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The role of organic manure and some antioxidants in enhancing the growth, yield and oil production of black cumin (*Nigella sativa*) plants

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Abstract

This field experiment was conducted during the two consecutive seasons of 2021/2022 and 2022/2023 to elucidate the influence of compost as organic manure and some antioxidants ,as well as, their interactions on the growth aspects (branch number /plant and herb dry weight /plant), yield attributes (capsule number /plant, seed yield /plant and per feddan) (feddan = 4200 m² = 0.420 hectares = 1.037 acres), essential oil production (essential oil % and yield /feddan), fixed oil production (fixed oil % and yield /feddan) and the elements of N, P and K % of black cumin (*Nigella sativa*) plants. Compost was added at 0, 9, 18 and 27 m^3 /feddan and the two examined antioxidants were foliar sprayed as follows: Control (no sprayed plants, citric acid (CA) at 200 and 300 ppm, ascorbic acid (AA) at 200 and 300 ppm, CA at 200 ppm + AA at 200 ppm and CA at 300 ppm + AA at 300 ppm. The obtained results exhibited that supplying the plants with compost at all levels led to a significant augment in all tested traits, except for compost at the low one (9 m^3 /feddan), in most cases. It is obvious that the use of compost at the high level (27 m^3 /feddan) proved to be more effective in elevating all studied parameters. As for antioxidant treatments, foliar spray with these materials, either individual or in combination at all concentrations resulted a significant increase in all studied traits, except for citric acid at the low concentration (200 ppm), mostly. In this concern, the most effective treatment in augmenting these examined aspects was obtained due to the utilization of the combined treatment (300 ppm CA + 300 ppm AA). Clearly, the most studied parameters were significantly affected by the interaction between the two factors. In general, the addition of compost at the high level (27 m^3 /feddan) + foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) achieved the most effective treatment in increasing the growth, seed yield, essential and fixed oils production and the elements of N, P and K %.

Keywords: black cumin, *Nigella sativa*, compost, citric acid, ascorbic acid.

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1. Introduction

Black cumin (*Nigella sativa*) is an annual herbaceous plant, it belongs to Ranunculaceae family. It is one of the most important medicinal and aromatic plants. It is widely cultivated in the middle and Upper Egypt locations for seed and oil. The seeds contain 0.8 - 1.1 % essential oil that mainly contain nigellon compound and other compounds such as, albuminous proteins, saponins, glycosides, tannins, mucilage resins and glucose (Burits and Bucar, 2000). Also, the seeds contain 30 - 35 % fixed oil which is utilized in food and pharmaceutical industries (Ustun *et al.*, 1990). The seeds are used in many therapeutically purposes namely, drug, diuretic, antispathmatic, cough, carminative and bronchitis (Schouenberg and Paris, 1977) besides to, flavoring agent and spice (Kybal, 1980). Additionally, the seeds can be used in the treatment of several diseases for examples: Diabetes, inflammatory, rheumatism, anti-hypertensive and enhancing kidney function and liver in cases of old age and augmenting immune cells activity (Bashandy, 1996; Hughton *et al.*, 1995; Salomi and Rajgopalar, 1989). Organic matter is considered the main source of N and P at 50-60% and 80% S, as well as, containing a lot of micronutrients namely, B and Mo (Bohn *et al.*, 1985). The application of organic manures led to an augment in the content and constituents of secondary metabolites like, alkaloids, essential oils, improve dehydrogenase of root, ATPase, activities of microorganisms and nutrients uptake (Lu *et al.*, 2002; Reuveni *et al.*, 2002; Zheljazkov, 2005). One of the fastest growing sectors is organic farming and its main objective to achieve a balance between the inter-connected system. The presence of organic matter led to elevate the fertility and productivity of the land, as well as produce nutritive and safe food (Ramesh *et al.*, 2005) i.e. human, animal, plant and soil organism (Berova *et al.*, 2010). Organic matter is the basis of soil fertility (Aboudrare, 2009). Compost is one of the most applied organic manures, which is produced via several microorganisms from organic materials (Lazcano *et al.*, 2009). It plays an important role in improving the physical and biological characteristics of soil like, pH, drainage, water retention capacity, better availability of microorganisms in soil and minimizing the native impact of chemical-based fertilizers and pesticides in the ecosystem (Zheljazkov and Warman, 2004). The capability of organic manures on augmenting the growth, yield and oil have been revealed by Shaalan (2005), Helmy (2008), Gahory (2012), Ariafar *et al.* (2013) and Ibrahim (2020) on *Nigella sativa*, Ali *et al.* (2016) and Fouad (2023) on fennel, Mahmoud (2021) on roselle and Abd El-Kader *et al.* (2022) on peppermint. The beneficial role of organic manures in enhancing the elements of N, P and K was discussed by Gahory (2012), and Ibrahim (2020) on black cumin and Abo-Kutta (2017) and Fouad (2023) on fennel. Citric acid is an antioxidant acts a definite role in elevating cell division, enzymes activity and protecting the plant cells from senescence, and death, augmenting the plant resistance to various disorders the biosynthesis of organic foods and plant hormones, as well as mitigation of the environmental stresses. It affects some natural cycles activity in higher plants and plays a vital role in electron transport system (Elade, 1992; Khan *et al.*, 2003). The efficiency of citric acid in elevating the growth have been obtained on pot marigold (Milad and Mohamed, 2009), on marjoram (Ahmed, 2005; Noor El-Deen, 2005), on sweet pepper (Abd El-al, 2009), on sweet corn (Al-Abagy *et al.*, 2008), and also, on sweet pepper (Abd El-al, 2009), on pot marigold (Milad and Mohamed, 2009), on roselle (Hassan, 2013), and on *Ammi visnaga* (Ali *et al.*, 2016), regarding the positive effect of citric acid on the yield. So, citric acid can be improved the essential oil % of marjoram (Ahmed, 2005) and the elements of N, P and K % of *Ammi visnaga* (Mahmoud, 2017). Ascorbic acid (vitamin C) is one of the most familiar antioxidants, it can be antioxidant defense, photo protection and regulate the plant growth and photosynthesis (Blokhina *et al.*, 2003). It acts as enzyme co-factor. It has significant impact on plant resistance against many plant pathogens like, bacteria, fungi, nematode and parasitic plants (Oertli, 1987). The positive influence of ascorbic acid on growth, yield and oil was emphasized by Ismail (2008) and Gahory (2012) on black cumin plants, Helmy (2016) on cumin, and Ali *et al.* (2017) on fennel. As for the stimulatory impact of ascorbic acid on N, P and K elements were detected by Ismail (2008) and Gahory (2012) on *Nigella sativa*, Abo Kutta (2017) on fennel and Helmy (2016) on cumin. Thus, the present work was conducted to study the influence of compost as organic manure and some antioxidants (citric acid and ascorbic acid), as well as, their interactions on the growth (number of branches /plant, and herb dry weight /plant), yield components (capsule number /plant, seed yield /plant and /feddan, essential oil production (essential oil % and yield per. feddan), fixed oil production (fixed oil % and yield per fed), as well as, the elements of N, P and K % of black cumin (*Nigella sativa*) plants to figure out the most suitable treatment for improving these traits.

2. Materials and methods

2.1 Experimental site and treatments description

This present work was carried out at the private farm in Abo-Kurkas, Minia, Egypt during the two successive seasons of 2021/2022 and 2022/2023 to examine the effects of compost as organic manure, some antioxidants and their interactions on the growth, seed yield, oil production and some chemical constituents of black cumin (*Nigella sativa* L.) plants. The experimental design was a split plot with three replicates, compost at the levels (0, 9, 18 and 27) m^3 /feddan (feddan = 4200 m^2 = 0.420 hectares = 1.037 acres) were the main plots (A), while antioxidant treatments occupied the sub-plots (B) which were as follows: 0, citric acid (CA) at 200 ppm and 300 ppm, ascorbic acid (AA) at 200 and 300 ppm, CA at 200 + AA at 200 ppm and CA at 300 ppm + AA at 300 ppm, consequently, the interaction (A × B) involved 28 treatments. The seeds of black cumin were obtained from Medicinal and Aromatic plants Department, Horticulture Research Institute, Agricultural Research Center, Giza, Egypt and were sown on October 20th for the two seasons. The experimental unit was 2.1 × 1.8 m and containing 3 rows spaced at 60 cm. The seeds were sown in hills 30 cm apart on one side of the ridge (each plot contained 21 hills). Forty days from sowing date, the plants were thinned to one plant /hill (21 plants /plot), in both seasons. The experimental soil was analyzed according to procedure of Jackson (1973) and are presented in Table (1).

Table (1): Physical and chemical characteristics of the experimental soil (average for the two seasons).

Soil texture	Organic matter (%)	$CaCO_3$ (%)	E C (m.mohs/ cm)	pH (1:2.5)	Available			Water Soluble Ions (meq/ l) in the soil paste				
Loamy	0.55	2.43	1.35	7.51	N %	P ppm	K mg/100g soil	Ca^{++}	Mg^{++}	HCO_3	Cl^-	SO_4

The used compost (called compost El-Neal) was obtained from the Egyptian Co. for Solid Waste Utilization, New Minia City. All assigned of compost were added during the preparation of soil to the cultivation, in both seasons. The applied compost was carried out according to Black (1965) and is shown in Table (2).

Table (2): The chemical analysis of the applied compost (average for both seasons).

Content	Value	Content	Value
Organic carbon (%)	24.3	Total P (%)	0.70
Humidity (%)	25.0	Total K (%)	0.85
Organic matter (%)	39.8	Fe (ppm)	1500
C/N ratio	20.3	Zn (ppm)	90.0
pH (1:2.5)	7.5	Mn (ppm)	110.0
E.C. (m. mhos /cm)	5.0	Cu (ppm)	160.0
Total N (%)	1.2		

The plants were foliar sprayed with the two tested antioxidants either individual or together, three times at two weeks interval starting December14th during the two growing seasons. Triton B as a wetting agent was added at 0.05 % to all treatments and the plants were sprayed till run off. All other agricultural practices were performed as usual. At the termination (the first week of April) in the two seasons.

2.2 Collected data

The data were recorded as follows: Number of branches /plant, herb dry weight (g) /plant, number of capsules /plant, seed yield (g) /plant and seed yield (Kg) /feddan was calculated, the fixed oil % of the seeds was extracted by Soxhlet apparatus according to A.O.A.C. (1970), then fixed oil yield (liter) /feddan was calculated by multiplying fixed oil % in seed yield (kg) /feddan. The essential oil % of the seeds was isolated and estimated according to the method described by Guenther (1961), then essential oil yield (liter) / feddan was measured by multiplying essential oil % in seed yield (kg) /feddan. In addition, the three examined elements (N, P and K %) in the dried herb were determined as follows: N

% was determined according to the modified micro-Kjeldahl method as described by Wilde *et al.* (1985), P % was measured colorimetrically according to Chapman and Pratt (1975) and K % was estimated by Flame photometer according to Cottenie *et al.* (1982). The obtained data were tabulated and statistically analyzed according to MSTAT- C (1986) using L.S.D. test at 5% to know the differences among all treatments according to Mead *et al.* (1993).

3. Results and Discussion

3.1 Vegetative growth traits

3.1.1 Number of branches/plants

The obtained data in Table (3) exhibited that branch number /plant of black cumin was positively affected by compost as organic manure during the two experimental seasons. Clearly, such aspect was significantly increased due to adding all compost levels, as compared to the check treatment, in both seasons. Obviously, branch number /plant was gradual significantly augmented with elevating compost levels in the two seasons. Thus, the high level of compost (27 m^3 /feddan) gave the highest values of such trait reached 40.3 and 19.6% over untreated ones, during the two growing seasons, respectively. The unique role of organic manures in augmenting branch number detected in this work was, also described by Shaalan (2005), Helmy (2008), Gahory (2012) and Ibrahim (2020) on *Nigella sativa* plants, Abd El-Kader (2022) on peppermint and Abo-Kutta (2017) and Fouad (2023) on fennel. As for antioxidant treatments, it appears that spraying black cumin plants with these materials significantly influenced branch number /plant for both seasons. Foliar spray with the two examined antioxidants either single or together at all concentrations led to a significant increase in branch number /plant, during the two consecutive seasons, except for citric acid (CA) at the low concentration (200 ppm), in the first season, in relative to no sprayed plants. Obviously, the high values of such parameter were obtained, mostly due to using the combined treatments than those revealed by individual treatments, in both seasons. Apparently, the highest values of branch number /plant were noticed when foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) which elevated it by 38.4 and by 33.3% over untreated ones, during the two successive seasons, respectively, as clearly shown in Table (3). The beneficial role of citric acid in increasing number of branches given in this research was, also reported by Milad and Mohamed (2009) on pot marigold, Ahmed (2005) on marjoram, Abd El-al (2009) on sweet pepper, Hassan (2013) on roselle and Ali *et al.* (2016) on *Ammi visnaga* and, also by Ismail (2008), Gahory (2012) and Abdou *et al.* (2013) on black cumin, Abo-Kutta (2017) on fennel, Ahmed (2005) on marjoram and Abd El-Kader (2022) on peppermint, regarding ascorbic acid application. Data in Table (3) cleared that the interaction between the two studied factors on branch number /plant of black cumin had significant effect in the first season only. It is obvious that the most combined treatments resulted a significant augment in branch number /plant, as compared to untreated plants, during the two seasons. Apparently, the most effective treatment in augmenting such trait was observed when applying compost at the high level (27 m^3 /feddan) with spraying the combined treatment (300 ppm CA + 300 ppm AA), in comparison with those revealed by other combination treatments, for both seasons.

Table (3): The impact of compost levels, some antioxidants and their interactions on branch number/plant of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	6.7	6.9	7.3	8.2	7.3
Citric acid (CA) at 200	6.8	7.2	7.8	8.6	7.6
Citric acid (CA)at 300	7.1	7.5	8.2	9.5	8.1
Ascorbic acid (AA) at 200	6.9	7.7	8.7	9.9	8.3
Ascorbic acid (AA) at 300	7.3	8.2	10.2	10.6	9.1
AC at 200 + AA at 200	7.8	8.8	10.7	11.3	9.7
AC at 300 + AA at 300	8.0	9.1	10.8	12.5	10.1
Mean (A)	7.2	7.9	9.1	10.1	
L.S.D. at 5%	A:0.5		B:0.4		AB:0.9
	Second season				
Control	8.0	8.5	8.7	9.4	8.7
Citric acid (CA) at 200	8.4	8.8	9.1	9.9	9.1
Citric acid (CA)at 300	9.0	9.2	9.8	10.6	9.7
Ascorbic acid (AA) at 200	8.8	9.5	10.2	10.9	9.9
Ascorbic acid (AA) at 300	9.4	10.2	10.6	11.5	10.4
AC at 200 + AA at 200	9.6	10.5	11.2	11.9	10.8
AC at 300 + AA at 300	10.9	11.0	11.9	12.6	11.6
Mean (A)	9.2	9.7	10.2	11.0	
L.S.D. at 5 %	A: 0.3		B: 0.3		AB: N.S

3.1.2 Herb dry weight (g)/plant

The given data in Table (4) claimed that herb dry weight /plant of black cumin was positively responded to the addition of compost as organic manure, during both seasons. In the presence of organic manure at all levels, except for the low one (9 m^3 /feddan), in the two experimental seasons, such aspect was significantly increased as compared to the check treatment. In this respect, the heaviest herb dry weight /plant was registered due to supplying the high level of compost (27 m^3 /feddan) as ranged 33.9 and 37.2 % over control, during the two consecutive seasons, respectively. The augment in herb dry weight proved in the present study due to adding organic manure was, also examined by Helmy (2008), Gahory (2012) and Ibrahim (2020) on black cumin, Ali *et al.* (2017) and Fouad (2023) on fennel, Mahmoud (2021) on roselle and Abd El-Kader (2022) on peppermint. In relation to antioxidant treatments, the listed data in Table (4) exhibited that herb dry weight /plant of black cumin was significantly affected by foliar spray with the tested antioxidants, in both seasons. Obviously, such parameter was significantly elevated, during the two growing seasons by foliar spray with all antioxidants either separately or in combination at all concentrations, except for citric acid (CA) at the low concentration (200 ppm), in the second season, as compared to no sprayed ones. The combined treatments gave higher values of herb dry weight /plant mostly, than those detected by individual ones in the two seasons.

Table (4): The impact of compost levels, some antioxidants and their interactions on herb dry weight (g) /plant of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	25.5	29.6	32.7	37.6	31.4
Citric acid (CA) at 200	28.4	33.2	36.7	40.8	34.8
Citric acid (CA)at 300	30.6	36.5	39.0	42.2	37.1
Ascorbic acid (AA) at 200	34.2	38.9	43.8	45.9	40.7
Ascorbic acid (AA) at 300	37.3	41.0	46.5	49.7	43.6
AC at 200 + AA at 200	41.8	42.5	47.5	51.7	45.9
AC at 300 + AA at 300	43.6	44.9	51.3	55.8	48.9
Mean (A)	34.5	38.1	42.5	46.2	
L.S.D. at 5%	A: 4.6		B: 2.2		AB: N.S
Second season					
Control	27.3	31.4	35.6	40.8	33.8
Citric acid (CA) at 200	29.1	31.2	37.8	42.3	35.1
Citric acid (CA)at 300	32.6	35.0	40.0	45.8	38.4
Ascorbic acid (AA) at 200	35.5	39.1	43.9	49.6	42.0
Ascorbic acid (AA) at 300	40.8	42.0	48.0	53.0	46.0
AC at 200 + AA at 200	41.3	44.6	49.8	54.7	47.6
AC at 300 + AA at 300	45.6	47.8	55.7	59.9	52.3
Mean (A)	36.0	38.7	44.4	49.4	
L.S.D. at 5 %	A: 3.4		B: 2.1		AB: N.S

Clearly, the use of the combined treatment (300 ppm CA + 300 ppm AA) proved to be more effective in increasing herb dry weight /plant than those obtained by other treatments and control, during both seasons. Numerically, this previous superior treatment augmented such trait by 55.7 and by 54.7% over the check treatment, during the two experimental seasons, respectively. The primitive effect of citric acid on herb weight observed in this investigation have been declared by Milad and Mohamed (2009) on pot marigold, Noor El-Deen (2005) and Ahmed (2005) on marjoram, Abd El-al (2009) on sweet pepper, Hassan (2013) on roselle and Ali *et al.* (2016) on *Ammi visnaga* and, also by Ismail (2008), Gahory (2012) and Abdou *et al.* (2013) on black cumin, Ahmed (2005) and Noor El-Deen (2005) on marjoram, Abo-Kutta (2017) on fennel and Abd El-Kader *et al.* (2022) on peppermint, concerning ascorbic acid application. With respect to the interaction, it was no significant effect on herb dry weight /plant of black cumin, during the two consecutive seasons. It seems that plants grown in organic conditions at the high level (27 m^3 /feddan) and spraying with the combined treatment (300 ppm CA + 300 ppm AA) recorded the highest values of herb dry weight /plant comparing to those revealed by other combination treatments, in both seasons, as clearly emphasized in Table (4).

3.2 Yield and its component

3.2.1 Number of capsules/plant

The presented data in Table (5) postulated that capsule number /plant of black cumin was positively responded to the addition of compost, in the two seasons. Obviously, plants grown in organic conditions at all levels, in both seasons, resulted a significant elevate in capsule number /plant, except for compost at the low level (9 m^3 /feddan), in the first season, as compared to the check treatment. In most cases, by increasing the levels of compost, such aspect was gradual significantly augmented, during the two growing seasons. Therefore, the maximum values of capsule number /plant were obtained due to the high level of compost (27 m^3 /feddan) reached 13.5 and 13.6% over unfertilized ones, in both seasons, respectively. The capability of organic manures on elevating capsule number noticed in the present research was, also mentioned by Tanious (2008), Azzaz *et al.* (2009) and Abo-Kutta (2017) on fennel and Helmy (2016) on cumin. Regarding antioxidants, data in Table (5) indicated that the studied antioxidants significantly influenced capsule number /plant of black cumin, during the two successive seasons. Apparently, foliar spray with all antioxidants, either individual or in combination at all concentrations caused a significant augment in capsule number /plant, during the two experimental seasons, except for the treatment of citric acid (CA) at the low concentration (200 ppm), in the second season, in relative to no sprayed plants. Higher values of capsule number /plant were given by applying the combined treatments, mostly than those detected by single ones, for the two seasons. Obviously, supplemented plants with the combined treatment (CA at 300 ppm + AA at 300 ppm) proved to be more effective in elevating such aspect as ranged 20.2 and 16.0% over untreated plants, during the two consecutive seasons, respectively. The importance role of citric acid in improving capsule number given in this investigation have been described on Mahmoud (2017) on *Ammi visnaga,* and also Ismail (2008) and Gahory (2012) on black cumin, Helmy (2016) on cumin, and Abo-Kutta (2017) on fennel, regarding ascorbic acid application. It worthy mentioned that capsule number /plant of black cumin was significantly affected by the interaction treatments, during the two growing seasons (Table 5). It is clear that all combined treatments led to a significant increase in capsule number /plant, except for the treatment of 0 compost plus citric acid at 200 ppm and compost at the low level (9 m^3 /feddan) without spraying antioxidants, for both seasons, besides compost at 9 m^3 /feddan with 200 ppm or 300 ppm citric acid, in the first season, as compared to untreated plants. Clearly, the most effective treatment in augmenting capsule number /plant was detected when supplying the plants with compost at the high level (27 m^3 /feddan) plus the combined treatment (300 ppm CA + 300 ppm AA), in comparison with those revealed by other combination treatments, during the two experimental seasons.

Table (5): The impact of compost levels, some antioxidants and their interactions on capsule number /plant of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	55.6	56.2	59.3	60.1	57.8
Citric acid (CA) at 200	56.9	57.8	61.4	65.0	60.3
Citric acid (CA)at 300	58.8	58.0	64.2	65.8	61.7
Ascorbic acid (AA) at 200	60.0	60.7	67.0	67.5	63.8
Ascorbic acid (AA) at 300	62.0	63.8	68.2	70.2	66.1
AC at 200 + AA at 200	63.8	64.4	71.0	72.8	68.0
AC at 300 + AA at 300	64.6	66.0	70.6	76.9	69.5
Mean (A)	60.2	61.0	66.0	68.3	
L.S.D. at 5%	A: 2.5		B: 1.3		AB: 2.5
	Second season				
Control	65.3	66.8	70.4	74.6	69.3
Citric acid (CA) at 200	67.0	68.9	72,4	74.8	70.8
Citric acid (CA)at 300	68.9	72.0	73.5	78.0	73.1
Ascorbic acid (AA) at 200	69.8	72.7	75.9	77.0	73.9
Ascorbic acid (AA) at 300	72.0	73.8	79.2	77.8	75.7
AC at 200 + AA at 200	71.9	76.0	78.0	83.2	77.3
AC at 300 + AA at 300	73.2	78.6	81.0	88.7	80.4
Mean (A)	69.7	72.7	75.8	79.2	
L.S.D. at 5 %	A: 2.3		B: 1.6		AB: 3.2

3.2.2 Seed yield /plant and per feddan

The obtained data in Tables (6 and 7) emphasized that seed yield /plant and per fed. of black cumin were positively affected by the application of compost, during the two growing seasons. It could be noticed that receiving the plants compost at all levels, in both seasons, led to a significant increase in seed yield /plant and per feddan, except for the low one (9 m^3 /feddan) of such manure, in the second season, as compared to the check treatment. Obviously, these aspects were gradual significantly elevated with increasing the levels of compost, during the two seasons. Thus, plants grown in organic conditions at the high level (27 m^3 /feddan) produced the maximum yield of seed reached 33.7 and 37.1% over unfertilized plants and amounted 616.4 and 723.0 kg seed /feddan, while control recorded 463.1 and 527.5 kg seed /feddan, during the two consecutive seasons, respectively. The efficiency of organic manures on enhancing seed yield detected in this work was pointed out by Shaalan (2005), Helmy (2008), Gahory (2012) and Ibrahim (2020) on *Nigella sativa*, Abdou *et al.* (2012), Ali *et al.* (2017) and Fouad (2023) on fennel, Ali *et al.* (2017) on *Ammi visnaga,* and Mahmoud (2021) on roselle.

Table (6): The impact of compost levels, some antioxidants and their interactions on seed yield (g) /plant of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	16.5	19.0	21.1	22.7	19.8
Citric acid (CA) at 200	18.3	20.8	24.4	25.9	22.4
Citric acid (CA)at 300	19.7	22.5	25.0	26.5	23.4
Ascorbic acid (AA) at 200	19.9	23.7	25.9	27.3	24.2
Ascorbic acid (AA) at 300	22.0	23.5	26.0	29.0	25.1
AC at 200 + AA at 200	23.5	25.9	26.7	30.5	26.7
AC at 300 + AA at 300	26.0	26.5	27.9	32.4	28.2
Mean (A)	20.8	23.1	25.3	27.8	
L.S.D. at 5%	A: 1.0		B: 0.8		AB:1.6
Second season					
Control	18.3	19.7	22.8	27.6	22.1
Citric acid (CA) at 200	20.8	21.5	25.9	28.8	24.3
Citric acid (CA)at 300	23.9	23.8	29.9	30.8	27.1
Ascorbic acid (AA) at 200	23.8	25.2	27.0	32.0	27.0
Ascorbic acid (AA) at 300	24.5	26.0	31.1	34.8	29.1
AC at 200 + AA at 200	26.8	27.0	31.0	34.0	29.7
AC at 300 + AA at 300	28.1	29.0	35.9	39.8	33.2
Mean (A)	23.7	24.6	29.1	32.5	
L.S.D. at 5 %	A: 1.2		B: 1.0		AB:2.0

Concerning antioxidant treatments, the presented data in Tables (6 and 7) revealed that seed yield /plant and per fed. of black cumin were positively influenced by using these materials, during the two experimental seasons. Clearly, foliar spray with the two examined antioxidants, either separately or together at all concentrations resulted a significant elevate in these parameters, during both seasons, in relative to no sprayed ones. In this connection, higher values of seed yield /plant and per fed. were obtained by utilizing the combined treatments, mostly than those proved by single treatments, during the two successive seasons. Apparently, spraying the combined treatment (300 ppm CA + 300 ppm AA) proved to be more effective in increasing seed yield than those revealed by other treatments and control, in both seasons. Numerically, this above-mentioned superior treatment augmented seed yield by 42.4 and by 50.2 % over no sprayed ones and yielded 626.4 and 737.6 kg seed /fed. in relative to no sprayed plants which gave 440.3 and 491.0 kg seed /feddan, during the two consecutive seasons, respectively. The promoting effect of citric acid on seed yield obtained in the present study was examined by Abd El-al (2009) on sweet pepper, Hassan (2013) on roselle, and Ali *et al.* (2017) on *Ammi visnaga,* and also, Ismail (2008) and Gahory (2012) on black cumin, Helmy (2016) on cumin and Ali *et al.* (2017) on fennel, regarding ascorbic acid application. Accordingly, the interaction effect between the two tested factors on seed yield /plant and per fed. of black cumin had significant, during the two growing seasons. Obviously, these traits were significantly increased, in both seasons, due to utilizing all combined treatments, except for the treatment of compost at the low level (9 m^3 /feddan) without spraying antioxidants, in the second season, comparing to untreated plants. From the obtained data, it could be noticed that the most effective treatment in augmenting seed yield was detected by adding compost at the high level (27 m^3 /feddan) with the combined treatment (300 ppm CA + 300 ppm AA), than those given by other combination treatments, in the two seasons. In connection, this previous superior treatment produced 719.1 and 884.3 kg seed /feddan, in relative to the control gave 366.6 and 406.6 kg seed /feddan, during the two experimental seasons, respectively, as clearly proved in Tables (6 and 7).

Table (7): The impact of compost levels, some antioxidants and their interactions on seed yield (kg) /feddan of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	366.6	422.1	468.8	503.6	440.3
Citric acid (CA) at 200	406.6	462.1	541.4	575.4	496.4
Citric acid (CA)at 300	437.7	499.2	555.5	588.8	520.3
Ascorbic acid (AA) at 200	442.1	526.6	574.6	606.5	537.5
Ascorbic acid (AA) at 300	488.8	522.1	577.7	644.3	558.2
AC at 200 + AA at 200	522.1	575.5	593.2	677.6	592.1
AC at 300 + AA at 300	577.7	588.8	619.9	719.9	626.6
Mean (A)	463.1	513.8	561.6	616.6	
L.S.D. at 5%	A: 22.7		B: 17.5		AB: 35.0
	Second season				
Control	406.6	437.7	506.6	613.2	491.0
Citric acid (CA) at 200	462.2	477.7	575.5	639.9	538.8
Citric acid (CA)at 300	531.0	528.8	664.3	684.3	602.1
Ascorbic acid (AA) at 200	528.7	559.9	599.9	711.0	599.9
Ascorbic acid (AA) at 300	544.3	577.7	691.0	773.2	646.6
AC at 200 + AA at 200	595.5	599.9	688.8	755.4	659.9
AC at 300 + AA at 300	624.3	644.3	797.6	884.3	737.6
Mean (A)	527.5	546.6	646.2	723.0	
L.S.D. at 5 %	A: 25.3		B: 21.0		AB: 42.0

3.3 Essential oil production

3.3.1 Essential oil percentage

The given data in Table (8) indicated that essential oil % of black cumin seeds was positively responded to the application of compost as organic manure, during the two successive seasons. Clearly, such aspect was significantly increased, due to adding compost at all levels, expect for the low one (9 m^3 /feddan) of such manure, in both seasons, as compared to the check treatment. It is obvious that essential oil % was gradual significantly augmented with increasing the levels of compost, for the two seasons. Therefore, the highest values of essential oil % were detected when supplying the plants with the high level (27 m^3 /feddan) of compost as ranged 18.6 and 20.2% over unfertilized ones, during the two experimental seasons, respectively. The efficiency of organic manures on elevating essential oil obtained in this work have been disclosed by Shaalan (2005), Helmy (2008), Gahory (2012) and Ibrahim (2020) on *Nigella sativa*, Ali *et al.* (2017) and Fouad (2023) on fennel, Helmy (2016) on cumin, Abd El-Kader *et al.* (2022) on peppermint, and Ali *et al.* (2017) and Fouad (2023) on fennel.

Table (8): The impact of compost levels, some antioxidants and their interactions on essential oil % of black cumin seeds during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	0.80	0.82	0.85	0.89	0.84
Citric acid (CA) at 200	0.88	0.88	0.90	0.96	0.91
Citric acid (CA)at 300	0.90	0.89	0.94	1.02	0.94
Ascorbic acid (AA) at 200	0.94	0.97	1.03	1.09	1.01
Ascorbic acid (AA) at 300	1.06	1.12	1.22	1.25	1.16
AC at 200 + AA at 200	1.08	1.10	1.27	1.33	1.20
AC at 300 + AA at 300	1.11	1.17	1.29	1.49	1.27
Mean (A)	0.97	0.99	1.07	1.15	
L.S.D. at 5%	A: 0.04		B: 0.03		AB: 0.06
	Second season				
Control	0.84	0.87	0.91	0.93	0.89
Citric acid (CA) at 200	0.86	0.90	0.95	0.97	0.92
Citric acid (CA)at 300	0.91	0.92	0.98	1.07	0.97
Ascorbic acid (AA) at 200	0.94	0.95	1.07	1.13	1.02
Ascorbic acid (AA) at 300	1.07	1.09	1.15	1.29	1.15
AC at 200 + AA at 200	1.13	1.19	1.22	1.41	1.24
AC at 300 + AA at 300	1.20	1.29	1.31	1.52	1.33
Mean (A)	0.99	1.03	1.08	1.19	
L.S.D. at 5 %	A: 0.05		B: 0.04		AB: 0.07

It is evident from the revealed data in Table (8) that treating black cumin plants with the two studied antioxidants significantly affected essential oil % in the seeds, during the two growing seasons. Apparently, foliar spray with these antioxidants, either alone or together at all concentrations significantly augmented essential oil %, except for the low concentration (200 ppm) of citric acid (CA), for the second season, in relative to no sprayed plants. Obviously, the use of the combined treatments gave higher values of such trait, mostly than those observed by individual ones, during both seasons. Moreover, foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) proved to be more effective in increasing essential oil % reached 51.2 and 49.4 % over untreated plants, during the two experimental seasons, respectively. The augment in essential oil % detected in the present research due to applying citric acid was, also explored by Ahmed (2005) on marjoram, and also, Ismail (2008) and Gahory (2012) on black cumin, Helmy (2016) on cumin, Ali *et al.* (2017) on fennel and Abd El-Kader *et al.* (2022) on peppermint, regarding ascorbic acid application. In relation to the interaction, it was statistically significant effect on essential oil % in seeds of black cumin, during the two seasons. In connection, the application of all combined treatments caused a significant increase in essential oil %, except for the treatment of compost at 9 or 18 m^3 /feddan plus 0 spraying antioxidants, in the first season, and also 0 compost + 200 ppm CA and compost at 9 m^3 /feddan plus 0 spraying antioxidants, in the second one, comparing to untreated plants. Clearly, plants growing in organic conditions at the high level (27 m^3 /feddan) in combination with spraying the combined treatment (300 ppm CA + 300 ppm AA) registered the maximum values of essential oil % than those noticed by other combination treatments, during the two experimental seasons, as clearly mentioned in Table (8).

3.3.2 Essential oil yield (liter) /feddan

Data in Table (9) showed that essential oil yield (liter) /feddan of black cumin seeds was positively influenced by the addition of compost, in the two seasons. It is clear that the presence of compost as organic manure at all levels, in both seasons, resulted a significant raise in essential oil yield /feddan, as compared to unfertilized ones. In this concern, by increasing the levels of compost, such parameter was gradual significantly elevated, during the two growing seasons. Thus, utilizing compost at the high level (27 m^3 /feddan) produced the heaviest essential oil yield /feddan (7.20 and 8.75 liter), while the check treatment recorded 4.55 and 5.29 liter per feddan essential oil, during the two consecutive seasons, respectively. Regarding antioxidant treatments, supplemented black cumin plants with these tested materials positively affected essential oil yield /feddan, in both seasons. However, foliar spray with antioxidants used, either separately or in combination at all concentrations, in the two seasons, led to a significant augment in essential oil yield /feddan, comparing to no sprayed plants. Moreover, higher values of such trait were noticed due to applying the combined treatments, mostly than those revealed by single treatments, during the two successive seasons. Apparently, the most effective treatment in increasing essential oil yield /feddan was obtained as a result of spraying the combined treatment (300 ppm CA + 300 ppm AA) than those given by other treatments and control, during both seasons. This previous superior treatment amounted 8.01 and 9.92 liter /feddan essential oil against the control gave 3.72 and 4.34 liter /feddan essential oil, during the two consecutive seasons, respectively, as clearly postulated in Table (9). As for the interaction, the listed data in Table (9) indicated that essential oil yield /feddan of black cumin seeds was significantly affected by the interaction treatments, in both seasons. Obviously, the use of all combined treatments, in the two seasons, resulted a significant increase in essential oil yield /feddan, in relative to untreated plants. In this regard, the addition of compost at the high level (27 m^3 /feddan) + foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) proved to be more effective in elevating essential oil yield /feddan than those detected by other combination treatments, during the two growing seasons. This above-mentioned superior treatment yielded 10.73 and 13.44 liter /feddan essential oil, in comparison with the control produced 2.93 and 3.22 liter essential oil /feddan, during the two experimental seasons, respectively.

Table (9): The impact of compost levels, some antioxidants and their interactions on essential oil yield (liter) /feddan of black cumin seeds during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	2.93	3.46	4.02	4.48	3.72
Citric acid (CA) at 200	3.58	4.06	4.85	5.52	4.50
Citric acid (CA)at 300	3.94	4.44	5.22	6.01	4.90
Ascorbic acid (AA) at 200	4.15	5.11	5.90	6.61	5.44
Ascorbic acid (AA) at 300	5.19	5.85	7.05	8.05	6.54
AC at 200 + AA at 200	5.64	6.33	7.53	9.01	7.13
AC at 300 + AA at 300	6.41	6.89	8.00	10.73	8.01
Mean (A)	4.55	5.16	6.08	7.20	
L.S.D. at 5%	A: 0.34		B: 0.24		AB: 0.48
Second season					
Control	3.22	3.81	4.62	5.69	4.34
Citric acid (CA) at 200	3.97	4.30	5.47	6.10	4.96
Citric acid (CA)at 300	4.84	4.86	6.51	7.32	5.88
Ascorbic acid (AA) at 200	4.97	5.32	6.42	8.04	6.19
Ascorbic acid (AA) at 300	5.83	6.30	7.80	9.98	7.48
AC at 200 + AA at 200	6.73	7.14	8.43	10.65	8.24
AC at 300 + AA at 300	7.50	8.30	10.45	13.44	9.92
Mean (A)	5.29	5.72	7.10	8.75	
L.S.D. at 5 %	A: 0.42		B: 0.29		AB: 0.58

3.4 Fixed oil production

3.4.1 Fixed oil

The obtained data in Table (10) revealed that fixed oil % of black cumin seeds was positively affected by using compost, in the two consecutive seasons. Clearly, the addition of compost at all levels, during the two successive seasons, led to a significant elevate in fixed oil %, except for compost at the low one (9 m^3 /feddan), for the second season, in relative to the check treatment. By augmenting the levels of compost, mostly in both seasons, fixed oil % was gradual significantly increased. Therefore, the highest fixed oil % were detected when utilizing the high level (27 m^3 /feddan) of compost which augmented it by 6.2 and by 5.0 % over unfertilized ones, during the two growing seasons, respectively. The beneficial role of organic manures in augmenting fixed oil given in the present study was, also obtained by Shaalan (2005), Helmy (2008), Gahory (2012) and Ibrahim (2020) on *Nigella sativa*.

Table (10): The impact of compost levels, some antioxidants and their interactions on fixed oil % of black cumin seeds during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	27.5	27.8	28.3	28.4	28.0
Citric acid (CA) at 200	27.9	28.5	29.3	30.1	29.0
Citric acid (CA)at 300	28.2	29.5	30.0	30.0	29.4
Ascorbic acid (AA) at 200	28.8	29.4	30.3	30.7	29.8
Ascorbic acid (AA) at 300	30.2	31.6	32.0	32.1	31.5
AC at 200 + AA at 200	29.9	30.8	31.8	32.4	31.2
AC at 300 + AA at 300	31.5	32.6	32.3	32.8	32.3
Mean (A)	29.1	30.0	30.6	30.9	
L.S.D. at 5%	A:0.3		B:0.4		AB:0.8
	Second season				
Control	28.7	28.2	29.0	29.2	28.8
Citric acid (CA) at 200	29.6	29.8	30.8	30.3	30.1
Citric acid (CA)at 300	29.9	29.7	30.5	30.9	30.3
Ascorbic acid (AA) at 200	29.5	30.7	31.2	32.0	30.9
Ascorbic acid (AA) at 300	30.6	31.0	31.9	32.7	31.6
AC at 200 + AA at 200	31.3	31.4	32.1	32.5	31.8
AC at 300 + AA at 300	31.6	32.3	34.0	34.3	33.1
Mean (A)	30.2	30.4	31.4	31.7	
L.S.D. at 5 %	A:0.6		B:0.5		AB:1.0

It worthies that spraying black cumin plants with the examined antioxidants significantly influenced fixed oil % of seeds, during the two consecutive seasons (Table, 10). All these antioxidants, either alone or together at all concentrations caused a significant raise in fixed oil %, during both seasons, as compared to no sprayed plants. In connection, foliar spray with the combined treatments resulted higher values of such aspect, mostly than those detected by individual ones, in the two seasons. Moreover, the combined treatment namely, 300 ppm CA + 300 ppm AA proved to be more effective in increasing fixed oil % than those obtained by other treatments and control, during the two experimental seasons. Numerically, this previous superior treatment elevated fixed oil % by 15.4 and by 14.9 % over no sprayed plants, during both seasons, respectively. The important role of ascorbic acid in augmenting fixed oil obtained in this work was, also discussed by Ismail (2008) and Gahory (2012) on black cumin. With respect to the interaction, the revealed data in Table (10) claimed that it was statistically significant impact on fixed oil % in black cumin seeds, during the two experimental seasons. Obviously, the application of all combined treatments led to a significant increase in fixed oil %, except for the treatment of 0 compost plus spraying citric acid at 200 or 300 ppm and, also 9 m^3 /feddan compost + no spraying antioxidants, comparing to control, in the first season. So, all combined treatments significantly augmented such parameter, except for the treatment of the low, moderate and high levels of compost with 0 spraying antioxidants, besides, 0 compost + 200 ppm CA or 0 compost with 200 ppm AA, as compared to untreated plants, in the second season. Apparently, supplying the plants with compost at the high level (27 m^3 /feddan) with the combined treatment (300 ppm CA + 300 ppm AA), followed by the moderate level (18 m^3 /feddan) of compost plus the same previous treatment of antioxidants were the most effective treatments in increasing fixed oil %, in comparison with those obtained by other combination treatments, during the two consecutive seasons.

3.4.2 Fixed oil yield (liter) /feddan

The presented data in Table (11) cleared that applying compost as organic manure positively affected fixed oil yield /feddan of black cumin seeds, during both seasons. It seems that fixed oil yield /feddan was significantly increased, in the two seasons, due to adding compost at all levels, except for the low one (9 m^3 /feddan) of such manure, in the second season, as compared to unfertilized plants. In this regard, such trait was gradual significantly elevated with increasing the levels of compost, during the two growing seasons. Thus, the high level of compost (27 m^3 /feddan) produced the heaviest fixed oil yield /feddan (191.4 and 230.5 liter), in relative to the check treatment amounted 135.8 and 160.2 liter /feddan fixed oil, during the two successive seasons, respectively. Concerning antioxidant treatments, the given data in Table (11) proved that fixed oil yield /feddan of black cumin seeds was positively responded to the utilization of the two studied antioxidants, during the two consecutive seasons. It is clear that all antioxidants applied, either single or in combination at all concentrations significantly increased fixed oil yield /feddan, comparing to no sprayed plants, in the two seasons. However, higher values of such aspect were obtained due to the use of the combined treatments, mostly than those revealed by individual treatments, during both seasons. Apparently, foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) proved to be more effective in augmenting fixed oil yield /feddan than those detected by other treatments and control, in the two seasons. This above-mentioned superior treatment yielded 202.6 and 245.0 liter /feddan fixed oil in contrast the control which registered 123.4 and 141.5 liter /feddan fixed oil, during the two experimental seasons, respectively. In relation to the interaction between the two examined factors, it was statistically significant effect on fixed oil yield /feddan of black cumin seeds, during the two growing seasons. In this connection, applying all combined treatments, in both seasons, resulted a significant augment in fixed oil yield /feddan, except for the treatment of compost at the low level (9 m^3 /feddan) plus 0 spraying antioxidants, in the second season, as compared to untreated ones. 0bviously, plants grown in organic conditions at the high level (27 m^3 /feddan) plus foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) achieved the most effective treatment in elevating fixed oil yield

/feddan which yielded 236.4 and 303.3 liter /feddan fixed oil, while untreated plants recorded 100.9 and 116.5 liter /feddan fixed oil, during the two consecutive seasons, respectively, as clearly declared in Table (11).

Table (11): The impact of compost levels, some antioxidants and their interactions on fixed oil yield (liter) /feddan of black cumin seeds during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	100.9	117.2	132.5	143.0	123.4
Citric acid (CA) at 200	113.1	131.8	158.8	173.3	144.3
Citric acid (CA)at 300	123.5	147.3	166.6	176.4	153.5
Ascorbic acid (AA) at 200	127.5	154.9	174.2	184.2	160.2
Ascorbic acid (AA) at 300	147.6	165.0	184.9	206.8	176.1
AC at 200 + AA at 200	156.3	177.1	188.5	219.5	185.4
AC at 300 + AA at 300	181.7	192.1	200.0	236.4	202.6
Mean (A)	135.8	155.1	172.2	191.4	
L.S.D. at 5%	A: 6.3		B: 5.8		AB: 11.6
Second season					
Control	116.5	123.3	146.8	179.3	141.5
Citric acid (CA) at 200	136.7	142.5	177.1	194.0	162.6
Citric acid (CA)at 300	158.8	156.9	202.5	211.6	182.5
Ascorbic acid (AA) at 200	156.2	172.1	187.1	227.5	185.7
Ascorbic acid (AA) at 300	168.2	178.9	220.6	252.6	205.1
AC at 200 + AA at 200	187.4	188.5	221.2	245.5	210.7
AC at 300 + AA at 300	197.4	207.8	271.5	303.3	245.0
Mean (A)	160.2	167.1	203.8	230.5	
L.S.D. at 5 %	A: 9.0		B: 7.1		AB: 14.2

3.5 Nitrogen, phosphorus and potassium percentages

The recorded data in Tables (12, 13 and 14) indicated that the elements of N, P and K % in black cumin herb were significantly influenced due to applying compost as organic manure, during the two experimental seasons. Clearly, the addition of compost at all levels, in both seasons, led to a significant increase in the three examined elements (N, P and K %), except for the low one (9 m^3 /feddan) of compost, concerning N %, in the second season, P % in the two seasons, and K %, in the first season, as compared to unfertilized plants. Obviously, by augmenting the levels of compost, the three studied elements were gradual significantly elevated, during both seasons. Therefore, the highest values of these elements were given by using compost at the high level (27 m^3 /feddan) as ranged 13.8 and 8.0 %, regarding N %, 5.6 and 5.9 %, concerning P % and 5.2 and 10.5 for K %, in relative to the check treatment, during the two growing seasons, respectively. The important role of organic manures in enhancing N, P and K elements observed in the present research have been examined by Gahory (2012) and Ibrahim (2020) on black cumin, Abo-Kutta (2017) and Fouad (2023) on fennel, Mahmoud (2017) on *Ammi visnaga*, Helmy (2016) on cumin and Mahmoud (2021) on roselle.

Table (12): The impact of compost levels, some antioxidants and their interactions on nitrogen % of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	1.60	1.66	1.71	1.81	1.70
Citric acid (CA) at 200	1.64	1.72	1.78	1.82	1.74
Citric acid (CA)at 300	1.70	1.76	1.81	1.94	1.80
Ascorbic acid (AA) at 200	1.75	1.80	1.84	1.99	1.85
Ascorbic acid (AA) at 300	1.82	1.88	1.98	2.02	1.93
AC at 200 + AA at 200	1.80	1.91	2.01	2.08	1.95
AC at 300 + AA at 300	1.89	1.98	2.11	2.20	2.05
Mean (A)	1.74	1.82	1.89	1.98	
L.S.D. at 5%	A: 0.02		B: 0.03		AB :0.05
Second season					
Control	1.68	1.73	1.79	1.85	1.76
Citric acid (CA) at 200	1.77	1.78	1.85	1.87	1.82
Citric acid (CA)at 300	1.82	1.84	1.91	1.93	1.88
Ascorbic acid (AA) at 200	1.90	1.88	1.94	2.03	1.94
Ascorbic acid (AA) at 300	1.91	1.93	2.02	2.12	2.00
AC at 200 + AA at 200	1.98	2.01	2.07	2.17	2.06
AC at 300 + AA at 300	2.09	2.10	2.14	2.24	2.14
Mean (A)	1.88	1.90	1.96	2.03	
L.S.D. at 5 %	A: 0.03		B: 0.03		AB: N.S

Table (13): The impact of compost levels, some antioxidants and their interactions on phosphorus % of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	0.290	0.292	0.295	0.299	0.294
Citric acid (CA) at 200	0.296	0.297	0.298	0.300	0.298
Citric acid (CA)at 300	0.303	0.302	0.306	0.311	0.306
Ascorbic acid (AA) at 200	0.298	0.304	0.312	0.318	0.308
Ascorbic acid (AA) at 300	0.305	0.309	0.320	0.324	0.315
AC at 200 + AA at 200	0.303	0.308	0.317	0.329	0.314
AC at 300 + AA at 300	0.313	0.315	0.327	0.345	0.325
Mean (A)	0.301	0.304	0.311	0.318	
L.S.D. at 5%	A: 0.004		B: 0.003		AB: 0.006
Second season					
Control	0.293	0.291	0.297	0.303	0.296
Citric acid (CA) at 200	0.294	0.299	0.302	0.301	0.299
Citric acid (CA)at 300	0.297	0.307	0.309	0.319	0.308
Ascorbic acid (AA) at 200	0.303	0.306	0.311	0.325	0.311
Ascorbic acid (AA) at 300	0.315	0.314	0.327	0.334	0.323
AC at 200 + AA at 200	0.313	0.310	0.323	0.337	0.321
AC at 300 + AA at 300	0.326	0.327	0.325	0.350	0.332
Mean (A)	0.306	0.308	0.313	0.324	
L.S.D. at 5 %	A: 0.004		B: 0.004		AB :0.008

In respect to antioxidant treatments, the given data postulated that the three tested elements (N, P and K %) of black cumin herb were positively responded to foliar spray with the studied antioxidants, during the two consecutive seasons. In connection, the percentages of N, P and K were significantly augmented, in the two seasons, due to foliar spray with the two examined antioxidants, either separately or in combination at all concentrations, except for, the treatment of citric acid at the low concentration (200 ppm), regarding P %, in the second season and the same previous treatment, concerning K %, in both seasons, as compared to no sprayed ones. Higher values of these elements were obtained as a result of supplying the plants with the combined treatments, mostly than those revealed by single ones, in both seasons. Moreover, foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) proved to be more effective in increasing N, P and K % than those obtained by other treatments and control, in both seasons. Numerically, this previous superior treatment increased N % by 20.6 and by 21.6 %, P % by 10.5 and by 12.2 % and K % by 14.3 and by 13.0 % over control plants, during the two successive seasons, respectively, as clearly mentioned in Tables (12, 13 and 14). The stimulating effect of citric acid on N, P and K elements detected in this work was, also reported by Mahmoud (2017) on *Ammi visnaga* and also, by Ismail (2008) and Gahory (2012) on black cumin, Helmy (2016) on cumin and Abo-Kutta (2017) on fennel, concerning ascorbic acid application.

Table (14): The impact of compost levels, some antioxidants and their interactions on potassium % of black cumin plants during 2021/2022 and 2022/2023 seasons.

Antioxidant treatments (ppm) (B)	Compost levels (m^3 /feddan) (A)				
	0.0	9	18	27	Mean (B)
	First season				
Control	1.43	1.45	1.49	1.52	1.47
Citric acid (CA) at 200	1.47	1.46	1.50	1.50	1.48
Citric acid (CA)at 300	1.51	1.55	1.57	1.61	1.56
Ascorbic acid (AA) at 200	1.53	1.51	1.58	1.64	1.57
Ascorbic acid (AA) at 300	1.60	1.62	1.66	1.62	1.63
AC at 200 + AA at 200	1.59	1.61	1.65	1.70	1.64
AC at 300 + AA at 300	1.63	1.63	1.69	1.76	1.68
Mean (A)	1.54	1.55	1.59	1.62	
L.S.D. at 5%	A: 0.02	B :0.03	AB :0.06		
Second season					
Control	1.57	1.61	1.66	1.65	1.62
Citric acid (CA) at 200	1.55	1.59	1.68	1.73	1.64
Citric acid (CA)at 300	1.57	1.63	1.72	1.75	1.67
Ascorbic acid (AA) at 200	1.56	1.62	1.71	1.79	1.67
Ascorbic acid (AA) at 300	1.68	1.73	1.79	1.84	1.76
AC at 200 + AA at 200	1.67	1.71	1.80	1.82	1.75
AC at 300 + AA at 300	1.74	1.77	1.82	1.98	1.83
Mean (A)	1.62	1.67	1.74	1.79	
L.S.D. at 5 %	A: 0.03	B :0.03	AB :0.06		

Accordingly, the interaction effect between the two studied factors on N, P and K % of black cumin herb was statistically significant, in the two seasons, except for N %, in the second season (Table 12, 13 and 14). Obviously, the most combined treatments significantly increased the three tested elements (N, P and K %), comparing to untreated plants, during the two seasons. Apparently, supplying the plants with compost at the high level (27 m^3 /feddan) plus foliar spray with the combined treatment (300 ppm CA + 300 ppm AA) was the most effective treatment in augmenting N, P and K %, in comparison with those detected by other combination treatments, during the two experimental seasons. From the obtained results, it could be discussed as follows: Supplying black cumin plants with compost as organic manure led to an augment in growth, yield, oil production (essential and fixed), and the elements of N, P and K % may be attributed to the physiological and biological roles of organic manures were described by many authors such as, Reynders and Vlassak (1982) suggested that organic manures contain microorganisms namely, *Azospirillium* and *Azotobacter* that acts N-fixing bacteria and release phytohormones (IAA, GA and Cytokinins) which are a vital role in augment the growth, dry matter and nutrients absorption. Saber (1977) revealed that organic manure is useful in minimizing the loss of nutrients by leaching. Additionally, Dhull *et al.* (2004) exhibited that microbial biomass was stimulated due to the presence of organic manures. Improving the studied aspects as a result of foliar spray with antioxidants (citric and ascorbic acids) reflect the beneficial roles of these materials which were explained by some researchers for examples: Concerning citric acid, it is an important role in augmenting cell division, enzymes activity and protecting the plant cells from senescence and death, as well as, raising the resistance of plant to various disorders the biosynthesis of organic foods and plant hormones, besides to capable alleviating the environmental stresses. Also, it can be affects the activity of some natural cycles in higher plants and acts an important role in electron transport system (Elade, 1992; Khan *et al.*, 2003). The use of citric acid can be modulating an antioxidant defense system, capable elevate high content of photosynthetic pigment and influencing secondary metabolites, as well as, improving the productivity of plants grown in stress soil (Tahjib-Ul-Arif *et al.*, 2021). As for ascorbic acid, it plays an important role in promoting cell division, photosynthesis, respiration, lipase, catalase and manage enzymes activities, besides to elevating the growth and oil % (Dewick, 2000; Eid *et al.*, 2010; Oertli, 1987; Reda *et al.*, 2005). From the obtained results, it could be recommended to supply the soil of black cumin (*Nigella sativa*) plants with compost at 27 m^3 /feddan and foliar spray with citric acid at 300 ppm and ascorbic acid at 300 ppm to enhance the growth, seed yield, the production of essential and fixed oils, and the elements of N, P and K % under the conditions of this work.

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