 g/plant when adding the extract at a concentration of 20 g/l, while the control treatment recorded an average of 70.70 g/plant (Table 7).

The concentration of 15 g/l resulted in an average of 78.37 g/plant. Regarding the interactions between using concentrations of nanofertilizer and concentrations of garlic extract, the highest average dry weight of the vegetative mass was 98.4 g/plant when using nanofertilizer at a concentration of 6 g/l combined with 20 g/l garlic extract. In contrast, the interaction involving the addition of garlic extract at a concentration of 0 g/l without adding it to nanofertilizer resulted in the lowest average dry weight of 66.1 g.

The results also showed a gradual increase with increasing concentrations of fertilizer and extract, as shown in Table (7). The dry weight of the vegetative mass (g/plant) (Table 4-7) was also affected by the addition of the nano-fertilizer. The results demonstrated a significant increase with the addition of different concentrations of the nano-fertilizer for pepper plants. The increase in the percentage of dry matter in the vegetative mass is due to the treatment with nano-fertilizers, which play a role in activating photosynthesis and thus enhance the plant's ability to absorb essential mineral nutrients from the soil, leading to increased growth of the vegetative mass. Furthermore, the increase in the percentage of dry matter in the vegetative mass may be attributed to the increased activity of the vegetative mass in manufacturing food and supplying it to the roots, resulting in an increase in its weight.

These results are consistent with the findings of both Helaly and EL-Bauome (2020) on hot pepper plants and also with Amini et al. (2024) regarding the addition of nano-phosphorus and

its effect on the dry weight of pepper in greenhouses. The effect of garlic extract is due to the role of major and minor nutrients it contains, which enhance metabolic activities. The presence of auxins also encourages cell division processes and increases dry weight. Some sulfur compounds in garlic may affect the balance of auxins and cytokinins, leading to the stimulation or inhibition of vegetative growth depending on the concentration (Pacurar and Krejci, 2010).

Table (7) Effect of nano fertilizer and garlic extract and their interactions on the dry weight of plants (g/plant)

Nanofertilizer (g/L^{-1})	garlic extract (g/L^{-1})			average
	0	15	20	
0	66.1	73.2	91.1	76.80
2	68.2	74.6	93.4	78.73
4	73.4	75.5	96.5	81.80
6	75.1	90.2	98.4	87.90
average	70.70	78.37	94.85	
LSD	Fertilizer= 6.020	Extract= 6.950	Combined= 12.050	

Conclusions

The study concludes that nano fertilizers and garlic plant extracts, and the interaction between them at different concentrations effected in most of the studied vegetative growth traits of the plants, and the increase was greater with the increase in the concentration of the nano fertilizer, such as plant height. Foliar application of the nano fertilizer resulted in a significant increase in the average plant height, stem diameter (cm) of the plant, number of leaves (leaves/plant), average fresh yield of leaves (g/plant), leaf area (cm), average dry yield of leaves (g/plant).

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