Iraqi Journal of Agricultural Sciences –2026:57(10):2595-2609
P-ISSN: 0075- 0530 /E-ISSN: 2410-0862
DOI: https://doi.org/10.36103/hm3ksx63

Contribution of Sustainable Organic Treatments to Enhancing Medicinal Compounds in Green Onion

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ABSTRACT

This study was carried out at the fields of the College of Agricultural Engineering Sciences, University of Baghdad from October 1 2024 to March 15, 2025, to study the effect of fertilization with palm waste at levels 0, 20 and 30 tons ha^{-1}, the organic sulfur in levels 0, 300 and 600 kg ha^{-1} and foliar spraying of garlic extract at concentrations 0 and 6 mL L^{-1} on the medicinal compound content of green onion. The experiment was conducted as a randomized complete block design (RCBD) with a Split Plot arrangement with three replications. The results indicated that applying palm waste at 30 tons ha^{-1} and organic sulfur at 600 kg ha^{-1} significantly increased significantly the concentrations of quercetin, kaempferol, rutin, apigenin, luteolin, DPPH activity, and vitamin C in green onion bulbs. Additionally, garlic extract foliar application enhanced the levels of DPPH antioxidant activity, and vitamin C content. Notably, the combined treatment of palm waste at 30 tons ha^{-1}, organic sulfur at 600 kg ha^{-1}, and garlic extract at 6 mL L^{-1} produced the highest concentrations of quercetin (140.24 ppm), kaempferol (83.67 ppm), rutin (129.24 ppm), apigenin (35.35 ppm), luteolin (59.57 ppm), DPPH activity (0.427 mg 100 g^{-1}), and vitamin C (11.57 mg 100 g^{-1}) in green onion bulbs.

Key words: garlic extract, kaempferol , palm waste, quercetin, recycling.

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Received: 22/5/2025, Accepted: 3/8/2025, Published: 31/10/2026

INTRODUCTION

The global agricultural scenario has experienced a great revolution towards environment-friendly and sustainable farming, which ensures food security while protecting the natural resources, where agricultural waste and organic sources are considered as a good alternative for chemical fertilizers for improving the soil properties and the bioactive compounds of the plants (Ali et al., 2025), particularly for the nutritionally and medicinally important crops such as green onions (*Allium fistulosum* L.) (Mahmood et al., 2021) as a strategic vegetable in Iraq and globally which belongs to Alliaceae family and is rich in carbohydrates and minerals mainly the sulfur compounds (Liu et al., 2024). Green onion is also widely recognized for its high medicinal value associated with a sulfur-containing compound, the main reason for its unique spicy taste. It also has natural antioxidants such as quercetin, one of the most found in large quantities of antioxidants in the green onion, important to help the human body fight against free radical damage usually associated with chronic diseases such as heart diseases and some cancers—and in strengthening the human immune system (Javed, 2025 and Kim et al., 2023). Furthermore, green onion contains kaempferol, phenolic compounds (Zhao et al., 2021), and vitamins C, A, and B9, etc. (Akbar et al., 2024 and Amare, 2020). While the intensive use of chemical fertilizers in modern agricultural systems has promoted crop yield, it has also produced many negative results for both the environment and human health. These include pollution of groundwater and reduced soil fertility. In view of the escalating environmental problems and the worldwide

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attention to sustainable food security, there is a dire need to obtain natural and environmentally friendly options for reducing and directing our dependence on the use of chemical inputs (Abdel-Hakim, 2020). Organic treatments are being identified as effective and sustainable alternatives that enhance soil properties and organic matter and plant available nutrient contents (Asha et al., 2023). They also force out beneficial microbes and establishing the ecological balance within the agricultural system. Increasingly, then, the transition to organic farming is seen as a strategic option to guarantee healthy and safe agriculture and food production, and to respect and preserve the environment and biodiversity (Du et al., 2022) Among these organic fertilizers is the use of date palm waste. This natural material plays a significant role in improving soil characteristics (Bayoumi et al., 2022; Ghouili et al., 2023), increasing the availability and absorption of nutrients, and consequently enhancing the nutritional status of plants (Le Guyader et al., 2024; Muslat et al., 2017). This research also incorporates the addition of organic sulfur due to its important role in plant growth (Desouza & et al., 2015; He et al., 2010), particularly for green onions. The productivity and quality of green onions are known to be influenced by sulfur application. Thus, sulfur is considered an essential element for plant growth and development (Manik et al, 2024; Taru et al., 2025). Sulfur is critical to plant metabolism, especially when combined with nitrogen (Demissie et al., 2024), for both are involved in the synthesis of amino acids and proteins. A sulfur shortage can result in the disturbance of protein synthesis and even the development of whole plant (Khorsheed & Al-Tamimi, 2018; Sable et al., 2024) some researchers. (Al-Amri & Al-Abdaly, 2021; Manik et al., 2024; Tilahun et al., 2021) studied the effect of agricultural sulfur on the growth of different onion varieties (*Allium cepa* L.) and found that sulfur fertilization treatments improved significantly most growth characters and total yield, confirming the relevance of sulfur in onion production(Demissie et al., 2024).These plant extracts are consistent with sustainable development using renewable natural resources and low environmental impact of chemical inputs (Al-Khafaji & AlJubouri, 2022). Among them, garlic extract is studied on the aspect of functional food material as it is enriched with various bioactive compounds, such as allicin, S-containing compounds, phenolics and flavonoids (Sunanta et al., 2023). All these are the factors that contribute to enhanced plant growth, disease resistance and nutrient use efficiency (Bulgari et al., 2019; Bar et al., 2022). Al-Hajj et al (Al-Hajj et al., 2022 and Maitig et al., 2025) also emphasized the broader importance of plant extracts — especially garlic extracts in promoting healthier plant development. Given the limited number of studies focusing on the combined application of palm waste, organic sulfur, and garlic extract on green onion (*Allium fistulosum)*, this research was designed to investigate how these organic inputs influence the production of medicinal compounds in green onions. This study aimed to explore sustainable alternatives that can enhance both crop quality and phytochemical content without relying heavily on synthetic fertilizers.

MATERIALS AND METHODS

The experiment was conducted at the Research Station (A) of the College of Agricultural Engineering Sciences, University of Baghdad, during the period from October 1, 2024, to March 15, 2025. The aim of this research was to investigate the impact of fertilization with palm waste, organic sulfur, and foliar application of garlic extract on the content of medicinal compounds in green onion. The field was divided into three blocks each with 18 experimental units. The land was arranged into raised beds, with each bed representing one experimental unit measuring 1 × 1 m². Planting was done in rows, spaced 10 cm apart, and with 7 cm between plants within each row—resulting in 150 plants per unit. A 0.50 m buffer zone was maintained between units to prevent cross-contamination between treatments. Well-decomposed palm waste compost was applied to the designated plots according to the assigned treatments, followed by the installation of a drip irrigation system. Seeds of a hybrid green onion cultivar

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(*Bunching Onion*) were sown on October 1, 2024, in polystyrene trays at a commercial nursery. Once the seedlings developed 2–3 true leaves, they were transplanted to the open field on November 15. The experiment comprised three factors and the levels of treatment being featured are:

1. Treatments Fertilization of Palm Waste 0, 20, and 30 ton ha^{-1} (symbol T_0, T_1 and T_2).
2. Sulfur Fertilization with three levels 0, 300 and 600 kg per ha produced by Spanish Afepasa company (symbol S_0, S_1 and S_2).
3. Foilar application of Garlic Extract Foliar Spray with two levels: 0 and 6 ml L^{-1} (symbol G_0 and G_1). The garlic extract was obtained by homogenizing 150 g fresh garlic cloves with 150 mL of distilled water by a mixer. Then, the mixture was filtered using two layers of muslin cloth to produce 100% garlic extract solution, and ml L^{-1} concentration was prepared from it (Al-Hajj et al., 2022).

The experiment conducted according to a Randomized Complete Block Design (RCBD) with split plot arrangement with three replications. The fertilization treatments with palm residues (T) were randomly distributed within the main plot factor. The interaction of organic sulfur fertilizer (S) and garlic extract treatments (G) were randomly distributed within the sub-plot factor (the more important factors). The means were compared using the Least Significant Difference (LSD) test at a probability level of 0.05 (Elsahooki & Waheeb, 1990).Studied Traits: A range of medicinal compounds and qualitative traits were measured in the green onion bulbs as follows:

1. Quercetin compound (ppm).
2. Kaempferol compound (ppm).
3. Rutin compound (ppm).
4.Luteolin compound (ppm).
5. Apigenin compound (ppm). The above medicinal compounds were calculated according to the method described in Radovanovic et al., (Radovanović et al., 2015).
6. DPPH antioxidants (mg $100g^{-1}$) according to the method described in (Bayoumi etal.,2022).
7. Vitamin C content in green onion heads (mg 100 g^{-1}) according to the method described by Ibrahim (2010).

RESULTS AND DISCUSSION

Quercetin concentration in green onion bulbs (ppm): Table (1) shows that significant differences were observed in the quercetin concentration of green onion bulbs because of varying levels of palm waste fertilizer. The highest concentration was recorded in treatment T2, reaching 127.26 ppm. Similarly, organic sulfur fertilizer had a significant effect on quercetin accumulation, with treatment S2 (600 kg ha^{-1}) recording a value of 125.64 ppm. Regarding spraying garlic extract, treatment G1 outperformed with a concentration of 122.96 ppm. the two-way interaction between palm waste and organic sulfur (T × S), the combination T2S2 (30 tons ha^{-1} palm waste + 600 kg ha^{-1} sulfur) produced the highest quercetin concentration of 135.38 ppm, significantly outperforming the untreated control (T0S0, which gave only 97.87 ppm). In terms of the interaction between palm waste and garlic extract (T × G), a significant increase was recorded, with the T2G1 combination reaching 135.06 ppm, in contrast to the lowest value of 98.84 ppm in the T0G0 treatment. The interaction between sulfur and garlic extract (S × G) also showed promising results, with the S2G1 treatment (600 kg ha^{-1} sulfur + 6 mL L^{-1} garlic extract) giving the highest quercetin level of 130.40 ppm Most notably, the three-way interaction (T × S × G) had the greatest impact. The T2S2G1 treatment resulted in the highest quercetin concentration in green onion bulbs, reaching 140.24 ppm, whereas the lowest value was recorded under T0S0G0 (93.51 ppm), highlighting the combined effectiveness of all three organic inputs.

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Table 1. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on quercetin concentration (ppm) in green onion bulbs

T × S	G_0	G_1	Means
T_0 S_0	93.51	102.22	97.87
T_0 S_1	96.40	111.22	103.81
T_0 S_2	106.62	117.57	112.10
T_1 S_0	99.29	114.46	106.87
T_1 S_1	104.50	122.55	113.52
T_1 S_2	125.49	133.40	129.44
T_2 S_0	108.75	127.32	118.04
T_2 S_1	119.10	137.63	128.36
T_2 S_2	130.53	140.24	135.38
L.S.D. 0.05	0.3202		0.2264
		T × G	T
T_0	98.84	110.34	104.59
T_1	109.76	123.47	116.61
T_2	119.46	135.06	127.26
L.S.D. 0.05	0.1849		0.0586
		S × G	S
S_0	100.52	114.67	107.59
S_1	106.67	123.80	115.23
S_2	120.88	130.40	125.64
L.S.D. 0.05	0.1849		0.1307
G	109.35	122.96	
L.S.D. 0.05	0.1067		

Kaempferol (ppm) concentration of green onion bulbs: The results of Table (2) indicated that adding palm waste fertilizer caused an increase in the Kaempferol compound in the green onion bulbs, especially treatment T2, which reached 72.91 ppm. Regarding the effect of fertilizing with organic sulfur, treatment S2 was superior in this trait, as the Kaempferol compound in it reached 71.37 ppm. Regarding spraying garlic extract, treatment G1 was superior with a content of 69.08 ppm. The two-way interaction between palm waste and organic sulfur (T × S) showed significant results, particularly for the T2S2 combination (30 tons ha^{-1} palm waste + 600 kg ha^{-1} sulfur), which produced the highest kaempferol concentration at 79.70 ppm — a substantial increase compared to the lowest value of 46.48 ppm recorded in the untreated control (T0S0).In terms of the interaction between palm waste and garlic extract (T × G), the T2G1 treatment significantly outperformed others, reaching 79.28 ppm, compared to only 47.12 ppm in the T0G0 group (no fertilizer or spray). Furthermore, the interaction between sulfur and garlic extract (S × G) also showed statistical significance. The S2G1 treatment (600 kg ha^{-1} sulfur + 6 mL L^{-1} garlic extract) gave the highest kaempferol level at 75.14 ppm , whereas the control interaction (S0G0) recorded the lowest at 49.16 ppm Regarding the three-way interaction effect among the study factors, the results showed the superiority of the T2S2G1 interaction treatment. In this treatment, the Kaempferol content in the bulbs increased to 83.67 ppm, while the T0S0G0 interaction treatment recorded the lowest content at 41.53 ppm.

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Table 2. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on Kaempferol (ppm) concentration of green onion bulbs

T × S	G_0	G_1	Means
$T_0 S_0$	41.53	51.43	46.48
$T_0 S_1$	44.40	59.11	51.76
$T_0 S_2$	55.42	64.27	59.84
$T_1 S_0$	48.62	62.49	55.56
$T_1 S_1$	53.38	69.10	61.24
$T_1 S_2$	71.66	77.47	74.56
$T_2 S_0$	57.33	73.73	65.53
$T_2 S_1$	66.53	80.46	73.49
$T_2 S_2$	75.73	83.67	79.70
L.S.D. 0.05	0.3406		0.2409
		T × G	T
T_0	47.12	58.27	52.69
T_1	57.89	69.69	63.77
T_2	66.53	79.28	72.91
L.S.D. 0.05	0.1967		0.2755
		S × G	S
S_0	49.16	62.55	55.85
S_1	54.77	69.55	62.16
S_2	67.60	75.14	71.37
L.S.D. 0.05	0.1967		0.1391
G	57.18	69.08	
L.S.D. 0.05	0.1135		

Rutin concentration of green onion bulbs (ppm): The results of Table (3) indicate that adding palm waste fertilizer T2 increased the rutin concentration of green onion heads to 118.85 ppm. Organic sulfur fertilization showed a significant effect on this trait, as treatment S2 gave the highest Rutin concentration of 117.16 ppm. Regarding the garlic extract spraying treatment, treatment G1 was superior, giving the highest value of 117.43 ppm compared to the treatment without spraying G0 (102.62 ppm). The interaction T×S had a positive effect on this trait, as the interaction T2S2 gave the highest Rutin concentration of 125.91 ppm. Regarding the effect of the T×G interaction, the interaction T2G1 was distinguished by giving the highest Rutin concentration of 125.50 ppm. The interaction between the organic sulfur fertilization treatments and the garlic extracts spraying S×G had a significant effect on increasing the Rutin compound in the bulbs, as the interaction S2G1 gave the highest value of 120.84 ppm. Regarding the triple interaction, the results indicated the superiority of the interaction T2S2G1, which produces the highest Rutin concentration. Rutin in the bulbs reached 129.24 ppm, compared to the lowest concentration in the T0S0G0 interference treatment of 88.55 ppm.

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Table 3. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on Rutin concentration of green onion bulbs (ppm)

T × S	G_0	G_1	Means
T_0 S_0	88.55	94.76	91.65
T_0 S_1	90.47	104.57	97.52
T_0 S_2	100.45	108.76	104.61
T_1 S_0	92.43	106.35	99.39
T_1 S_1	97.72	114.41	106.07
T_1 S_2	117.40	124.52	120.96
T_2 S_0	102.55	120.45	111.50
T_2 S_1	111.44	126.82	119.13
T_2 S_2	122.58	129.24	125.91
L.S.D. 0.05	0.3635		0.2570
		T × G	T
T_0	93.15	102.70	97.93
T_1	102.51	115.09	108.80
T_2	112.19	125.50	118.85
L.S.D. 0.05	0.2098		0.2110
		S × G	G
S_0	94.51	107.19	100.85
S_1	99.88	115.27	107.57
S_2	113.47	120.84	117.16
L.S.D. 0.05	0.2098		0.1484
G	102.62	117.43	
L.S.D. 0.05	0.1212		

Apigenin concentration (ppm) in green onion bulbs: The results in Table (4) indicate that different levels of added palm residue fertilizer led to an increase in the Apigenin concentration of green onion bulbs Treatment T2 yielded the highest concentration of 28.65 ppm, outperforming treatment T0, where apigenin decreased to 17.46 ppm. Organic sulfur fertilization was accompanied by a significant increase in this trait, with treatment S2 yielding the highest apigenin concentration of 27.63 ppm, compared to treatment S0 (18.98 ppm). Spraying with garlic extract outperformed treatment G1 in this trait, with its apigenin concentration reaching 26.38 ppm. The results of the two-way interaction between T×S showed the significant superiority of the T2S2 interaction treatment, which gave the highest Apigenin concentration of 32.55 ppm, compared to the T0S0 interaction treatment, which gave the lowest concentration of 13.97 ppm. Regarding the two-way interaction between T×G, the results indicated the significant distinction of the T2G1 interaction treatment, which gave the highest Apigenin concentration in the bulbs at 32.40 ppm. Furthermore, the interaction between organic sulfur fertilization and garlic extract spraying had a significant effect on increasing this trait, with the S2G1 interaction treatment giving the highest concentration of 30.08 ppm. The results of the three-way interaction among the study factors showed the superiority of the T2S2G1 interaction treatment, which produces the highest Apigenin concentration in the bulbs at 35.35 ppm, compared to the lowest concentration observed in the T0S0G0 interaction treatment, which was 12.41 ppm.

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Table 4. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on Apigenin (ppm) concentration of green onion bulbs

T × S	G_0	G_1	Means
T_0 S_0	12.41	15.52	13.97
T_0 S_1	13.11	21.73	17.32
T_0 S_2	18.45	23.73	21.09
T_1 S_0	14.73	22.40	18.56
T_1 S_1	16.45	25.85	21.15
T_1 S_2	27.35	31.17	29.26
T_2 S_0	20.45	28.35	24.40
T_2 S_1	24.52	33.50	29.01
T_2 S_2	29.76	35.35	32.55
L.S.D. 0.05	0.3915		0.2769
		T × G	T
T_0	14.67	20.26	17.46
T_1	19.51	26.47	22.99
T_2	24.91	32.40	28.65
L.S.D. 0.05	0.2261		0.0853
		S × G	S
S_0	15.86	22.09	18.98
S_1	18.03	26.96	22.49
S_2	25.19	30.08	27.63
L.S.D. 0.05	0.2261		0.1598
G	19.69	26.38	
L.S.D. 0.05	0.1305		

Luteolin concentration (ppm) in green onion bulbs: The effect of varying levels of palm residue fertilizer addition on the Luteolin concentration of green onion bulbs was diverse, as indicated in Table (5). A significant superiority was observed with increasing addition levels, with treatment T2 outperforming by giving the highest values of 50.25 ppm. A significant effect was also noted with organic sulfur fertilization, where fertilization treatment S2 was distinguished by giving the highest Luteolin concentration of 48.79 ppm. Regarding the effect of spraying with garlic extract, treatment G1 excelled in this trait, giving 45.81 ppm. The dual interaction effect of T×S varied in increasing Luteolin concentration in the bulbs, showing a significant superiority for treatment T2S2 (56.53 ppm) compared to the lowest concentration recorded in the T0S0 interaction treatment (24.96 ppm). The T2G1 interaction treatment recorded the highest Luteolin concentration in the bulbs at 54.12 ppm, while the lowest concentration was found in the T0G0 treatment (26.05 ppm). A significant increase in the Luteolin concentration of the bulbs was also observed as a result of the S×G interaction, with the S2G1 interaction treatment giving the highest values of 52.41 ppm. The results in the same table showed that the triple interaction significantly affected the increase in the studied trait. The T2S2G1 interaction treatment outperformed the other treatments by giving the highest Luteolin concentration in the bulbs at 59.57 ppm, compared to the lowest values found in the T0S0G0 interaction treatment, which was 21.46 ppm.

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Table 5. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on luteolin concentration (ppm) in green onion bulbs

T × S	G_0	G_1	Means
T_0 S_0	21.46	28.46	24.96
T_0 S_1	24.40	36.75	30.58
T_0 S_2	32.30	42.35	37.32
T_1 S_0	26.77	39.73	33.25
T_1 S_1	30.53	47.29	38.91
T_1 S_2	49.71	55.33	52.52
T_2 S_0	34.32	45.37	39.84
T_2 S_1	51.35	57.42	54.38
T_2 S_2	53.50	59.57	56.53
L.S.D. 0.05	0.2649		0.1873
		T × G	T
T_0	26.05	35.85	30.95
T_1	35.67	47.45	41.56
T_2	46.39	54.12	50.25
L.S.D. 0.05	0.1529		0.3685
		S × G	S
S_0	27.05	37.85	32.69
S_1	35.43	47.15	41.29
S_2	45.17	52.41	48.79
L.S.D. 0.05	0.1529		0.1081
G	36.04	45.81	
L.S.D. 0.05	0.0883		

Green onion heads DPPH antioxidant concentration (mg l00g-1) The results of Table (6) indicate significant differences between palm waste fertilization treatments in the bulbs' DPPH antioxidant concentration. Treatment T2 outperformed, yielding the highest concentration of 0.360 mg $l00g^{-1}$, compared to treatment T0, which yielded the lowest concentration (0.294 mg $l00g^{-1}$). Organic sulfur fertilization also had a significant effect on this trait, as treatment S2 yielded the highest DPPH concentration in bulbs, reaching 0.364 mg $l00g^{-1}$, compared to the lowest DPPH found in treatment S0, which was 0.291 mg $l00g^{-1}$. In the garlic extract spray treatments, treatment G1 outperformed, yielding 0.336 mg $l00g^{-1}$. The interaction between the treatments of fertilization with palm waste and organic sulfur affected this trait, as the interaction treatment T2S2 gave the highest concentration of DPPH in the heads, reaching 0.403 mg.$100g^{-1}$ Regarding the effect of fertilization with palm waste and spraying with garlic extract, the interaction treatment T2G1 was distinguished by giving the highest concentration of DPPH in the heads, reaching 0.378 mg .$100g^{-1}$.The interaction between the treatments of fertilization with organic sulfur and spraying with garlic extract also had a significant effect on this trait, as the interaction treatment S2G1 gave the highest value, reaching 0.369 mg 100 g^{-1}. Regarding the three-way interaction, the results indicated the superiority of the interaction treatment T2S2G1, which gave the highest concentration of DPPH in the heads, amounting to 0.427 mg 100 g-1, compared to the lowest concentration in the interaction treatment T0S0G0, which was 0.220 mg 100 g^{1}.

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Table 6. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on green onion bulbs DPPH antioxidant concentration (mg l00g^{-1})

T × S	G_0	G_1	Means
T_0 S_0	0.220	0.257	0.238
T_0 S_1	0.297	0.347	0.322
T_0 S_2	0.307	0.340	0.323
T_1 S_0	0.280	0.273	0.277
T_1 S_1	0.377	0.337	0.357
T_1 S_2	0.390	0.340	0.365
T_2 S_0	0.347	0.367	0.357
T_2 S_1	0.300	0.340	0.320
T_2 S_2	0.380	0.427	0.403
L.S.D. 0.05	0.0335		0.0237
		T × G	T
T_0	0.274	0.314	0.294
T_1	0.349	0.317	0.333
T_2	0.342	0.378	0.360
L.S.D. 0.05	0.0193		0.0163
		S × G	S
S_0	0.282	0.299	0.291
S_1	0.324	0.341	0.333
S_2	0.359	0.369	0.364
L.S.D. 0.05	0.0193		0.0137
G	0.322	0.336	
L.S.D. 0.05	0.0111		

Vitamin C concentration in green onion bulbs (mg 100 g^{-1}): The results of Table 7 indicate that different levels of fertilization with palm waste significantly affect the bulbs' vitamin C concentration. Treatment T2 outperformed, yielding the highest vitamin C concentration, reaching 8.92 mg 100g-1, compared to treatment T0, which yielded the lowest vitamin C concentration in bulbs, at 6.87 mg 100g-1. Organic sulfur fertilization also produced a significant impact on this trait. Treatment S2 gave the highest vitamin C concentration at 9.46 mg 100 g^{-1}, compared to the lowest value recorded in treatment S0 (6.27 mg 100 g^{-1}). Regarding garlic extract foliar application, treatment G1 was superior, reaching 8.20 mg 100 g^{-1}. The interaction between palm waste and organic sulfur (T × S) had a significant effect as well, with treatment T2S2 achieving the highest vitamin C concentration (11.05 mg 100 g^{-1}), while the lowest value was seen in T0S0 (5.81 mg 100 g^{-1}). Regarding the effect of fertilization with palm waste and spraying with garlic extract, the interaction treatment T2G1 was distinguished by producing the highest concentration of vitamin C in the bulbs, reaching 9.35 mg 100 g $^{-1}$. The interaction between the treatments of fertilization with organic sulfur and spraying with garlic extract also had a significant effect on this trait, as the interaction treatment S2G1 gave the highest value, reaching 9.69 mg 100 g $^{-1}$. Finally, the three-way interaction (T×S×G) resulted in the most substantial effect, as treatment T2S2G1 recorded the highest vitamin C concentration in green onion bulbs at 11.57 mg 100 g^{-1}, while the lowest content was found in T0S0G0 at 5.53 mg 100 g^{-1}.

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Table 7. Effect of palm waste fertilization, organic sulfur, and garlic extract foliar spray on vitamin C concentration in green onion bulbs (mg 100 g^{-1})

T × S	G_0	G_1	Means
T_0 S_0	5.53	6.09	5.81
T_0 S_1	6.51	7.41	6.96
T_0 S_2	7.74	7.94	7.84
T_1 S_0	6.18	6.40	6.29
T_1 S_1	7.86	8.32	8.09
T_1 S_2	9.43	9.58	9.51
T_2 S_0	6.23	7.18	6.71
T_2 S_1	8.72	9.30	9.01
T_2 S_2	10.52	11.57	11.05
L.S.D. 0.05	0.3681		0.2603
		T × G	T
T_0	6.59	7.15	6.87
T_1	7.82	8.10	7.96
T_2	8.49	9.35	8.92
L.S.D. 0.05	0.2125		0.2192
		S × G	S
S_0	5.98	6.56	6.27
S_1	7.70	8.34	8.02
S_2	9.23	9.69	9.46
L.S.D. 0.05	0.2125		0.1503
G	7.64	8.20	
L.S.D. 0.05	0.1227		

The results of Tables (1, 2, 3, 4, 5, 6 and 7) revealed that application of palm waste fertilizer resulted in an increase in the head content of medicinal and qualitative compounds. This response may be due to the effect of the added organic fertilizer that led to the improvement of the physical, chemical and biological properties of soil such as activity of microorganisms, water holding capacity and nutrient content particularly N, P & K (Kavvadias et al., 2024; Liu et al., 2024). The decomposition of organic matter also produces some organic and amino acids, which play an important role in the vital processes in the plant and stimulate the production of secondary compounds, which is positively reflected in increasing the accumulation of medicinal compounds in green onions. The use of organic fertilizer or liquid organic fertilizer led to an increase in the content of total phenols, flavonoids and vitamin C in green onions, also that organic fertilization contributed to increasing the soil sulfur content, which in turn enters the formation of sulfur compounds in the plant, which contributes to increasing its content of medicinal compounds. The results also agreed with (Fahrurrozi et al., 2022; Liu et al., 2024). The increase in the above characteristics when adding organic sulfur is attributed to the role of sulfur and its importance for plant growth, as it enters into the formation of protein through the formation of many amino acids, especially Cysteine and Methionine, which are among the most important sulfur-containing amino acids in plants and work as basic building blocks in protein construction. Sulfur is also important in the formation of S-S bonds to form the amino acids Glutamic and Glycine, and it has an important role in the formation of CoASH, vitamins, and the formation of Ferredoxin, which is a strong reducing agent and is one of the components of the electron transport chain for light reactions in the process of photosynthesis (Brosnan et al., 2006; González-Morales et al., 2017; Wang et al., 2023). The increase in the above-mentioned traits as a result of spraying with garlic extract may be due to the garlic crops being rich in polyphenols, which prepares the precursors for their production when spraying garlic extract on the plant, in addition to its role in stimulating antioxidant activity (Ei et al., 2024; Golubkina et al., 2022; Hamza et al., 2024). The increase in these compounds may also be attributed to the presence of compounds in garlic extract that act as biostimulants, such as auxins, gibberellins, and

salicylates, which stimulate growth and photosynthesis processes in plants, which positively reflects in improving plant growth and increasing the amount of biologically active compounds in the plant, enhancing its nutritional and medicinal value (Golubkina et al., 2024; Hayat et al., 2022). The increase in the plant concentration of DPPH antioxidants may be due to the role of garlic extract in activating the antioxidant defense system in plants, as it stimulates the first line of defense (SOD), which controls the oxidation of lipids and reduces their damage by converting O_2-(H_2O_2 and O_2), and then the highly toxic H_2O_2 is cleaned by (CAT) and decomposed by (POD) (Ali et al., 2019).

CONCLUSION

The current study demonstrated that sustainable organic treatments—including palm waste compost, organic sulfur, and garlic extract foliar application—significantly enhanced the medicinal compound concentration in green onion (*Allium fistulosum*). These treatments improved levels of key bioactive compounds such as quercetin, kaempferol, rutin, apigenin, luteolin, antioxidants (DPPH), and vitamin C. The combined application of 30 tons ha^{-1} of palm waste, 600 kg ha^{-1} of organic sulfur, and 6 mL L^{-1} of garlic extract yielded the highest concentrations of these compounds, indicating strong synergistic effects. These findings support the integration of organic inputs as viable alternatives to chemical fertilizers in sustainable agriculture, particularly for enhancing the nutritional and medicinal value of crops.

ACKNOWLEDGEMENT

The authors would like to express their sincere appreciation to the Department of Horticulture and Landscape Gardening/ College of Agricultural Engineering Sciences for providing laboratory facilities and technical support that contributed to the successful completion of this research.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR/S DECLARATION

The authors declare that this manuscript is original, has not been published previously, and is not currently under consideration by any other journal. All figures and tables are original and prepared by the authors. Any material obtained from third parties has been included with the required permissions. All authors have read and approved the final manuscript.

AUTHORS' CONTRIBUTION STATEMENT

All authors made equal contributions to the study design, methodology, experimental work, data analysis, and manuscript writing. All authors reviewed and approved the final version of the manuscript

Author's contribution

The author wrote the draft, formulated the data, analyzed it, and finalized the manuscript.

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Iraqi Journal of Agricultural Sciences –2026:57(10):2595-2609
P-ISSN: 0075- 0530 /E-ISSN: 2410-0862
DOI: https://doi.org/10.36103/hm3ksx63

اسهام المعاملات العضوية المستدامة في تعزيز المركبات الطبية في البصل الأخضر

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المستخلص

نفذت هذه الدراسة في حقول كلية علوم الهندسة الزراعية – جامعة بغداد للمدة من2024/10/1 لغاية 2025/3/15 لمعرفة تأثير التسميد بمخلفات النخيل (0، 20 و30 طن هـ$^{-1}$) والكبريت العضوي (0، 300، 600 كغم هـ$^{-1}$) والرش بمستخلص الثوم (0، 6 مل لتر$^{-1}$) في المركبات الطبية في البصل، نفذت التجربة وفق تصميم القطاعات الكاملة المعشاة (RCBD) وبترتيب القطع المنشقة (Split Plot Design) وبثلاث مكررات .أظهرت نتائج هذه الدراسة أن إضافة سماد مخلفات النخيل بمستوى 30 طن هـ$^{-1}$ والكبريت العضوي بمستوى 600 كغم هـ$^{-1}$ أدى الى زيادة معنوية في مركب Quercetin و Kaempferol وRutin و Apigenin و Luteolin و DPPH وحامض الاسكوربيك (فيتامين C) في رؤوس البصل الاخضر، كما ان رش مستخلص الثوم سبب زيادة في محتوى رؤوس البصل من المركبات الطبية وDPPH وفيتامين C. وعن تأثير التداخل بين عوامل الدراسة فقد تفوقت المعاملة (سماد النخيل 30 طن هـ$^{-1}$ + الكبريت العضوي 600 كغم هـ$^{-1}$+ مستخلص الثوم مل لتر$^{-1}$) في زيادة محتوى رؤوس البصل الأخضر من مركب Quercetin (140.24 ppm) و Kaempferol (83.67 ppm) وRutin (129.24 ppm) وApigenin (35.35 ppm) وLuteolin (59.57 ppm) و DPPH (0.427 ملغم 100غم$^{-1}$) وفيتامين C (11.57 ملغم 100غم$^{-1}$).

الكلمات المفتاحية: مستخلص الثوم ، الكمفيرول، مخلفات النخيل، كيورسيتين، إعادة تدوير.