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Potential Effect of Compost Treatment Combined with Foliar Application of Bismuth (Bi), Titanium (Ti), Molybdenum (Mo) and Selenium (Se) on Potato Growth and Productivity

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STUDYING the potential positive effects of periodic table elements on the performance of strategic plants, such as potatoes, is currently essential due to the nutrient gap. Therefore, a field experiment was conducted during the 2024/2025 growing season, aiming at maximizing the productivity of potatoes *via* organic fertilization treatments and foliar spraying of some trace elements under the experimental design of split-split plot. The compost treatments (applied or not) represented the main factor, while the type of trace elements [bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se)] were arranged in subplots. Three levels of each trace element were studied (0.0, 5.0, 10.0 mg L^{-1}) as the sub-sub main factor. Growth criteria (*e.g.,* fresh and dry weights), photosynthetic pigments (*e.g.,* chlorophyll a &b), chemical composition in leaves and tubers (*i.e.,* NPK), biochemical traits of tuber (*e.g.,* VC and TDS), available nutrients in soil (*i.e.,* NPK) and organic matter content of soil were determined. The highest values of all growth, performance yield and quality traits were achieved with treatment of compost, while the lowest values were recorded under control treatment (without compost). In terms of effectiveness, the superior element was selenium (Se) followed by molybdenum (Mo) then titanium (Ti) and lately bismuth (Bi). On the other hand, the positive effect of each studied elements increased as their rates increased from 0.0 to 5.0 then 10.0mgL^{-1}. Concerning the interaction effect, it can be noticed that the combined superior treatment was compost x selenium at rate of 10.0mgL^{-1}. On the other hand, the compost enhanced the soil content of NPK and OM compared to the control treatment (without compost). Regarding spraying the studied trace elements, their influence on soil properties (NPK and OM) was unclear. Based on these results, it can be concluded that the trace elements used in this study, especially bismuth and titanium, have vital roles for potato growth, and research should be intensified on their importance to other plants, and work should begin on including them in fertilization programs alongside organic fertilization.

Keywords: Bismuth, Titanium, Molybdenum, Selenium.

Introduction

Studying the potential positive effects of periodic table elements on the performance of strategic plants is currently essential due to the nutrient gap. Expanding the use of some unconventional elements of the periodic table such as bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) in fertilization programs is considered one of the unconventional solutions to reduce this gap and achieve food security, due to their potential role in enhancing vital processes within plants and improving the quality and nutritional value of agricultural products (**El-Ghamry *et al.* 2024**).

Bismuth has a role in increasing the efficiency of the chlorophyll molecule **(Zacchini, 2024).** Ti is known for its role in enhancing photosynthetic efficiency and its ability to promote non-biological nitrogen fixation, but its effectiveness was lower than selenium and molybdenum (**El-Ghamry *et al.* 2024**). Mo leads to strengthened cell walls in higher plants, thus preventing both sucking and piercing insects from penetrating them, hence protecting the higher plant from these insect attacks. Mo is also involved in the formation of ascorbic acid, as mentioned by **Meng *et al.* (2021).** Additionally, it is essential for enzymes responsible for reducing nitrate to nitrite, as mentioned by **Abbasifar *et al.* (2020).** Se has a vital role as an antioxidant, as it scavenges free radicals (ROS) under environmental stress, as reported by **El-Ramady *et al.* (2016).** It can also stimulate the activity of enzymes responsible for metabolism **(Ghazi *et al.* 2024).**

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On the other hand, the traditional use of organic fertilizers remains vital in improving the soil's physical, chemical and biological properties. This positively impacts soil fertility and, consequently, agricultural production. Compost is known for its ability to retain moisture and nutrients and increase soil aeration (**Elshaboury *et al.* 2024**). Moreover, it has high organic matter content, which leads to an increase in microbial activity **(Shaban *et al.* 2025).** Furthermore, it may have played an effective role in maintaining soil pH and increasing the availability of soil nutrients, thus creating a suitable environment for growth and nutrient absorption **(Abdel-Motaleb *et al.* 2025).** Additionally, compost may have caused a slow supply of micro- and macro-elements throughout the plant growth period. Hence, the importance of combining traditional approaches such as compost with modern solutions such as foliar spraying with new elements from the periodic table to achieve agricultural production sufficient to meet the population's needs while maintaining high quality.

Potato plant (*Solanum tuberosum* L.) one of Egypt's most important strategic crops, boasting high nutritional value and a significant export crop. Therefore, improving their productivity and quality is a top priority for agricultural policymakers. Accordingly, developing potato fertilization programs in Egypt represents a significant and effective step toward achieving food security and increasing economic returns **(Hamed, 2020).** Therefore, the major objective of the current research work is maximizing the productivity of potato plants *via* organic fertilization treatments as a traditional approach and foliar spraying of some trace elements as a modern approach.

2. Materials and Methods

A field experiment was conducted during the 2024/2025 growing season in the experimental farm of agricultural faculty, Mansoura University, Egypt, aiming at maximizing the productivity of potatoes *via* organic fertilization treatments and foliar spraying of some trace elements under the experimental design of split-split plot with three replicates. The compost treatments (applied or not) represented the main factor, while the type of trace elements [bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se)] were arranged in subplots. Three levels of each trace element were studied (0.0, 5.0, 10.0 mg L^{-1}) as the sub-sub main factor. Fig1 illustrate the flowchart of the experiment. The properties of the initial soil are shown in Table 1, as the soil sample was taken at a depth of 30cm.

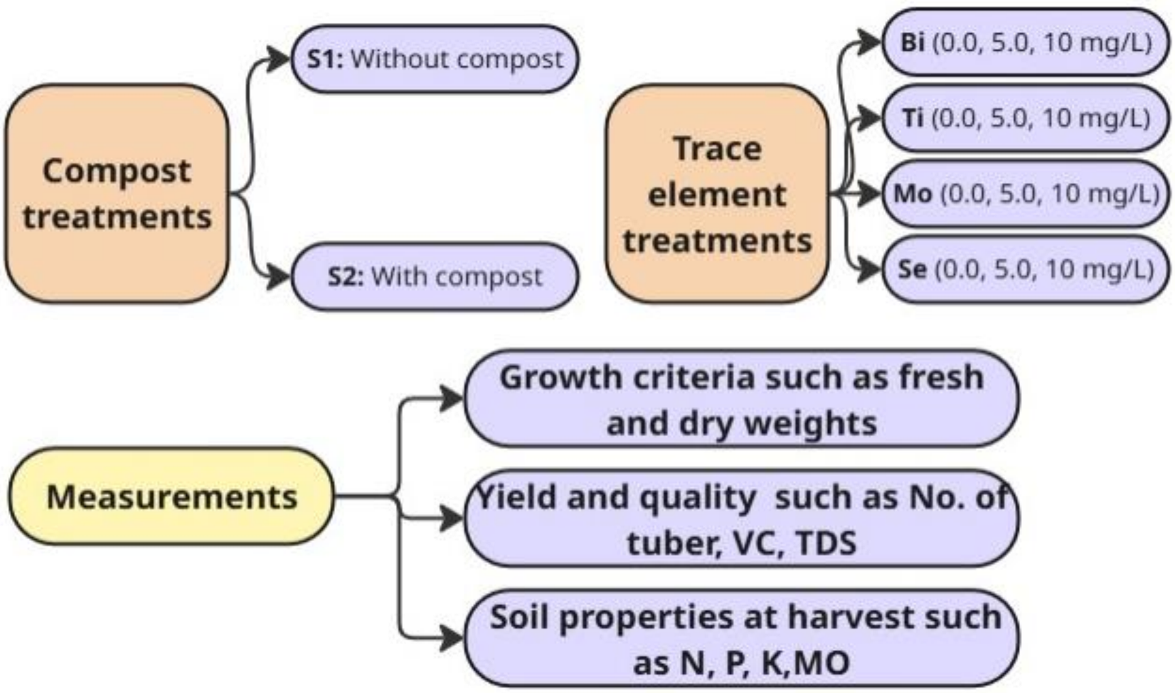

Fig. 1. The flowchart of the experiment.

Table 1. Characteristics of the initial soil.

Clay	Silt	Sand	Texture Class is	N	P	K	Bi	Ti	Mo	Se	O.M,%	EC, dSm^{-1}	pH	WHC,%
%				mg kg^{-1}										
50	30	20	Clay	18.20	7.3	201	*ND	*ND	0.10	0.08	1.17	2.78	8.00	42

- Bi, Ti were not detected in the studied soil.
- Particle size distribution was done *via* using pipette method, while the texture class was identified using soil texture triangle **(Gee and Baudet 1986)**
- The availability of these elements were determined *via* Kjeldahl method, spectrophotometric method and flame photometer for NPK, respectively. To estimate molybdenum, the soil was extracted with oxalic acid and ammonium oxalate, then an orange complex was formed using stannous chloride ($SnCl_2$) and ammonium thiocyanate, and finally, the colour intensity was measured using a spectrophotometer (**Dewis and Freitas, 1970; Hesse, 1971)**. Bi, Ti and Se were determined by ICP-MS.
- Organic matter was determined by Walkly and Balck method. Soil EC (1:2.5, soil extract) was determined by EC-meter. Soil pH(1:2.5, soil suspension) was estimated using pH-meter. Water holding capacity (WHC) was measured *via* mixing and burette **Dewis and Freitas, (1970)**

Compost was prepared in the experimental site using the plant residues. It was prepared as described by **Inckel *et al.* (2005),** where wheat and rice straw waste were collected, chopped well, and a pyramid-shaped pile was made at the experimental site. An active mixture consisting of ammonium sulfate, superphosphate, and potassium sulfate was added to the pile with stirring, and it was left to mature for about 5 months Table 2 illustrate the characteristics of the compost studied.

Bismuth (III) nitrate as the Bi source, titanium dioxide as the Ti source, ammonium molybdate as the source of Mo and sodium selenite as the Se source were obtained from Sigma Company. Table 3 shows the characteristics of these salts. Standard solutions were prepared for Bi, Ti, Mo and Se, with a specific concentration *via* dissolving precise amounts of the respective salts in water to obtain the standard solutions for Bi, Ti, Mo, and Se were then used to obtain the studied concentrations under the current research work.

Table 2. Characteristics of the compost studied.

Characters	Value
EC, dSm^{-1}(Extract 1:10)	3.60
Moisture,%	20.0
pH	6.20
N,%	1.76
P,%	1.50
K,%	1.30
O,M,%	31.50
C/N ratio	13.20
CEC, cmol kg^{-1}	255.0

The compost was analyzed using the standard methods as described by **Tandon,(2005)**

Table 3. Characteristics of the element salts studied.

Trace element	Bismuth (Bi)	Titanium (Ti)	Molybdenum (Mo)	Selenium (Se)
Salt	Bismuth (III) nitrate	Titanium Dioxide	Ammonium Molybdate	Sodium selenite
Chemical Formula	$Bi(NO_3)_3 \cdot 5H_2O$ (53.0 % Bi)	TiO_2 (59.94%Ti)	$(NH_4)_6Mo_7O_{24}.4H_2O$ (54.35%Mo)	Na_2SeO_3 (45.56 %Se)
Purity	99%	99.9%	99%	99%
Density	2.83 g cm^{-3}	3.90 g cm^{-3}	2.5 g cm^{-3}	3.1 g cm^{-3}
Solvent used	HNO_3	HNO_3	Distilled water	Distilled water

Potato tubers (Cv Sponta) were obtained from the Ministry of Agriculture and Soil Reclamation (MASR). The tubers were divided into pieces, with approximately 40.0 g on average then were planted on 15 October.

The compost was added according to the studied treatments at rate of 20 m^3 fed^{-1} at 15 days before planting. Mineral NPK fertilization was done at rate of 70,150 and 50 unit of N, P_2O_5, K_2O, respectively per feddan. The recommended mineral fertilizers were added, taking into account the organic additives as well as the soil content of these elements. Before planting, calcium superphosphate was added to the soil. Urea was added in two doses at 30 and 50 days after planting. Potassium sulphate was added at the beginning of tuber formation. The spraying process with the studied trace elements was carried out 3 times with a time interval of 10 days, so that the first spraying date was 45 days after planting. Irrigation was carried out every 8 days. The MASR's guidelines were followed in the potato production process. The harvest process was done after 110 days from planting. Measurements were carried out during two stages as shown in Table 4. The obtained data were statistically analyzed by CoStat software **(Version 6.303, CoHort, USA, 1998-2004)** and Duncan's Multiple Range Test as described by **Gomez and Gomez (1984)** at a significance level of 0.05.

Table 4. Measurements during the two different stages.

	Parameters	Methods	References
a.	**Growth parameters, photosynthetic pigments and leaves chemical content at 75 days from planting**		
1.	Plant height (cm)	Manually	--------------
2.	No. of leaves $plant^{-1}$		
3.	Fresh and dry weights ($gplant^{-1}$)		
4.	Leaf area,(cm^2 $plant^{-1}$)		
5.	Chlorophyll a & b (mg g^{-1} FW)	Spectrophotometrically, using acetone	**[1]**
6.	Carotene (mg g^{-1})		
7.	Digestion of leaves	Using a mixture of $HClO_4$ + H_2SO_4	**[2]**
8.	Potato leaf chemical NPK (%DW)	*Via* Kjeldahl method, spectrophotometric method and flame photometer for NPK, respectively	**[3]**
b.	**Yield and quality traits at harvest**		
1.	Average tuber weight (g)	Manually	--------------
2.	No. of tuber $plant^{-1}$		
3.	Yield (ton fed^{-1})		
4.	Digestion of tubers	Using a mixture of $HClO_4$ + H_2SO_4	**[2]**
5.	Potato tuber chemical NPK (%DW)	*Via* Kjeldahl method, spectrophotometric method and flame photometer for NPK, respectively	**[3]**
6.	Total Carbohydrates (%)	Calculated by difference*:* 100 - (% moisture + protein + fat + ash + fiber)	**[4]**
7.	Total Sugars, %	*Phenol-sulfuric acid method*	
8.	Vitamin C (VC, mg $100g^{-1}$)	Titration with 2,6-dichlorophenolindophenol	
9.	Total Dissolved Solids (TDS, %)	Gravimetric method (Evaporate filtered sample then weigh the residue)	
c.	**Soil analyses at harvest**		
1.	Availability of NPK	*Via* Kjeldahl method, spectrophotometric method and flame photometer for NPK, respectively	**[5]**
2.	Organic matter	By Walkly and Balck method	**[6]**

List of refs: [1] Wellburn (1994),[2] Peterburgski (1968),[3] Walinga *et al.* (2013),[4] AOAC (2000),[5] Hesse,(1971),[6] Dewis and Freitas, (1970)

3. Results

3.1. Growth criteria

Table 5 shows the impact of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on potato growth criteria, including plant height (cm), No. of leaves plant^{-1}, fresh and dry weights (gplant^{-1}), leaf area,(cm^2 plant^{-1}) at period of 75 days from planting during season of 2023/2024. Regarding the individual effect of organic fertilization, it can be noticed that the highest values of all aforementioned traits were achieved with treatment of compost, while the lowest values were recorded under control treatment (without compost). In terms of effectiveness, the superior element was selenium (Se) followed by molybdenum (Mo) then titanium (Ti) and lately bismuth (Bi). On the other hand, the positive effect of each studied elements increased as their rates increased from 0.0 to 5.0 then 10.0mgL^{-1}. Concerning the interaction effect, it can be noticed that the combined superior treatment was compost x selenium at rate of 10.0mgL^{-1}.

Table 5. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on potato growth criteria at period of 75 days from planting during season of 2023/2024.

Treatments	Plant height, cm	No. of leaves plant^{-1}	Fresh weight, g plant^{-1}	Dry weight, g plant^{-1}	Leaf area, cm^2 plant^{-1}
Main factor: Organic fertilization					
S_1: Without compost	54.96b	16.69b	285.75b	32.39b	1645.08b
S_2: With compost	62.39a	21.89a	327.36a	35.72a	2380.92a
F test	***	***	***	***	***
Sub main factor: Trace elements					
Bismuth (Bi)	56.48c	17.50d	292.61d	32.94d	1750.44d
Titanium (Ti)	57.95bc	18.78c	300.29c	33.76c	1950.33c
Molybdenum (Mo)	59.44ab	19.83b	310.06b	34.45b	2149.17b
Selenium (Se)	60.85a	21.06a	323.26a	35.08a	2202.06a
F test	***	***	***	***	***
Sub sub main factor : levels of elements					
F_1: At rate of 0.0mgL^{-1}	56.15a	16.75c	300.39c	31.82b	1960.67c
F_2: At rate of 5.0mgL^{-1}	58.79a	19.33b	305.87b	33.98b	2016.29b
F_3: At rate of 10.0mgL^{-1}	59.10a	19.79a	310.42a	34.37a	2059.04a
F test	***NS**	***	***	***	***
Interaction					
F test	***	***	***	***	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
*NS= non- significant

3.2. Photosynthetic pigments in leaves

Table 6 displays the influence of compost addition and foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on potato photosynthetic pigments (Chlorophyll a& b and carotene, mg g^{-1}) at period of 75 days from planting during season of 2023/2024. With respect to the individual effect of organic fertilization, the compost treatment significantly increased all measured photosynthetic pigments, achieving the highest values, whereas the lowest values were realized with the corresponding plants grown without the compost. In terms of the efficacy of the trace elements foliar applications, selenium (Se) was the most effective, followed by molybdenum (Mo), titanium (Ti), and bismuth (Bi), respectively. Moreover, the beneficial effect of each studied element increased progressively with the application level, from 0.0 to 5.0 then to 10.0 mg L^{-1}. Regarding the interaction effect, the most significant improvement in all measured photosynthetic pigments was observed when plants treated with the compost and selenium at the highest rate of 10.0 mg L^{-1} as a combined treatment.

Table 6. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on potato photosynthetic pigments at period of 75 days from planting during season of 2023/2024.

Treatments	Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	Carotene, mg g^{-1}
Main factor: Organic fertilization			
S_1: Without compost	0.858b	0.637b	0.313b
S_2: With compost	0.943a	0.725a	0.368a
F test	***	***	***
Sub main factor: Trace elements			
Bismuth (Bi)	0.877d	0.653d	0.323d
Titanium (Ti)	0.895c	0.674c	0.336c
Molybdenum (Mo)	0.908b	0.691b	0.346b
Selenium (Se)	0.922a	0.705a	0.357a
F test	***	***	***
Sub sub main factor : levels of elements			
F_1: At rate of 0.0mgL^{-1}	0.895b	0.676c	0.337c
F_2: At rate of 5.0mgL^{-1}	0.900b	0.681b	0.340b
F_3: At rate of 10.0mgL^{-1}	0.906a	0.686a	0.344a
F test	**	***	***
Interaction			
F test	***	***	***

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

3.3. Nutritional status of the leaves

Table 7 displays the impact of compost soil addition in combination with spraying of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on the leaves chemical composition of potato after 75 days from planting during the growing season of 2023/2024. The data pronouncedly show that compost treatment significantly enhanced the nutritional status (nitrogen, phosphorus, and potassium) of the leaves compared to the control treatment (without compost). With regard to the foliar application of trace elements, Se illustrated a clear superiority compared with the other studied trace elements in enhancing the chemical composition of the potato leaves. The Mo element came in the second order, followed by Ti and Bi, respectively. Additionally, the influence of the foliar trace elements was positively correlated with the applied rates, as the increasing concentration of each studied element from the lowest rate to the highest rate consistently improved the NPK content in the leaves. The interaction effects among compost treatments, studied trace elements and their applied rate were significant. The most effective combination was observed when plants treated with compost alongside selenium at the highest rate (10mg L^{-1}), leading to the most pronounced increases in NPK content values in the leaves.

Table 7. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on chemical constituents in leaves of potato at period of 75 days from planting during season of 2023/2024.

Treatments	Nitrogen, %	Phosphorus, %	Potassium, %
Main factor: Organic fertilization			
S_1: Without compost	2.81b	0.353b	2.63b
S_2: With compost	3.59a	0.426a	3.24a
F test	***	***	***
Sub main factor: Trace elements			
Bismuth (Bi)	3.02d	0.369d	2.78d
Titanium (Ti)	3.13c	0.381c	2.86c
Molybdenum (Mo)	3.25b	0.395b	2.98b
Selenium (Se)	3.39a	0.413a	3.12a
F test	***	***	***
Sub sub main factor : levels of elements			
F_1: At rate of 0.0mgL^{-1}	3.16b	0.385c	2.90b
F_2: At rate of 5.0mgL^{-1}	3.19ab	0.389b	2.94ab
F_3: At rate of 10.0mgL^{-1}	3.24a	0.395a	2.97a
F test	**	***	***
Interaction			
F test	***	***	***

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

3.4. Tuber yield

Table 8 shows the effect of compost and trace elements (Bi, Ti, Mo and Se) on the tuber yield components after 110 days from planting during the 2023/2024 season. Additionally, Fig 2 shows the interaction effects on the tuber yield (ton fed^{-1}). The data illustrate that compost treatment possessed a positive impact on tuber yield traits such as average tuber weight (g) and yield (ton fed^{-1}) compared to the plants grown without compost, while the effect on No. of tuber $plant^{-1}$ was non-significant.

Table 8. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on yield of potato at period of 110 days from planting during season of 2023/2024.

Treatments	Average tuber weight, g	No. of tuber $plant^{-1}$	Yield, ton fed^{-1}
Main factor: Organic fertilization			
S_1: Without compost	296.90b	2.01a	13.98b
S_2: With compost	350.07a	2.06a	16.11a
F test	***	*	***
Sub main factor: Trace elements			
Bismuth (Bi)	304.66d	2.05a	14.28d
Titanium (Ti)	317.57c	2.02ab	14.81c
Molybdenum (Mo)	329.99b	2.02ab	15.35b
Selenium (Se)	341.71a	2.04a	15.74a
F test	***	*	***
Sub sub main factor : levels of elements			
F_1: At rate of 0.0mgL^{-1}	319.61c	2.04a	14.89c
F_2: At rate of 5.0mgL^{-1}	323.63b	2.03a	15.04b
F_3: At rate of 10.0mgL^{-1}	327.22a	2.03a	15.20a
F test	**1.40**	***NS**	**0.09**
Interaction			
F test	***	*	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
*NS= non- significant

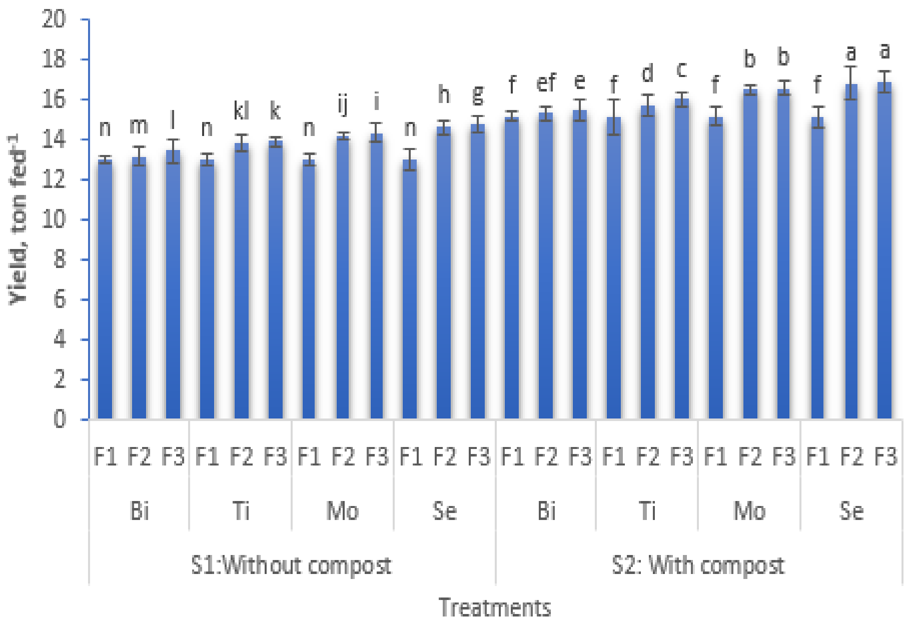

Fig. 2. The interaction effects on the tuber yield (ton fed^{-1}).

Among the foliar-applied elements, Se was the most effective in improving yield attributes, followed by Mo, Ti and Bi, respectively. The data also indicate a consistent trend in which increasing the rate of the studied trace elements led to a gradual increases in tuber yield traits *i.e.,* average tuber weight (g) and yield (ton fed^{-1}), while the effect on No. of tuber $plant^{-1}$ was non-significant. Notably, the interaction effects among compost and Se at rate of 10 mg L^{-1} proved to be the most productive combination, achieving the highest values of yield parameters.

3.5. Nutritional status of the tubers

Table 9 displays the impact of compost soil addition in combination with spraying of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on the tuber chemical composition of potato after 110 days from planting during the growing season of 2023/2024. The data pronouncedly show that compost treatment significantly enhanced the nutritional status (nitrogen, phosphorus, and potassium) of the tuber compared to the control treatment (without compost). With regard to the foliar application of trace elements, Se illustrated a clear superiority compared with the other studied trace elements in enhancing the chemical composition of the potato leaves tubers. The Mo element came in the second order, followed by Ti and Bi, respectively. Additionally, the influence of the foliar trace elements was positively correlated with the applied rates, as the increasing concentration of each studied element from the lowest rate to the highest rate consistently improved the NPK content in the tubers. The interaction effects among compost treatments, studied trace elements and their applied rate were significant. The most effective combination was observed when plants treated with compost alongside selenium at the highest rate (10mg L^{-1}), leading to the most pronounced increases in NPK content values in the tubers.

Table 9. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on chemical constituents in tuber of potato at period of 110 days from planting during season of 2023/2024.

Treatments	Nitrogen, %	Phosphorus, %	Potassium, %
Main factor: Organic fertilization			
S_1: Without compost	2.18b	0.305b	2.24b
S_2: With compost	2.61a	0.358a	2.65a
F test	***	***	***
Sub main factor: Trace elements			
Bismuth (Bi)	2.25d	0.315d	2.30d
Titanium (Ti)	2.35c	0.327c	2.39c
Molybdenum (Mo)	2.44b	0.337b	2.50b
Selenium (Se)	2.54a	0.347a	2.59a
F test	***	***	***
Sub sub main factor : levels of elements			
F_1: At rate of 0.0mgL^{-1}	2.36b	0.328c	2.41b
F_2: At rate of 5.0mgL^{-1}	2.39ab	0.332b	2.45a
F_3: At rate of 10.0mgL^{-1}	2.44a	0.335a	2.48a
F test	***	***	**
Interaction			
F test	***	***	**

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

3.6. Tuber quality (biochemical traits)

Table 10 shows the effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on tuber quality at period of 110 days from planting during season of 2023/2024.

Table 10. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on tuber quality at period of 110 days from planting during season of 2023/2024.

Treatments	T. Carbohydrates, %	Total sugars, %	Dry matter, %	Vitamin C, mg $100g^{-1}$	*TDS, %
Main factor: Organic fertilization					
S_1: Without compost	25.59b	4.94b	20.21b	21.53b	6.39b
S_2: With compost	27.70a	5.45a	22.06a	23.21a	7.70a
F test	***	***	***	***	***
Sub main factor: Trace elements					
Bismuth (Bi)	25.96d	5.00d	20.52d	21.79d	6.75c
Titanium (Ti)	26.42c	5.13c	20.94c	22.16c	6.98b
Molybdenum (Mo)	26.86b	5.27b	21.33b	22.54b	7.11b
Selenium (Se)	27.33a	5.38a	21.76a	23.00a	7.34a
F test	***	***	***	***	***
Sub sub main factor : levels of elements					
F_1: At rate of 0.0mgL^{-1}	26.45b	5.15c	21.01b	22.19c	6.95b
F_2: At rate of 5.0mgL^{-1}	26.67a	5.20b	21.14ab	22.41b	7.06a
F_3: At rate of 10.0mgL^{-1}	26.81a	5.23a	21.27a	22.52a	7.12a
F test	**	***	**	***	**
Interaction					
F test	***	***	***	***	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
*TDS=Total dissolved solid

The biochemical characteristics of potato tubers [T. carbohydrates (%), total sugars (%), dry matter (%), vitamin C (mg 100g^{-1}) and TDS (%)] showed notable enhancement in response to both compost and trace element treatments. Compost addition significantly increased all measured quality parameters compared to non-composted treatments. Among the studied trace elements, selenium consistently led to the highest values across all quality traits followed by molybdenum then titanium, and lately bismuth. Additionally, increasing the applied rate of trace element from 0.0 to the highest investigated concentration (5.0 then 10 mgL^{-1}) resulted in progressive improvements in tuber biochemical traits, indicating a dose-dependent impact. The interaction between compost treatments and foliar treatments further emphasized the synergistic role, as the combined treatment of compost and selenium at the highest concentration (10 mg L^{-1}) resulted in the highest values of all aforementioned tuber quality traits.

3.7. Postharvest soil analysis

Table 11 illustrates the impact of compost combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on soil properties [(available nitrogen, phosphorus and potassium (NPK, mgkg^{-1}) and organic matter content (OM,%)] as mean values after 110 days from planting (harvest stage) during the 2023/2024 season.

Table 11. Effect of compost treatment combined with foliar application of bismuth (Bi), titanium (Ti), molybdenum (Mo) and selenium (Se) on soil properties (as mean values) at period of 110 days from planting during season of 2023/2024.

Treatments			N, $mgkg^{-1}$	P, $mgkg^{-1}$	K, $mgkg^{-1}$	Organic matter,%
	Initial soil		20.20b	7.3b	210b	1.17b
S_1:Without compost	Bi	$0.0mgL^{-1}$	20.30b	7.6b	211b	1.18b
		$5.0mgL^{-1}$	20.50b	7.4b	212b	1.14b
		$10.0mgL^{-1}$	20.60b	7.2b	212b	1.17b
	Ti	$0.0mgL^{-1}$	20.25b	7.5b	211b	1.16b
		$5.0mgL^{-1}$	20.55b	7.7b	214b	1.14b
		$10.0mgL^{-1}$	20.59b	7.3b	210b	1.18b
	Mo	$0.0mgL^{-1}$	20.23b	7.4b	211b	1.18b
		$5.0mgL^{-1}$	20.46b	7.6b	213b	1.17b
		$10.0mgL^{-1}$	20.52b	7.5b	212b	1.17b
	Se	$0.0mgL^{-1}$	20.33b	7.3b	210b	1.18b
		$5.0mgL^{-1}$	20.59b	7.5b	213b	1.16b
		$10.0mgL^{-1}$	20.60b	7.4b	211b	1.15b
S_2: With compost	Bi	$0.0mgL^{-1}$	28.46a	8.5a	221a	1.30a
		$5.0mgL^{-1}$	28.73a	8.5a	222a	1.33a
		$10.0mgL^{-1}$	28.80a	8.4a	223a	1.32a
	Ti	$0.0mgL^{-1}$	28.21a	8.6a	223a	1.30a
		$5.0mgL^{-1}$	28.43a	8.7a	222a	1.35a
		$10.0mgL^{-1}$	28.88a	8.3a	225a	1.35a
	Mo	$0.0mgL^{-1}$	28.68a	8.5a	221a	1.34a
		$5.0mgL^{-1}$	28.70a	8.7a	222a	1.33a
		$10.0mgL^{-1}$	28.78a	8.6a	224a	1.35a
	Se	$0.0mgL^{-1}$	28.57a	8.4a	223a	1.32a
		$5.0mgL^{-1}$	28.88a	8.6a	221a	1.31a
		$10.0mgL^{-1}$	28.90a	8.5a	224a	1.34a
F test			*	*	*	*

The data illustrate that the highest positive influence on the investigated soil properties was achieved due to the addition of compost to the soil. In other words, compost enhanced the soil content of NPK and OM compared to the control treatment (without compost). Regarding spraying the studied trace elements, the data of Table 11 indicate that their influence on soil properties (NPK and OM) was unclear. However, the presence of compost helped in improving the usage of these elements, despite the contribution of foliar application alone to affecting soil properties remaining limited.

4. Discussion

The results obtained in terms of growth criteria, chemical traits of leaves and tubers, and soil properties are primarily due to the effective role of the compost used, which may have contributed to improving soil structure. Compost is known for its ability to retain moisture and nutrients and increase soil aeration (**Elshaboury *et al.* 2024**). Moreover, it has high organic matter content, which leads to an increase in microbial activity **(Shaban *et al.* 2025).** Furthermore, it may have played an effective role in maintaining soil pH and increasing the availability of soil nutrients, thus creating a suitable environment for growth and nutrient absorption **(Abdel-Motaleb *et al.* 2025).** Additionally, compost may have caused a slow supply of micro- and macro-elements throughout the potato growth period. This positively impacted vegetative growth criteria, photosynthetic pigments, and leaf nutrient content in the first phase of the study (75 days after planting) as well as the yield and quality of tubers and soil content of available nitrogen, phosphorus, potassium, and organic matter at harvest. The obtained results are in harmony with those of **Wilson *et al.* (2019).**

Regarding foliar spraying with trace elements, selenium (Se) ranked first as the most positively impacting element. This is attributed to its essential role as an antioxidant, as it scavenges free radicals (ROS) under environmental stress **(El-Ramady *et al.* 2016).** It has the ability to stimulate the activity of enzymes responsible for metabolism **(Ghazi *et al.* 2024).** It has a vital role in photosynthesis and carbohydrate biosynthesis, in addition to its ability to improve plant resistance to stress (**Huang et al. 2020**), explaining its positive impact on vegetative growth parameters, photosynthetic pigments, and leaf nutrient content in the first study phase (75 days after planting), as well as on the yield and quality of tubers at harvest. The findings are in accordance with those of **Li *et al*. (2023).**

Molybdenum (Mo) came in second place compared to the other studied trace elements, playing a key role in improving the efficiency of plant metabolism **(Heshmat *et al.* 2021).** It also strengthens cell walls, thus preventing piercing and sucking insects from penetrating them, thus protecting the plant from these insect attacks. It is also involved in the formation of ascorbic acid (**Meng *et al.* 2021**). It is also important for enzymes responsible for reducing nitrate to nitrite (**Abbasifar *et al.* 2020**), which explains its positive impact on vegetative growth parameters, photosynthetic pigments, and leaf nutrient content in the first study phase (75 days after planting). It also affected the yield and quality of tubers at harvest, ranking first in effectiveness compared to the other studied elements. The findings are in agreements with those of **Mushinskiy *et al*. (2025).** Titanium, on the other hand, showed a moderate effect, ranking third in effectiveness, which was lower than selenium and molybdenum. Titanium is known for its role in enhancing photosynthetic efficiency and its ability to promote non-biological nitrogen fixation, but its effectiveness was lower than selenium and molybdenum (**El-Ghamry *et al.* 2024**). Bismuth (Bi) came in last place in terms of effect, as its effectiveness was less compared to selenium, molybdenum and titanium, but there is a recent study that assumes that bismuth has a role in increasing the efficiency of the chlorophyll molecule **(Zacchini, 2024).**

5. Conclusion

The results of this investigation confirmed that the use of compost played a pivotal role in improving soil health, which positively influenced potato performance and productivity. Additionally, the study highlighted the importance of using non-traditional elements like selenium, molybdenum, titanium, and bismuth in improving tuber quality, especially at a rate of 10 mg L^{-1}. Based on these results, it can be concluded that the trace elements used in this study, especially bismuth and titanium, have vital roles for potato growth, and research should be intensified on their importance to other plants, and work should begin on including them in fertilization programs alongside organic fertilization.

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6. References

Abbasifar, A., ValizadehKaji, B., & Iravani, M. A. (2020). Effect of green synthesized molybdenum nanoparticles on nitrate accumulation and nitrate reductase activity in spinach. Journal of Plant Nutrition, 43(1), 13-27.

Abdel-Motaleb, M. A., Abdel-Hady, E. S., Zaghloul, A. K., Abdel Ghany, G. B., & Sheta, M. H. (2025). Impact of bentonite, biochar and compost on physical and hydro-physical properties of a sandy soil. Egyptian Journal of Soil Science, 65(1).

AOAC (2000).˝Official Methods of Analysis˝. 18th Ed. Association of Official Analytical Chemists, Inc., Gaithersburg, MD, Method 04.

CoStat, Version 6.303, Copyright (1998-2004), CoHort Software, Monterey, CA, USA.

Dewis, J., & Freitas, F. (1970). Physical and chemical methods of soil and water analysis. FAO soils Bulletin, (10).

El-Ghamry, A., Ghazi, D. A., Rashwan, E., Elsherpiny, M. A., & Lokman, D. (2024). Exploring the potential nutritional benefits of elements in the periodic table for plants. Egyptian Journal of Soil Science, 64(3).

El-Ramady, H., Abdalla, N., Taha, H. S., Alshaal, T., El-Henawy, A., Faizy, S. E. D. A., & Schnug, E. (2016). Selenium and nano-selenium in plant nutrition. Environmental Chemistry Letters, 14, 123-147.

Elshaboury, H. A. E. F., Ibrahim, N. R., & Elsherpiny, M. A. (2024). Enhancing soybean productivity in saline soil conditions: synergistic effects of organic fertilizer and proline co-application. Egyptian Journal of Soil Science, 64(2), 385-395.

Gee, G.W., & Bauder, J.W. (1986). Particle-size Analysis. p 383-411 In A. Klute (ed.) Methods of Soil Analysis Part 1. Soil Science Society of America Book Series 5, Madison, Wisconsin, USA.

Ghazi, D. A., Elsherpiny, M. A., & Helmy, A. A. (2024). Investigating zeolite's role in retaining mineral nitrogen fertilizers and the effects of titanium and selenium on garlic plants under water deficit conditions. Egyptian Journal of Soil Science, 64(4), 1567-1584.

Gomez, K. A., & Gomez, A. A. (1984). "Statistical Procedures for Agricultural Research". John Wiley and Sons, Inc., New York.pp:680.

Hamed, E. T. (2020). An economic study of the impact of losses on potato production and consumption in Egypt. Egyptian Journal of Agricultural Research, 98(2), 201-213.

Heshmat, K., Asgari Lajayer, B., Shakiba, M. R., & Astatkie, T. (2021). Assessment of physiological traits of common bean cultivars in response to water stress and molybdenum levels. Journal of Plant Nutrition, 44(3), 366-372.

Hesse, P. R (1971). A textbook of soil chemical analysis. Cambridge university press.

Huang, C., Yu, M., Sun, L., Qin, N., & Wei, L. (2020). Physiological responses of sweet potato seedlings under drought-stress conditions with selenium applications. Journal of Agricultural and Crop Research, 8(5), 98-112.

Inckel, M., de Smet, P., Tersmette, T., & Veldkamp, T. (2005). The preparation and use of compost (Vol. 27). Agromisa.

Li, S., Chen, H., Jiang, S., Hu, F., Xing, D., & Du, B. (2023). Selenium and nitrogen fertilizer management improves potato root function, photosynthesis, yield and selenium enrichment. Sustainability, 15(7), 6060.

Meng, L. I., yan Wang, H., Najm, A. A. K., Othman, B. A., & Law, D. (2024). Effects of molybdenum on growth and fruit quality of small fruit melon (*Cucumis melo* L.) cultivated under high-temperature stress. Acta Scientiarum Polonorum Hortorum Cultus, 23(4), 41-54.

Mushinskiy, A., Saudabaeva, A., Vasilyeva, T., Fomin, S., & Panfilov, A. (2025). Analysis of morphobiological response of potato plants to treatment with silicon dioxide and molybdenum nanoparticles. In BIO Web of Conferences (Vol. 160, p. 01025). EDP Sciences.

Peterburgski, A. V. (1968)."Handbook of Agronomic Chemistry". Kolos Publishing House, Moscow, (in Russian, pp. 29-86).

Shaban, K. A., I Gaber, E. S., Soliman, A. S., & H Ozraeil, M. (2025). Impact of a Nano-NPK fertilizer with/without the compost on some soil chemical characteristics and cowpea yield under salinity conditions. Egyptian Journal of Soil Science, 65(2).

Tandon, H. L. S. (2005). Methods of analysis of soils, plants, waters, fertilisers & organic manures. Fertiliser Development and Consultation Organization.

Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W. and Novozamsky, I. (2013). Plant Analysis Manual. Springer Science & Business Media.

Wellburn, A. R. (1994). The spectral determination of chlorophylls a and b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. Journal of plant physiology, 144(3), 307-313.

Wilson, C., Zebarth, B. J., Burton, D. L., Goyer, C., Moreau, G., & Dixon, T. (2019). Effect of diverse compost products on potato yield and nutrient availability. American Journal of Potato Research, 96, 272-284.

Zacchini, M. (2024). Bismuth interaction with plants: uptake and transport, toxic effects, tolerance mechanisms-a review. Chemosphere, 142414.