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Impact of applying potassium fulvate and manganese sources on growth performance, yield and quality of beans plants (*phaseolus vulgaris*)

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INCREASING the yield of kidney bean plants is a challenge to humankind dependent on many management practices *e.g.,* fertilizing. Despite the efforts of workers in the plant nutrition field to find ways to maximize the productivity of strategic crops such as beans plants (*phaseolus vulgaris*), only a few publications focus on the effect of potassium fulvate combined with manganese on the plant. So, a pot trial was executed during the growing season of 2022 at the Farm of Agric. Fac., Mansoura Univ., Egypt, (31°03′00″N 31°22′59″E) to evaluate the response of kidney bean plants (*phaseolus vulgaris*)plant to applying potassium fulvate and different manganese sources via different application methods. There are two factors under this experimentation; the main factor was the application methods (**M_1**: Foliar application and **M_2**: Soil addition).While the sub main factor was the added substances either solely or in combinations *i.e.*, **T_1:** Control (without added substances),**T_2:** Potassium fulvate at rate of 0.12 g L^{-1} **, T_3:** Potassium fulvate at rate of 0.15 g L^{-1} , **T_4:** Manganese at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$, (24%Mn),**T_5:** Manganese at rate of 1.153 g L^{-1} using Mn - EDTA (12%Mn),**T_6:** As a combined treatment (T_2 + T_4), **T_7:** As a combined treatment (T_2 + T_5), **T_8:** As a combined treatment (T_3 + T_4) and **T_9:** As a combined treatment (T_3 + T_5). The plant height (cm), foliage fresh and dry weights (g $plant^{-1}$), chlorophyll (SPAD), No. of pods $plant^{-1}$, pods length (cm) and diameter (cm), pods yield (ton ha^{-1}), N, P, K (%), Mn ($mgkg^{-1}$), protein, carbohydrates and fiber were determined. The results showed that the plants fertilized with the studied substances via the foliar method had values of both growth criteria and pods' physical and qualitative traits were greater than those of the corresponding plants fertilized with the studied substances as soil addition. Concerning the studied substances, the superior treatment was **T_9** treatment followed by **T_8** then **T_7 , T_6, T_3 , T_2, T_5 , T_4**, respectively and lately **T_1** treatment (without added substances). All studied parameters of growth, yield and pod quality significantly increased in response to both KF and Mn treatments. Both KF and Mn treatments (either single or combined) substantially improved the growth performance and yield of kidney bean plants compared to the control treatment (T1: without added substances). The combined treatments of KF and Mn (**T_6, T_7, T_8** and **T_9**) were better than the single treatments (**T_2, T_3, T_4** and **T_5**). The values increased as the added rate of KF increased under both single and combined treatments. Also, kidney bean plants treated with Mn in chelating compound form (EDTA, 12% Mn) recorded growth performance and yield better than that treated with Mn in the inorganic salt form under both single and combined treatments. Meantime, the KF treatments caused improved the performance of kidney bean plants better than Mn treatments (both studied forms).

Keywords: Foliar application, soil addition, Mn –EDTA, $MnSO_4.4H_2O$ and kidney bean.

1. Introduction

Although the world has begun to use many technologies that have changed the agricultural map all over the world, there is still an urgent need to find practical solutions to cause vertical and horizontal agricultural expansion, thus increasing the productivity of strategic crops. Also, these solutions used to increase crop productivity must be safe for both humans and ecosystems **(Mohamed and Gouda, 2018; Fadl and Sayed, 2020; Seadh *et al.*,2021; El- Shamy *et al.*, 2022; El-Sherpiny *et al.*, 2022 and Elsherpiny and Helmy, 2022).**

Humic substances HS (as part of humus-soil organic matter) are compounds arising from the chemical,

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microbiological and physical transformation (humification) of biomolecules (**Taha, 1985 and Taha *et al.*, 2016**). They are complex aggregates of brown to dark-coloured amorphous. HS have important roles in increasing soil fertility and are considered to have primal relevance for the stabilization of soil aggregates (**Lipczynska-Kochany, 2018**). They can be divided into three components according to their solubility: humic acids, fulvic acids and humin (**Sarlaki *et al.*, 2019**). Due to humic substances possessing good water solubility and strong resistance to hard water, they are mainly used either as soil addition or under a fertigation system (**Omar *et al.*, 2020).**

Potassium is a crucial nutrient, which can enhance higher plant dry matter and crop productivity **(Tolba *et al.*, 2021).** Potassium fulvate is a necessary natural substance that can be used to improve the physio-biochemical attributes of soils and their performance, which reflect on the productivity of plants as mentioned by **Taha *et al.*, (2016).** Potassium fulvate is fulvic acid potassium salt completely water-soluble. It is mainly extracted from lignite **(Mohamed, 2020).** Potassium fulvate can act as a biostimulant to encourage seeds germination, root growth and elongation and increase growth parameters and total photosynthetic pigments content in leaves in addition to their potential to deliver bioactive molecules and free radical scavenging **(Elzemrany and Faiyad, 2021).**

In Egypt, most fertilization programs don't include manganese as a significant element. However, fertilization with manganese element is necessary due to the decline in its availability in Egyptian soils, which have high pH values **(El-Ramady *et al.*, 2019).** Manganese is included in the composition of many enzymes of respiration, photosynthesis, and nitrogen representation within the plant and it is proven that there is a close relationship between this element and iron, so its deficiency causes the yellowing of the leaves (**Oliveira *et al.*, 2020 and Alejandro *et al.*, 2020).**

When manganese is added to the soil in the form of inorganic salts such as manganese sulfate ($MnSO_4.4H_2O$), this form is exposed to interactions that reduce its availability for the plant. But, when it is added in the form of chelating compounds, its association with these compounds protects it from entering into interactions in the soil and thus increases its availability **(Niu *et al.*, 2021).**

In current agriculture, the usage of chelate fertilizers plays a vital role in the production process **(Souri, 2016).** The chelate fertilizers "sequestering agent's" are cyclic organic compounds attached to one or more metals strongly deferring from one chelated compound to another, and they are soluble in water in the form of powder or liquid **(Souri and Aslani, 2018).** The chelate compounds prevent the fixation of the elements in the soil, thus making it easier for the element to be absorbed by the plant without losing it by fixation in the soil **(Dwyer, 2012).** Among the chelating compounds commonly used in agriculture are EDTA, DTPA, CDTA and EDDHA**.**

The application methods of fertilizers to higher plants differ in their efficiency **(Serrão and Havenhand, 2009).** The foliar application method is more effective than the soil application strategy due to the minimum losses involved in the foliar spray **(Wang *et al.*, 2012).** Also, the foliar application strategy can reduce the lag time between the application and uptake by the plant **(Rasht, 2013).** Foliar fertilization depends on supplying the higher plants with the necessary nutrients through spraying on the plant's vegetative foliage, which can absorb these elements through the stomata spread on the upper and lower leaf surfaces. Foliar fertilization protects the higher plants and their proper growth and eliminates manifestations of deficiency of microelements such as yellowing of leaves, spotting and weak knots (**Kazemi, 2014).** It is possible through foliar fertilization to increase the leaves area, which leads to an increase in the size and quality of the fruits **(Aslani and Souri, 2018).**

Kidney bean (*Phaseolus vulgaris*), which belongs to the Fabaceae family, is one of the most popular leguminous vegetable crops grown in Egypt either for local consumption or exportation **(Hemida *et al*., 2017).** It is a substantial legume vegetable crop that was cultured for its production of edible green pods and dry seeds demanded in the market highly **(Rashwan *et al*., 2020).** The kidney bean is used for human nutrition due to it is considered a brilliant nutritive source of carbohydrates, proteins, nutrients (N, P, K, Fe, Mn.... *etc*), fiber and vitamins (C and A) **(Choe *et al.*, 2022).**

The specific objectives of the study are to evaluate the influence of applying potassium fulvate with different manganese sources (solely and in combinations) either to the soil or to the leaves on the performance of kidney bean plant and to find out the superior combined treatment for improving plant growth performance, yield, quality and its components.

2. Material and Methods

A pot trial was executed to evaluate the response of kidney bean plant to applying potassium fulvate at two rates (0.12 and 0.15 g L^{-1}) as well as different manganese sources *i.e.,* inorganic salt form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)] and chelating compound form (EDTA, 12% Mn) either solely or in combinations via two application methods *i.e.*, soil addition and foliar application.

2.1. Experimental location.

This research work was carried out during the growing season of 2022 at the Farm of Agric. Fac., Mansoura Univ., Egypt, (31°03′00″N 31°22′59″E).

2.2. Soil sampling and analysis.

Soil samples were collected from the Farm of Agric. Fac., Mansoura Univ., Egypt. Before the execution of the experiment, it was analyzed as presented in Table1.

Table 1. Characteristics of the studied soil before sowing.

Particle size distribution (%)				Texture class	Available nutrients				Organic matter	EC, dSm^{-1}**	pH*
C. Sand	F. Sand	Silt	Clay		N	P	K	Mn			
					(mg kg^{-1})				(%)		
3.50	15.8	30.7	50.0	Clay	45.06	9.04	226.48	0.91	1.28	2.03	8.43
Using pipette method				Using soil texture triangle	Kjeldahl method	Spectrophotometric method	Flame photometer	Atomic absorption spectrophotometer	By Walkly and Balck method	Using EC-meter	Using pH-meter
Gee and Baudet (1986).					Hesse, (1971).				Dewis and Freitas, (1970).		

Notes: *** pH (1:2.5 soil suspension).**
****EC_w (soil extract 1:5).**

2.3. Pots used.

Plastic pots with diameter of 25 cm and depth of 30 cm were used and filled by air-dry soils equaled to 10.0 kg oven dry soil.

2.4. Kidney bean seeds.

Kidney bean seeds "(*Phasuolas vlugaris* L. Cv Nebraska)" were obtained from Ministry of Agric. and Soil Rec. (MASR).

2.5. Substances studied.

Potassium fulvate and both manganese sources were purchased from the agriculture commercial market. Table 2 shows the specification of potassium fulvate.

Table 2. Some characteristic of potassium fulvate.

HA	FA	Solubility	Moisture	pH	Total macro element			Functional groups	
					N	P_2O_5	K_2O	Carboxylic groups	Phenolic groups
%					%			mmol/100g HS	
3.80	64.0	100	5.60	5.63	3.56	3.0	8.0	590	365
Javanshah and Saidi, (2016).					Tandon, (2005).			Taha, (1985).	

2.6. Experimental design and treatments.

The execution of this research work was done in a split-plot design with three replicates. Consequently, total number of pots was 54 as follows; 2 “application methods” ×9 “added materials in single addition and combined addition” × 3 “replicates”.

There are two factors under this experimentation; the main factor was the application methods of the studied substances which included two ways. While the sub main factor was the added substances either solely or in combinations. The soil addition of the studied substances was applied to the soil directly. While the foliar application was made by hand sprayer until saturation point.

Treatments

Main factor		Sub main factor
	M_1 Foliar application	**T_1:** Control (without added substances).
		T_2: Potassium fulvate at rate of 0.12 g L^{-1}.
		T_3: Potassium fulvate at rate of 0.15 g L^{-1}.
		T_4: Manganese at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$, (24%Mn).
		T_5: Manganese at rate of 1.153 g L^{-1} using Mn -EDTA (12%Mn).
		T_6: As a combined treatment ($T_2 + T_4$).
		T_7: As a combined treatment ($T_2 + T_5$).
		T_8: As a combined treatment ($T_3 + T_4$).
		T_9: As a combined treatment ($T_3 + T_5$).
	M_2 Soil addition	**T_1:** Control (without added substances).
		T_2: Potassium fulvate at rate of 0.12 g L^{-1}.
		T_3: Potassium fulvate at rate of 0.15 g L^{-1}.
		T_4: Manganese at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$, (24%Mn).
		T_5: Manganese at rate of 1.153 g L^{-1} using Mn -EDTA (12%Mn).
		T_6: As a combined treatment ($T_2 + T_4$).
		T_7: As a combined treatment ($T_2 + T_5$).
		T_8: As a combined treatment ($T_3 + T_4$).
		T_9: As a combined treatment ($T_3 + T_5$).

The standard aqueous solutions were prepared from each studied substance with a known concentration by dissolving a known mass of the compound in the solvent (water), and then preparing the different concentrations of each studied substance at the above-mentioned rates.

2.7. Cultivation

One hour before sowing, kidney bean seeds were inoculated with Okadin bio fertilizer at rate of 200g of rhizobium inoculant carried on peat moss per fed using sugar solution as a sticker. Kidney bean seeds were sown at rate of 4-5 seed pot^{-1} on 3rd of March.

2.8. Fertilization

Chemical fertilization (N, P and K) and other normal agricultural practices were done for kidney bean production according to MASR. Before sowing, calcium super phosphate (15.5 % P_2O_5) was applied at rate of 150 kg fed^{-1}. Effective nitrogen dose as ammonium sulphate (20.6 %N) was added at rate of 20 unit N fed^{-1} in one dose after 21 days from sowing before the first irrigation. Potassium sulphate (48 % K_2O) was applied at rate of 50 Kg fed^{-1} at flowering stage (45 days from sowing).

Foliar application and soil addition of both potassium fulvate and Mn sources were done at two different periods from sowing (after 21 and 35 days). The volume of sprayed both potassium fulvate and Mn solutions either in single or combined treatment was 400 L fed^{-1} under both studied application methods.

2.9. Irrigation

The life watering was after 21 days from sowing. Irrigation was done as plants needed. All pots were irrigated almost by seven irrigations according to the traditional irrigation regime in the studied region, where the source of irrigation was Nile River.

2.10. Harvesting

Pods of kidney bean plant were harvested at the proper maturing stage through two pickings (pods collecting) with intervals of 10 days between the first and second

2.11. Measurement traits

Flowering stage: At a period of 45 days from sowing seeds, two plant samples were randomly taken from each pot to measure some growth criteria and chemical constituents in leaves of kidney bean plant as follows;

- **Growth criteria** *i.e.,* plant height, foliage fresh and dry weights and leaf area were measured. Leaf area index was determined according to **Watson, (1958)** as the following formula:

  LAI = unit leaf area per plant/unit ground area occupied by plant

- **Photosynthetic pigments:** Chlorophyll (SPAD, reading) and carotene content which was determined according to **Ranganna, (1997).** Pigments were determined in fresh weight samples.
- **Nutrients:** The samples of kidney bean plant foliage were dried at 70^{0}c then the oven-dried samples were ground and wet digested by a mixture of perchloric and sulfuric acids (1:1) as described by **Peterburgski (1968).** All nutrients were determined as described by **Walinga *et al.*, (2013).** Nitrogen was determined using kjeldahl method. Phosphorus was determined using spectrophotometer. Potassium was determined using flam photometer. Manganese was determined using atomic absorption (FAAS Perkin Elmer HGA 4000 programs).

Harvesting stage: When pods reached to the proper maturing stage, some physical and biochemical characteristics of pods were measured as follows;

- **Yield and its components** *i.e.,* No. of pods plant^{-1}, pods length, pods weight, pods diameter and pods yield were measured.
- **Pods quality traits**: N, P, K and Mn were determined as formerly mentioned in leaves, while crude protein, carbohydrates, fiber and total dissolved solid, (TDS) were determined according to **AOAC, (2007).** Crude protein content was calculated by multiplying the total N by the factor of 6.25 **(AOAC, 2007).**

2.12. Statistical analyses

The obtained data were subjected to analysis of variance according to **Gomez and Gomez (1984).** Treatment means were compared by using the least significant difference (LSD) at 0.05 level of probability (Version 6.303, CoHort, USA, 1998–2004).

3. Results and Discussion

Growth criteria, photosynthetic pigments and chemical constituents after 45 days from sowing.

a-Growth criteria.

Table 3 shows the individual and interaction effects of applying different rates of potassium fulvate (0.12 and 0.15 g L^{-1}) and different manganese sources *i.e.,* inorganic salts form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)] and chelating compound form (EDTA, 12% Mn) either to the soil or to the leaves on kidney bean growth criteria *i.e.,* plant height (cm), foliage fresh and dry weights (g plant^{-1}) and leaf area (cm^2 plant^{-1}).

- Individual effect of the application method.

The kidney bean plant fertilized with the studied substances via the foliar application method had plant height (cm), foliage fresh and dry weights (g plant^{-1}) and leaf area (cm^2 plant^{-1}) values greater than those of the corresponding plants fertilized with the studied substances via soil addition method. Generally, the obtained results (Table 3) confirm that the foliar application strategy is more efficient than the soil addition way and this trend may be due to the ability of the external application to reduce the lag time between application and uptake by the kidney bean plant.

It can be said that the foliar application of potassium fulvate and both manganese forms on the vegetative foliage of the plants made these materials easily absorbed through the stomata holes spread on the surfaces of the upper and lower leaf. Also, the application of potassium fulvate and manganese (in its different studied forms) as soil addition may reduce their efficiency due to the high losses under soil addition way by leaching or turning to unavailable form, especially Mn. The obtained results are in accordance with those of **Ling and Silberbush, (2002)** who reported that the foliar application method might partially compensate for insufficient uptake by the roots but requires sufficient leaf area to become effective. Beside**, Bybordi and Mamedov, (2010)** concluded that the foliar application method was more effective than the soil application.

- Individual effect of the studied substances.

Regarding the studied substances, analysis of the plant growth performance showed that plant height (cm), foliage fresh and dry weights (g plant^{-1}) and leaf area (cm^2 plant^{-1}) significantly increased in response to both potassium fulvate (KF) and manganese (Mn) treatments. Both KF and Mn treatments (either single or combined) substantially improved the growth performance of kidney bean plants compared to the control treatment (**T_1**: without added substances).

In this respect, the combined treatments of KF and Mn (**T_6, T_7, T_8** and **T_9**) were better than the single treatments (**T_2, T_3, T_4** and **T_5**).

The values of plant height (cm), foliage fresh and dry weights (g plant^{-1}) and leaf area(cm^2 plant^{-1}) increases as the added rate of KF increased under both single and combined treatments. Also, kidney bean plants treated with Mn in chelating compound form (EDTA, 12% Mn) recorded growth performance expressed in plant height (cm), foliage fresh and dry weights (g plant^{-1}) and leaf area (cm^2 plant^{-1}) better than that treated with Mn in inorganic salts form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)] under both single and combined treatments. Meantime, the KF treatments caused improve growth performance of kidney bean plants better than Mn treatments (both studied form).

Generally, it can be noticed that the sequence order of the studied substances treatments from top to less was as follows;

$T_9 > T_8 > T_7 > T_6 > T_3 > T_2 > T_5 > T_4 > T_1$ (without added substances**).**

Applying KF either solely or in combination with Mn enhanced the growth traits compared to the corresponding plants grown without KF under both foliar and soil applications. This pronounced promotional effect may be resulting from potassium which is a crucial nutrient leading to enhanced dry matter of kidney bean plant. plant. Also, the potassium fulvate might increase the organic matter of the soil under soil injection and improve the soil structure, accordingly largely promoting the buffering power of the soil and these impacts reflect on the growth performance of kidney bean plants.

Under foliar application, the small molecular weight of KF with a short molecular chain makes it easy to be absorbed by kidney bean plants. The superior of K-fulvate may be due to its high content of HA, FA, N, P and K (%) and their content of phenolic -OH, COOH and alcoholic- OH groups.

Under soil addition, KF may reduce the soil pH and thereby increase the availability of the most element nutrients and this effect positively reflect on growth performance.

Generally, it can be said that KF can be used as plant biostimulants to increase plant growth performance due to its low molecular weight, high oxygen content and many (-OH) and (-COOH) groups that increase its exchange capacity. These findings are in agreement with those of **Taha *et al.*, (2016), Omar *et al.*, (2020) and Mohamed, (2020).**

Table 3. Effect of the studied treatments on the growth criteria of kidney bean plant at period of 45 days from sowing during growing season of 2022.

Treatments	Plant height (cm)	Fresh weight (g $plant^{-1}$)	Dry weight (g $plant^{-1}$)	Leaf area (cm^2 $plant^{-1}$)
Addition methods				
M_1: Foliar application.	46.74a	116.73a	21.14b	298.62a
M_2: Soil addition.	40.97b	108.46b	18.74a	275.64b
LSD at 5%	**0.59**	**0.12**	**0.42**	**0.79**
Substances studied				
T_1: Control (without added substances**)**	37.64g	103.47g	17.51f	261.98i
T_2: Potassium fulvate at rate of 0.12 g L^{-1}	43.28e	112.20de	19.78d	285.55f
T_3: Potassium fulvate at rate of 0.15 g L^{-1}	44.35d	113.43cd	20.24c	289.18e
T_4: Mn at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$.	42.08f	110.05f	18.92e	279.45h
T_5: Mn of 1.153 g L^{-1} using Mn –EDTA.	42.73e	110.91ef	19.73d	282.68g
T_6: As a combined treatment ($T_2 + T_4$).	44.95d	114.14c	20.36c	292.50d
T_7: As a combined treatment ($T_2 + T_5$).	45.64c	114.72bc	20.67b	294.56c
T_8: As a combined treatment ($T_3 + T_4$).	46.44b	116.09b	20.75b	297.62b
T_9: As a combined treatment ($T_3 + T_5$).	47.58a	118.36a	21.49a	300.68a
LSD at 5%	**0.62**	**1.75**	**0.31**	**1.38**
Interaction M x T	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

Applying Mn either in inorganic salts form or in chelating compound form enhanced the growth traits compared to the corresponding plants grown under control treatment (**T_1**) under both foliar and soil applications. This pronounced promotional effect may be due to that Mn is included in the composition of many enzymes of respiration, photosynthesis, and nitrogen representation within the plant. Manganese is a necessary element for the formation of chlorophyll, although it is not included in the composition of the chlorophyll molecule. It acts as an enzymatic activator in the processes of respiration and protein assimilation. Manganese is necessary and essential for the functioning of many other enzymes, such as oxalsuccinic dehydrogenase and malic dehydrogenase, which are from Krebs cycle enzymes **(Kobraee, 2019** and **Shahrajabian *et al.*, 2020).**

The superiority of the chelating compound form to the inorganic salts form may be due to that the translocation of Mn away from the treated leaf to other plant parts under EDTA form was faster than the $MnSO_4$ form, thus the kidney bean plants treated with Mn-EDTA gave growth performance better than $MnSO_4$. Also, the chelate compounds may prevent the fixation of the Mn in the soil, thus making it easier for the element to be absorbed by the kidney bean plants without losing it by fixation in the soil. Generally, it can be said that applied Mn was more mobile in the phloem of kidney bean plants when applied with EDTA compared with $MnSO_4$. Similar results were found by **Ozbahce and Zengin, (2014) and Dwyer, (2012).**

- **Interaction effect**

As shown in Table 3, the combination of the best treatments specific to each studied factor realized the best growth performance of kidney bean plants. In other words, the highest values of plant height (cm), foliage fresh and dry weights (g $plant^{-1}$) and leaf area (cm^2 $plant^{-1}$) were realized when plants were sprayed with KH at a rate of 0.15 g L^{-1} and simultaneously with Mn-EDTA at rate of 1.153 g L^{-1}.

b-Photosynthetic pigments and leaves chemical constituents

It can be noticed that the studied treatments significantly affected kidney bean performance expressed in photosynthetic pigments [*i.e.*, chlorophyll (SPAD, reading) and carotene content (mg g^{-1}), as shown in **Table 4**] and leaves chemical constituents [N, P, K (%) and Mn (mg kg^{-1}), as shown in **Table 5**].

- **Individual effect of the application method**

Tables 4 and 5 elucidate that both studied application methods of KH and Mn treatments to kidney bean plants differ in their efficiency for all aforementioned traits, where the foliar application was more effective than soil addition and this trend may be due to the minimum losses involved in the foliar spray compared to soil addition method. Also, the foliar application may reduce the lag time between application and uptake by the kidney bean plant. Similar results were found by **Wang *et al.*, (2012), Rasht, (2013), Kazemi, (2014), Sooraki and Moghadamyar, (2017) and Aslani and Souri, (2018).**

- **Individual effect of the studied substances**

Tables 4 and 5 illustrate that the trend of photosynthetic pigments and leaves chemical constituents looked just like the trend of growth parameters shown in Table 3.

In other words, both KF and Mn treatments (either single or combined) significantly increased the values of photosynthetic pigments [*i.e.*, chlorophyll (SPAD, reading) and carotene content (mg g^{-1})] and leaves chemical constituents [N, P, K (%) and Mn (mg kg^{-1})] of kidney bean plants compared to the control treatment (**T_1**: without added substances).

The same Tables show that the plants grown under the combined treatments of KF and Mn (**T_6, T_7, T_8** and **T_9**) possessed the values of photosynthetic pigments [*i.e.*, chlorophyll (SPAD, reading) and carotene content (mg g^{-1})] and leaves chemical constituents [N, P, K (%) and Mn (mg kg^{-1})] greater than the plants grown under the single treatments (**T_2, T_3, T_4** and **T_5**).

The values of all aforementioned traits increased as the added rate of KF increased under both single and combined treatments. Also, kidney bean plants treated with Mn in chelating compound form (EDTA, 12% Mn) possessed values of chlorophyll (SPAD, reading), carotene content (mg g^{-1}), N, P, K (%) and Mn (mg kg^{-1}) higher than that treated with Mn in inorganic salts form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)] under both single and combined treatments.

It is also worth noting that the KF treatments are superior to Mn treatments (either in chelating compound form or in inorganic salt form).

On other words, the superior treatment for chlorophyll (SPAD, reading), carotene content (mg g^{-1}), N, P, K (%) and Mn (mg kg^{-1}) was **T_9** treatment followed by **T_8** then **T_7 , T_6, T_3 , T_2, T_5 , T_4**, respectively and lately **T_1** treatment **(**without added substances**).**

Table 4. Individual effect of the studied treatments on the photosynthetic pigments of kidney bean plant at period of 45 days from sowing during growing season of 2022.

Treatments	Chlorophyll (SPAD)	Carotene (mg g^{-1})
Addition methods		
M_1: Foliar application.	41.60a	0.541a
M_2: Soil addition.	38.95b	0.491b
LSD at 5%	**0.57**	**0.005**
Substances studied		
T_1: Control (without added substances**)**	37.45f	0.456i
T_2: Potassium fulvate at rate of 0.12 g L^{-1}	40.08de	0.514f
T_3: Potassium fulvate at rate of 0.15 g L^{-1}	40.60cd	0.521e
T_4: Mn at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$.	39.55e	0.496h
T_5: Mn of 1.153 g L^{-1} using Mn –EDTA.	39.82e	0.505g
T_6: As a combined treatment ($T_2 + T_4$).	40.79bc	0.528d
T_7: As a combined treatment ($T_2 + T_5$).	41.06bc	0.536c
T_8: As a combined treatment ($T_3 + T_4$).	41.31ab	0.542b
T_9: As a combined treatment ($T_3 + T_5$).	41.81a	0.548a
LSD at 5%	**0.60**	**0.003**
Interaction M x T	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

Table 5. Individual effect of the studied treatments on the leaves chemical constituents of kidney bean plant at period of 45 days from sowing during growing season of 2022.

Treatments	N (%)	P (%)	K (%)	Mn (mg kg^{-1})
Addition methods				
M_1: Foliar application.	3.99a	0.462a	2.76a	41.58a
M_2: Soil addition.	3.53 b	0.413b	2.36b	28.47b
LSD at 5%	**0.11**	**0.002**	**0.01**	**0.19**
Substances studied				
T_1: Control (without added substances)	3.32f	0.380g	2.15g	22.03i
T_2: Potassium fulvate at rate of 0.12 g L^{-1}	3.72de	0.432e	2.52de	33.79f
T_3: Potassium fulvate at rate of 0.15 g L^{-1}	3.78d	0.442d	2.58cd	35.72e
T_4: Mn at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$.	3.63e	0.421f	2.43f	30.21h
T_5: Mn of 1.153 g L^{-1} using Mn –EDTA.	3.70de	0.428e	2.48ef	32.33g
T_6: As a combined treatment ($T_2 + T_4$).	3.80cd	0.449c	2.61c	37.55d
T_7: As a combined treatment ($T_2 + T_5$).	3.89bc	0.453c	2.70b	39.50c
T_8: As a combined treatment ($T_3 + T_4$).	3.97ab	0.460b	2.76ab	41.13b
T_9: As a combined treatment ($T_3 + T_5$).	4.04a	0.467a	2.83a	42.98a
LSD at 5%	**0.10**	**0.004**	**0.07**	**0.18**
Interaction M x T	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05% level.

The same Tables show that the plants grown under the combined treatments of KF and Mn (**T_6, T_7, T_8** and **T_9**) possessed the values of photosynthetic pigments [*i.e.*, chlorophyll (SPAD, reading) and carotene content (mg g^{-1})] and leaves chemical constituents [N, P, K (%) and Mn (mg kg^{-1})] greater than the plants grown under the single treatments (**T_2, T_3, T_4** and **T_5**).

The values of all aforementioned traits increased as the added rate of KF increased under both single and combined treatments. Also, kidney bean plants treated with Mn in chelating compound form (EDTA, 12% Mn) possessed values of chlorophyll (SPAD, reading), carotene content (mg g^{-1}), N, P, K (%) and Mn (mg kg^{-1}) were higher than that treated with Mn in inorganic salts form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)] under both single and combined treatments.

It is also worth noting that the KF treatments superiorities to Mn treatments (both studied forms).

On other words, the superior treatment for chlorophyll (SPAD, reading), carotene content (mg g^{-1}), N, P, K (%) and Mn (mg kg^{-1}) was **T_9** treatment followed by **T_8** then **T_7 , T_6, T_3 , T_2, T_5 , T_4**, respectively and lately T_1 treatment **(**without added substances**).**

Potassium fulvate attracts water molecules and this may help the soil to remain moist and aid the movement of element nutrients into kidney bean plant roots. Generally, it can be said that potassium fulvate easily binds or chelates minerals, as it can deliver these elements to plants directly. Applying KF either solely or in combination with Mn enhanced the photosynthetic pigments [*i.e.*, chlorophyll (SPAD, reading) and carotene content (mg g^{-1})] and leaves chemical constituents [N, P, K (%) and Mn (mg kg^{-1})] compared to the corresponding plants grown without KF under both foliar and soil applications and this trend may be due to, as mentioned above, that potassium improved soil properties and these impacts reflect on the photosynthetic pigments and leaves chemical constituents of kidney bean plants at period of 45 days from sowing. While, under foliar application, the small molecular weight of KF with a short molecular chain makes it easy to be absorbed by kidney bean plants and this attribute positively reflect on the photosynthetic pigments and leaves chemical constituents of plants at period of 45 days from sowing.

Under soil addition, KF may reduce the soil pH and thereby increase the availability of the most element nutrients and this effect positively reflect on the photosynthetic pigments and leaves chemical constituents of kidney bean plants at period of 45 days from sowing. Similar results were obtained by **Omar *et al.*, (2020)** and **Mohamed, (2020).**

The vital role of Mn in forming chlorophyll, compositing many enzymes of respiration, photosynthesis, and nitrogen representation within the plant made Mn treatments superior to control treatment **(T_1)** for the photosynthetic pigments and leaves chemical constituents of kidney bean plants at period of 45 days from sowing**. As** well as manganese is required for oxygen to be isolated during photosynthesis **(Kobraee, 2019; Shahrajabian *et al.*, 2020).**

The superiority of Mn in EDTA form to the inorganic salts form due to the Mn-EDTA does not lead to burning the leaves. Also, the chelating compounds protect the Mn from entering into reactions with soil that reduce its availability. These effects reflected on the photosynthetic pigments and leaves chemical constituents of kidney bean plants at period of 45 days from sowing. Similar results were found by **Ozbahce and Zengin, (2014) and Dwyer, (2012).**

- Interaction effect.

The obtained data illustrate that the highest values of chlorophyll (SPAD, reading) **Fig.1**, carotene content (mg g^{-1}) (**Fig. 2**), N, P, K (%)and Mn (mg kg^{-1}) (**Figs. 3, 4, 5 and 6**) were recorded when kidney bean plants were sprayed with KH at a rate of 0.15 g L^{-1} and simultaneously with Mn-EDTA at rate of 1.153 g L^{-1}.

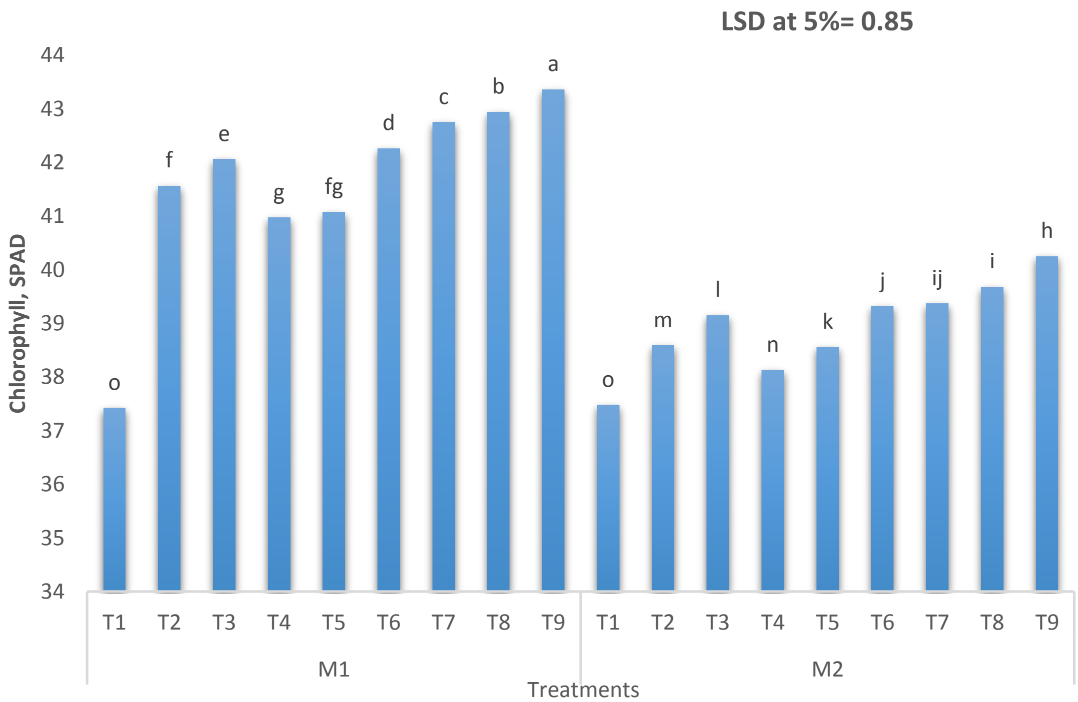

Fig 1. Interaction effect of the studied treatments on the chlorophyll content of kidney bean plant at period of 45 days from sowing during growing season of 2022.

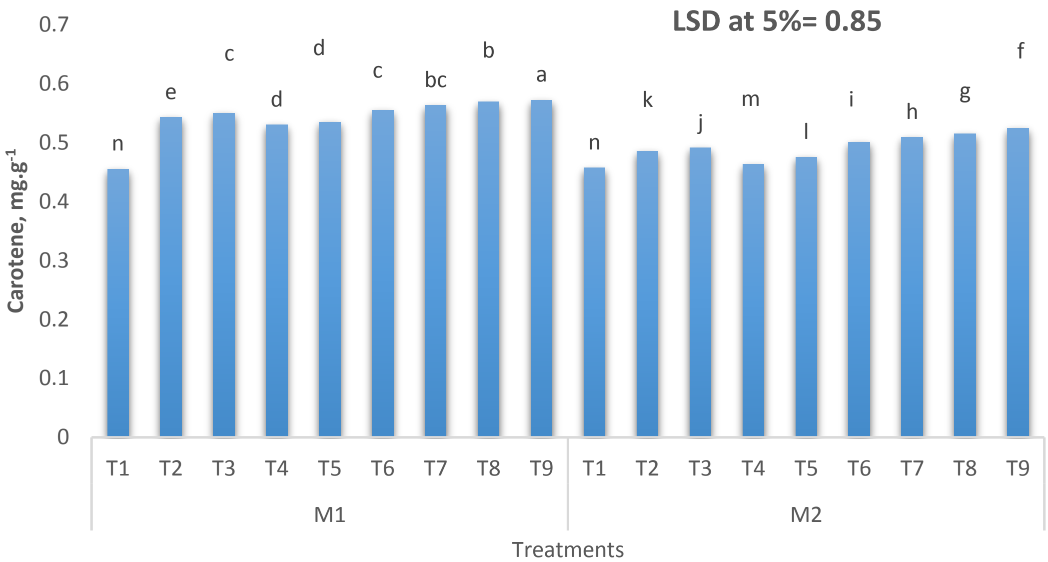

Fig. 2. Interaction effect of the studied treatments on the carotene content of kidney bean plant at period of 45 days from sowing during growing season of 2022.

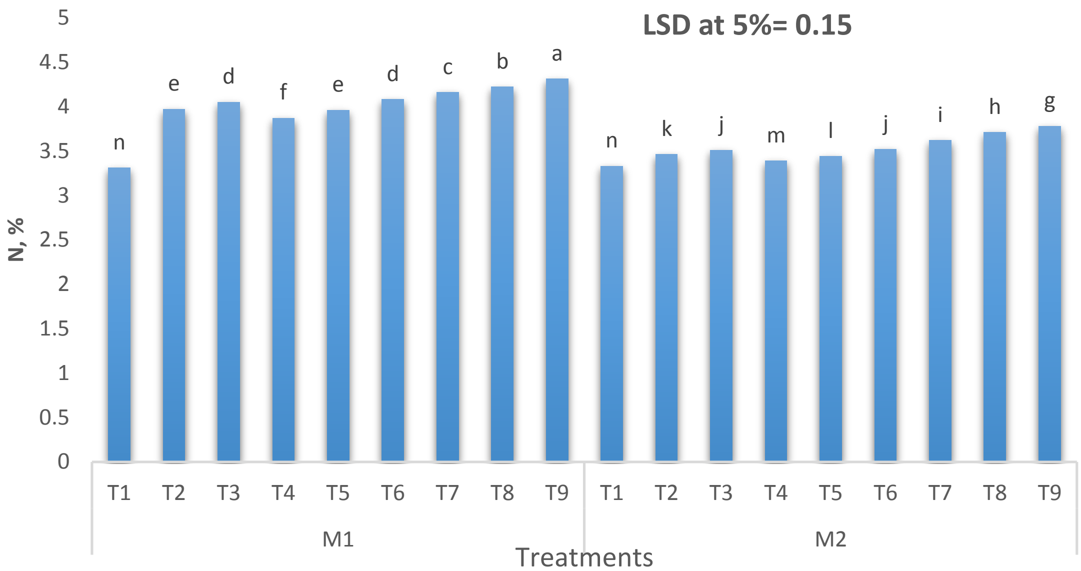

Fig. 3. Interaction effect of the studied treatments on the nitrogen content of kidney bean plant at period of 45 days from sowing during growing season of 2022.

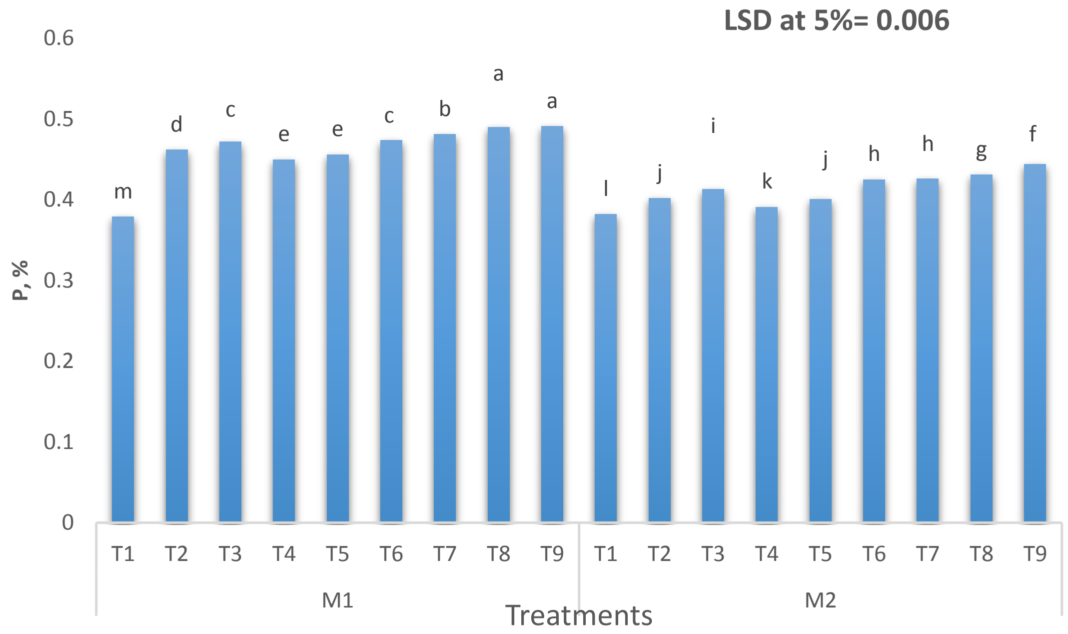

Fig4. Interaction effect of the studied treatments on the phosphorus content of kidney bean plant at period of 45 days from sowing during growing season of 2022.

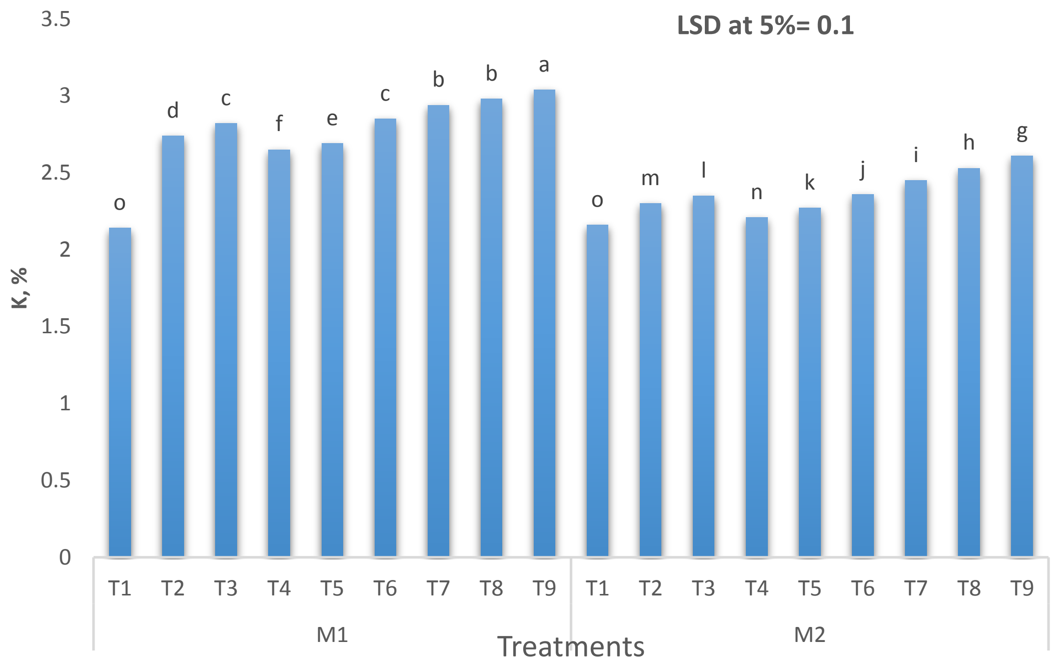

Fig5. Interaction effect of the studied treatments on the potassium content of kidney bean plant at period of 45 days from sowing during growing season of 2022.

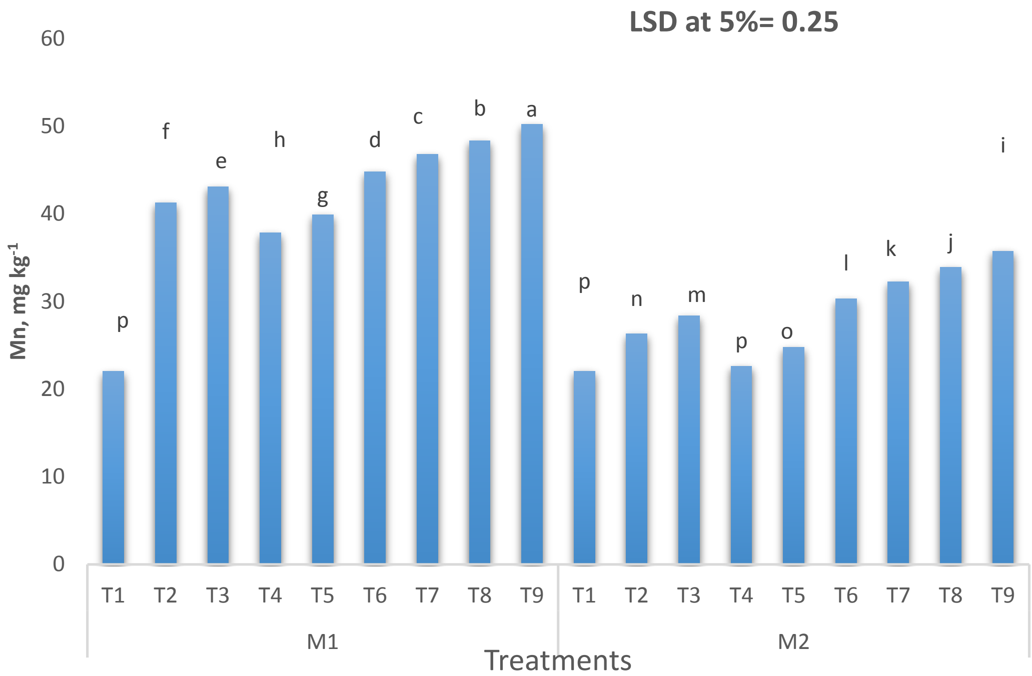

Fig6. Interaction effect of the studied treatments on the manganese content of kidney bean plant at period of 45 days from sowing during growing season of 2022.

Yield, quality and qualitative traits at harvest stage.

It is clear from data illustrated in Tables 8, 9 and 10 that physical and qualitative traits of kidney bean pods *i.e.* No. of pods plant^{-1}, pods length (cm), weight (g) and diameter (cm), pods yield (ton h^{-1}) (**Table 6**), N, P, K (%), Mn (mgkg^{-1}) (**Table 7**), crude protein, carbohydrates, fiber and TDS (%)(**Table 8**) at harvest stage were significantly affected as a result of the studied treatments.

- Individual effect of the application method.

The values of No. of pods plant^{-1}, pods length (cm), weight (g) and diameter (cm), pods yield (ton h^{-1}), N, P, K (%), Mn (mgkg^{-1}), crude protein, carbohydrates, fiber and TDS (%) were pronouncedly affected as a result of the studied application methods. The significant differences were clear. In other words, the highest values of all the above-mentioned traits were realized when kidney bean plants were sprayed with the studied substances followed by that treated with the studied substances as soil addition. It is worth observing that foliar application stimulated plant performance, which was manifested in accelerating the setting pods.

Generally, increasing all pod's physical and qualitative traits as well as total pods yield of kidney bean plant treated with the studied substances as foliar application compared to the plants treated with the studied substances as soil addition may be due to that the foliar application method is more effective than soil application strategy due to the minimum losses involved in the foliar spray. These results are in harmony with those of **Wang *et al.*, (2012).** Also, the foliar application strategy can reduce the lag time between the application and uptake by the plant **(Rasht, 2013).**

Table 6. Effect of the studied treatments on yield and its components of kidney bean plant at maturity stage during growing season of 2022.

Treatments	No. of pods plant^{-1}	Pod length (cm)	Pod weight (g)	Pod diameter (cm)	Pods yield (ton ha^{-1})
Addition methods					
M_1: Foliar application.	29.07a	12.30a	6.81a	0.58a	7.75a
M_2: Soil addition.	26.30b	10.75b	6.13b	0.40b	5.65b
LSD at 5%	**0.73**	**0.23**	**0.19**	**0.05**	**0.11**
Substances studied					
T_1: Control (without added substances**)**	22.67f	10.74g	6.12e	0.41h	5.65i
T_2: Potassium fulvate at rate of 0.12 g L^{-1}	27.67cde	11.35de	6.33d	0.47ef	6.53f
T_3: Potassium fulvate at rate of 0.15 g L^{-1}	28.00b-e	11.54cd	6.52c	0.49de	6.78e
T_4: Mn at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$.	26.67e	10.97f	6.23d	0.43gh	5.84h
T_5: Mn of 1.153 g L^{-1} using Mn –EDTA.	27.17de	11.19e	6.29d	0.45fg	6.17g
T_6: As a combined treatment ($T_2 + T_4$).	28.50a-d	11.72bc	6.53c	0.50cd	6.95d
T_7: As a combined treatment ($T_2 + T_5$).	29.17abc	11.83b	6.66b	0.53bc	7.17c
T_8: As a combined treatment ($T_3 + T_4$).	29.50ab	12.09a	6.71b	0.54b	7.47b
T_9: As a combined treatment ($T_3 + T_5$).	29.83a	12.27a	6.85a	0.58a	7.72a
LSD at 5%	**1.56**	**0.19**	**0.10**	**0.03**	**0.05**
Interaction M x T	**	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

Table 7. Effect of the studied treatments on pods nutritional status of kidney bean plant at maturity stage during growing season of 2022.

Treatments	N (%)	P (%)	K (%)	Mn (mg kg^{-1})
Addition methods				
M_1: Foliar application.	3.43a	0.380	2.18a	31.73a
M_2: Soil addition.	3.07b	0.343	1.80b	25.54b
LSD at 5%	**0.01**	**0.002**	**0.01**	**0.10**
Substances studied				
T_1: Control (without added substances**)**	2.86f	0.324h	1.65g	21.79i
T_2: Potassium fulvate at rate of 0.12 g L^{-1}	3.23de	0.357e	1.95de	28.05f
T_3: Potassium fulvate at rate of 0.15 g L^{-1}	3.28d	0.365d	1.99d	28.93e
T_4: Mn at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$.	3.14e	0.349g	1.89f	26.50h
T_5: Mn of 1.153 g L^{-1} using Mn –EDTA.	3.19de	0.354f	1.92ef	27.38g
T_6: As a combined treatment ($T_2 + T_4$).	3.29cd	0.371c	2.06c	29.80d
T_7: As a combined treatment ($T_2 + T_5$).	3.38bc	0.373c	2.10bc	30.71c
T_8: As a combined treatment ($T_3 + T_4$).	3.40b	0.378b	2.14b	31.77b
T_9: As a combined treatment ($T_3 + T_5$).	3.50a	0.383a	2.21a	32.79a
LSD at 5%	**0.09**	**0.003**	**0.06**	**0.17**
Interaction M x T	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

Table 8. Effect of the studied treatments on pods quality traits of kidney bean plant at maturity stage during growing season of 2022.

Treatments	Protein	Carbohydrates	Fiber	TDS
	(%)			
Addition methods				
M_1: Foliar application.	21.45b	39.46a	14.26a	6.74a
M_2: Soil addition.	19.19a	34.60b	13.24b	6.18b
LSD at 5%	**0.03**	**0.24**	**0.06**	**0.03**
Substances studied				
T_1: Control (without added substances**)**	17.90f	32.31i	12.91e	5.81f
T_2: Potassium fulvate at rate of 0.12 g L^{-1}	20.16de	36.39f	13.53d	6.42d
T_3: Potassium fulvate at rate of 0.15 g L^{-1}	20.49d	37.28e	13.66cd	6.50c
T_4: Mn at rate of 0.50 g L^{-1} using $MnSO_4.4H_2O$.	19.64e	35.50h	13.46d	6.28e
T_5: Mn of 1.153 g L^{-1} using Mn –EDTA.	19.96de	36.02g	13.47d	6.34e
T_6: As a combined treatment ($T_2 + T_4$).	20.53cd	38.16d	13.82bc	6.57c
T_7: As a combined treatment ($T_2 + T_5$).	21.11bc	38.59c	13.90b	6.67b
T_8: As a combined treatment ($T_3 + T_4$).	21.24b	39.07b	14.38a	6.70b
T_9: As a combined treatment ($T_3 + T_5$).	21.84a	39.94a	14.61a	6.82a
LSD at 5%	**0.59**	**0.18**	**0.24**	**0.07**
Interaction M x T	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level.

Foliar fertilization depends on supplying the kidney bean plants with the K F and Mn through spraying on the plant's vegetative foliage, which can absorb these elements through the stomata spread on the upper and lower leaf surfaces. Foliar fertilization might protect the kidney bean plants and their proper growth and eliminates manifestations of deficiency of microelements such as yellowing of leaves, spotting and weak knots **(Kazemi, 2014).** It is possible through foliar fertilization to increase the leaf area, which leads to an increase in the size and quality of the pods **(Aslani and Souri, 2018).**

It can be said that the application method (foliar feeding) could play a role through their strong effect on improving plant performance, yield and quality of kidney bean plants. Many studies have shown that higher plants had higher nutrient uptake and efficiency in response to foliar application rather than the soil addition of fertilizer **(Sooraki and Moghadamyar, 2017).**

- **Individual effect of the studied substances**

The trend of growth performance and leaves chemical constituents at period of 45 days after sowing reflected on the yield, quality and qualitative traits at the harvest stage. The values of No. of pods plant^{-1}, pods length (cm), weight (g) and diameter (cm), pods yield (ton h^{-1}), N, P, K (%), Mn (mgkg^{-1}), crude protein, carbohydrates, fiber and TDS (%) were significantly affected as a result of the studied substances. The plants treated with T_9 treatment (Potassium fulvate at rate of 0.15 g L^{-1} + Mn of 1.153 g L^{-1} using Mn –EDTA) possessed the highest values of all aforementioned yield, quality and qualitative traits followed by **T_8** then **T_7 , T_6, T_3 , T_2, T_5 , T_4**, respectively and lately T_1 treatment **(**without added substances**).**

Also, it can be noticed that values of all aforementioned yield, quality and qualitative traits under the combined treatments of KF and Mn (**T_6, T_7, T_8** and **T_9**) were higher than that under the single treatments (**T_2, T_3, T_4** and **T_5**). The second level of KF was superior compared to the first level as well as chelating compound form (EDTA, 12% Mn) was superior compared to the inorganic salts form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)]. It is also worth noting that the KF treatments are superior to Mn treatments (both studied forms).

KF may stimulate the supply of nutrients to the kidney bean plants and increase the coefficient of nutrient absorption by the plants. Increasing potassium absorption via potassium fulvate may positively affect the metabolism of carbohydrates and nitrogen as well as the synthesis of lipids, starch and protein. KF may enhance the activity of beneficial bacteria in the soil and activate the synthesis of vitamins in plants, which is especially important for kidney bean plants. KF may increase plant resistance to frost, drought, hot winds, and high doses and concentrations of mineral fertilizers. Also, KF may enhance the effectiveness of the pesticides, activate the growth of the plant, increase its yield and promote the conversion of nitrates into protein, which increased the quality of kidney bean plants. Thus, KF is an excellent stimulant for the beans plant. So, the use of KF is justified at different stages of growth, development and quality of the crop.

Appling Mn in both studied forms led to an increase in kidney bean yield and improve quality and qualitative traits of pods due to the problems of Mn under Egyptian soils, which have high pH values. It is known that the availability of Mn reduces as soil pH value increases in addition to the high calcium carbonate content and low organic matter content under Egyptian conditions. Therefore, yield, quality and qualitative traits of pods significantly increased in response to Mn treatments compared to control treatment. On the other hand, the values of yield and its component with Mn-EDTA were the best compared to $MnSO_4$ due to the translocation of Mn away from the treated leaf to other plant parts under EDTA form was faster than the $MnSO_4$ form.

- Interaction effect

As shown in Tables 6, 7 and 8, the combination of the best treatments specific to each studied factor realized the highest values of all aforementioned yield, quality and qualitative traits of kidney bean plants. In other words, the highest of No. of pods plant^{-1}, pods length (cm), weight (g) and diameter (cm), pods yield (ton h^{-1}), N, P, K (%), Mn (mgkg^{-1}), crude protein, carbohydrates, fiber and TDS (%)were recorded when plants were sprayed with KH at a rate of 0.15 g L^{-1} and simultaneously with Mn-EDTA at rate of 1.153 g L^{-1}. The results are in harmony with those of Ozbahce and Zengin, (2014), Dwyer, (2012), Kobraee, (2019), Shahrajabian *et al.,* (2020), Omar *et al.*, (2020), Mohamed, (2020).

4. Conclusion

According to the obtained results, the external application of potassium fulvate at rate of 0.15 g L^{-1} combined with Mn-EDTA to leaves is considered the most suitable treatment for achieving the best performance and yield of kidney bean plant. Generally, it can be concluded some facts as follows (1) potassium fulvate as an organic amendment is a non-toxic mineral chelating additive and water binder that maximizes uptake through the leaves and stimulates kidney bean plant productivity. (2) Due to the Egyptian soils suffering from a shortage of nutrients, the application of potassium fulvate can improve soil properties and lead to increasing their fertility by increasing the amounts of nitrogen, phosphorus and potassium in the soil (maybe in the long run), which boosts kidney bean plant performance, yield and quality. (3) Mn element is a crucial nutrient, which can enhance plant dry matter and crop productivity. (4) Chelating compound form (EDTA, 12% Mn) is more suitable than inorganic salt form [manganese sulfate ($MnSO_4.4H_2O$, 24%Mn)]. (5) Foliar application is the best method of both KF and Mn application to control their losses from the soil and make it more and easily available to the plant and in turn increase the yield and quality of plants. Generally, this study provides evidence that applying KF combined with Mn-EDTA to leaves of kidney bean will achieve the highest yield and its components and will meet people's needs for strategic crops.

Conflicts of interest

Authors have declared that no competing interests exist.

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