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Article

Response of onion growth and seed yield to various phosphorus rates and foliar application of Nano-Boron, Nano-Chitosan and Naphthalene Acetic Acid

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Abstract: Onion (*Allium cepa* L.) is one of the important vegetables in Egypt. The study was conducted in the vegetable field to study the effect of different rates of phosphorus fertilizers and foliar application of Nano-Boron, Chitosan, and Naphthalene Acidic Acid (NAA) on growth and seed productivity of Onion plant (*Allium cepa* L., cv. Giza 6 Mohassan). The experiments were carried out in a split-plot design with three replicates. The main plot contains 3 rates of phosphorus treatments (30, 45 and 60 kg P_2O_5/feddan), Subplot includes foliar application of Nano-Boron, Nano-Chitosan and Naphthalene Acidic Acid (NAA) at a concentration of 50 ppm for each and sprayed at three times (50, 65 and 80 days after transplanting). Increasing the phosphorus fertilizers rate to 60 kg P_2O_5/fed significantly affects the growth and seed production of the Onion plant. Foliar application of nano-boron at 50 ppm concentration gave maximum values of onion seed yield in both seasons. Results stated that the correlation between yield and yield contributing characters over two years was highly significant. It could be recommended that P application at a rate of 60 kg P_2O_5 and sprayed onion plants at 50 ppm nano-boron three times (at 50, 65, and 80 days from transplanting) gave the highest seed yield of onion plants. Moreover, the maximum increments of inflorescence diameter (94.4%) were recorded to nano-boron foliar spray (60 p × nB) compared to the other treatments in both seasons.

Keywords: *Allium cepa*; NAA; fertilizer; Giza 6 Mohassan; productivity; correlation

1. Introduction

Egyptian onions have a lot of potential for export Due to their early availability in foreign markets, high pungency, nutritional value, and longer shelf-life than other onion cultivars (Marey and Elmasry, 2024). The onion production area in Egypt covered 94,457 hectares, resulting in a total production of 3,312,469 metric tons, having an average yield of approximately 35 tons per hectare (FAOSTAT, 2023). Currently, the cultivation of onions is being expanded in newly reclamation lands, therefore, it is necessary to expand seed production projects to meet the country's need for these seeds. Moreover, it is necessary to use new and modern methods to increase seed production by using foliar spray methods with growth regulators and nanometric compounds. Foliar microelements are more efficient than soil application according to the requirements of the crop. This efficiency increases by adding these elements in the form of nano-metric compounds. This method may have an economic effect and benefits on the crop compared to soil additions. Nano fertilizers have an important effect in improving many aspects of onion plant physiology, i.e., photosynthesis, reproduction, nitrogen fixation, flowering, seed production, and maturation dates. The utilization of nano-boron has many advantages; increasing water and nutrient absorption, and low material costs which reduce the economic cost of the agricultural process (El-Khafagy et al., 2013) recorded significant superiority due to spraying onion plants by 200 ppm boron three times. They obtained higher percentage of flower setting (82%), the highest number of seeds in flowers (2.202 seeds), the highest weight of 1000 seeds (4.156 g), the highest total yield (931 kg/ha) and the highest germination percentage (83.7%) compared to the control treatment. Spraying nano chitosan at the rate of 50 ppm resulted in the highest values of all growth characters and yield-related traits as compared with the other spraying treatments or the control (Geries et al., 2020). Ahmed et al. (2019) found that nano chitosan at a rate of 120 ppm was the most effective treatment for vegetative growth characteristics, yield, and its components. Moreover, Shaheen et al. (2017) reported that foliar spray of onion plants by chitosan at 5 cm/L. (three sprays with 15-day intervals) gave significant superiority to large mother bulbs (6-8 cm diameter) which consequently gave more onion seeds weight. NAA is considered one of the growth regulators whose small quantity affects plant growth. It plays a key role in cell elongation, cell division, vascular tissue differentiation, root initiation, apical dominance, leaf senescence, leaf and fruit abscission, fruit setting and flowering. Devi et al., (2018) found that spraying onion plants with NAA (1-*Naphthaleneacetic acid*) at a rate of 100 ppm at the first flower stalk emergence and second spray at 10 percent flowering stage (i.e., 35 and 45 days after planting, DAP) enhanced seed recovery and yield by 22.7 percent. Bista, et al., (2022) reported that the combined application of 150 mg L^{-1} of NAA at 3-leaf stage and 150 mg L^{-1} of gibberellin A3 or GA_3 at 7 leaf stage can be recommended to enhance the growth and yield of onion. Therefore, the objective of the current work is to investigate the effect of different levels of phosphorus fertilizer and some stimulator compounds (nanometric compounds and growth regulator) on the growth and seed yield components of onion.

2. Materials and Methods

A field experiment was conducted at the Experimental Farm of Al-Azhar University, Assiut Governorate, Upper Egypt during the two successive growing seasons of 2020/2021 and 2021/2022 to study the effect of phosphorus soil application in different levels and the foliar spray of some stimulators and their interactions on growth and seed productivity of Onion plant (*Allium cepa* L., cv. Giza 6 Mohassan). Some physical and chemical properties of the experimental sites were determined according to Klute (1986) and Page et al. (1982). The experimental soil was loamy in texture and chemical properties were: organic matter 0.92 and 1.17%; pH (1:5 extract) 7.22 and 7.56 and Electrical conductivity (EC) 0.33 and 0.48 (dS/m) in both seasons, respectively. Total N 0.15 and 0.17 (%); available P 11 and 13 (ppm); K 229.5 and 236.6 (ppm).

2.1. Experimental design

The experiment treatments were arranged in a split-plot design with three replicates. Each plot area was 10.5 m^2 (including 5 rows × 0.6 cm width × 3.5 meters long), whereas; one row was left without planting as a guard row between plots to avoid the interference of various treatments. Phosphorous application treatments occupied the main plots which were subdivided into 4 subplots each containing one of the stimulator treatments. The experiments included 12 treatments (3 phosphorous × 4 stimulator treatments including the corresponding control treatment). The plants were treated 3 times with stimulators foliar spray (Nano Boron, Nano chitosan and Naphthalene acetic acid). The first treatment started after 50 days after planting (DAP) and was repeated each 15 days interval. The treatments were arranged as follow:

- a. Phosphorous (soil application).
  Main-plot 1. 30 kg P_2O_5/fed. (fed. = feddan = 4200 m^2)
  Main-plot 2. 45 kg P_2O_5/fed. (fed. = feddan = 4200 m^2)
  Main-plot 3. 60 kg P_2O_5/fed. (fed. = feddan = 4200 m^2)
- b. Stimulators (Foliar spray).
  Subplot 1. Control treatment (spraying with water)
  Subplot 2. nB: Nano Boron at 50 ppm
  Subplot 3. nCS: Nano chitosan at 50 ppm
  Subplot 4. NAA: Naphthalene acetic acid at 50 ppm

Onion bulbs with a diameter of 4–7 cm was planted in mid-November at a spacing of 25 cm between plants and 60 cm between rows. All the treatments were fertilized with the recommended rates of NK, i.e., 120 kg N/fed and 50 units K_2O/fed, where Nitrogen fertilization was carried out 30 DAP in the form of ammonium nitrate (33.5% N) and repeated twice with potassium applications in the form of potassium sulphate (48–52% K_2O) after 50 and 80 DAP. The other cultural practices were applied according to the instructions laid down by the Ministry of Agriculture, Egypt. The monthly temperature range for this location is 19.6 to 31.9 degrees Celsius for daytime temperatures and 7.9 to 18.2 degrees Celsius for nighttime temperatures. But depending on the season, the variations in temperature between day and night might range from 11.8 to 13.7 °C (**Figure 1**).

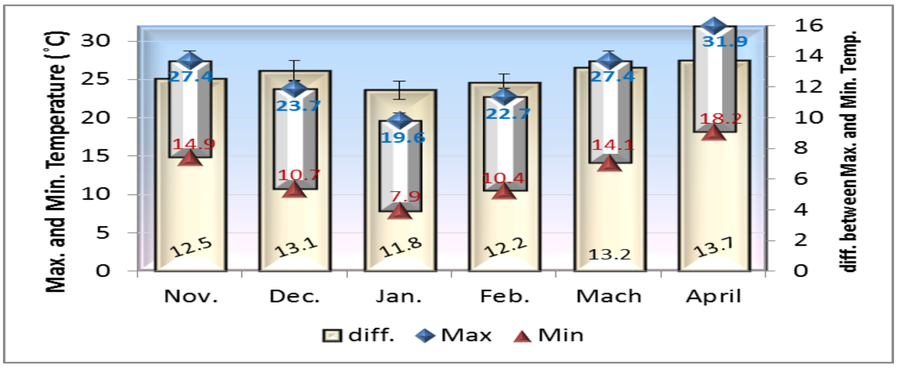

Figure 1. Day (max.), night (min.) and differences between them (diff.) in average of both seasons.

2.2. Recorded data

2.2.1. Vegetative growth characteristics

After 90 days from planting, vegetative samples (5 plants) were randomly collected from each plot to record some vegetative parameters, i.e., seed stalk height (SSH) and Number of seed stalk/plant (NSS/P) as well as the diameter of both seed stalk (SSD) and Inflorescence (Infl.D).

2.2.2. Seeds yield and related traits

In early May, seeds were harvested for recording:

- Seed yield/plant from 5 randomly sampled plants per plot.
- 1000-seed weights were counted from each plot and then weighed with electric balance in grams up to three decimal units.
- Total seed yield per kg/feddan (one feddan = 4200 m^2 = 0.42 hectare) was measured by converting the respective seed yield per plot.
- Germination percentage (%). 100 onion seeds were prepared and placed on Petri dishes covered with filter paper and allowed to imbibe distilled water at room temperature until 15 days.

The percentage of germination has three replications using a total of 48 Petri dishes. A seed was considered germinated when the radicle protrusion attained approximately 1 mm. Then germination percentage was determined from counts of normal seedlings and the total seeds placed on Petri dishes. Germination percentages were calculated after harvest as follows.

$$\text{Germination \%} = \frac{\text{Number of germinated seed}}{\text{Total seed}} \times 100$$

2.2.3. Statistical analysis

All data collected were subjected to statistical analysis as described by Gomez and Gomez (1984) at 5% of significance level and the means were compared using LSD test to check difference. Data for the studied traits were subjected to Principal Component (PC) Analysis in two patterns, i.e., based on 4 vegetative growth traits (1st pattern) and 7-agro-morphological traits (2nd pattern) using Minitab V.17 statistical software. The PC was used to determine the extent of variation in nutrient and stimulator treatments. Eigenvalues were obtained from PC, which was used to determine the relative discriminative power of the axes and their associated characters (Pradhan et al., 2011). The treatments were categorized in a bi-plot figure and compared with the cluster analysis.

3. Results

3.1. Phosphorous fertilization rates

3.1.1. Vegetative growth characteristics

The results illustrated in **Figure 2** indicate that the application of phosphorus positively affected the studied vegetative growth traits (Seed stalk height, number of seed stalk/plant, seed stalk diameter, and inflorescence diameter) as the application of 60 kg P/fed recorded significantly the highest values for all vegetative traits followed by 45 kg P/fed and 30 kg P/fed, in descending order during the two study seasons. However, the demonstrated morphological properties increased gradually with increasing P application rates.

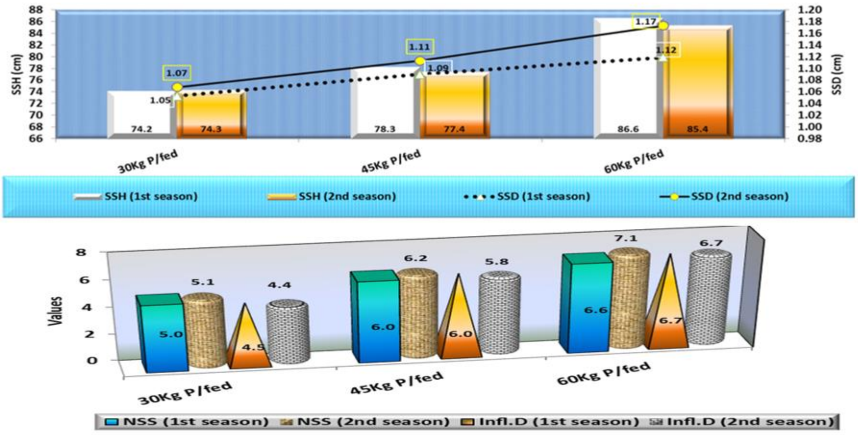

Figure 2. Main effect of phosphorous application rates on some morphological properties.

SSH: Seed stalk height, SSD: Seed stalk diameter, NSS: Number of seed stalk/plant, Inf.D: Inflorescence diameter.

Fertilized plants with different phosphorus rates showed that 60 kg P/fed exhibited a highly significant increment in all vegetative studied traits on an average of both seasons **Figure 3**, i.e., Seed stalk height (SSH), number of seed stalk/plant (NSS/P), seed stalk diameter (SSD), and Inflorescence diameter (Infl.D) by 15.8%, 35.8%, 8.1 and 52.2%, respectively, over the application of 30 kg P/fed followed by 45 kg P/fed by 4.8%, 21.4%, 3.9% and 32.5%, respectively.

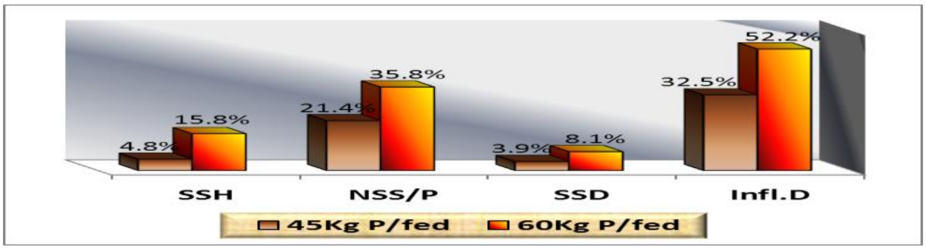

Figure 3. Changes percentage in vegetative growth (average of both seasons) as affected by 45 kg and 60 kg phosphorous rates application comparing to 30 kg P.

SSH: Seed stalk height, SSD: Seed stalk diameter, NSS: Number of seed stalk/plant, Inf.D: Inflorescence diameter

3.1.2. Seed yield and its attribute

Responses of the percentage of seed germination (Germ.), seed yield per plant (Syp), 1000 seed weight (1000-SW) and total seed yield per feddan (Tyf) of onion plants cultivated in loamy soil to phosphorus fertilizer application rates are presented in **Figure 4**.

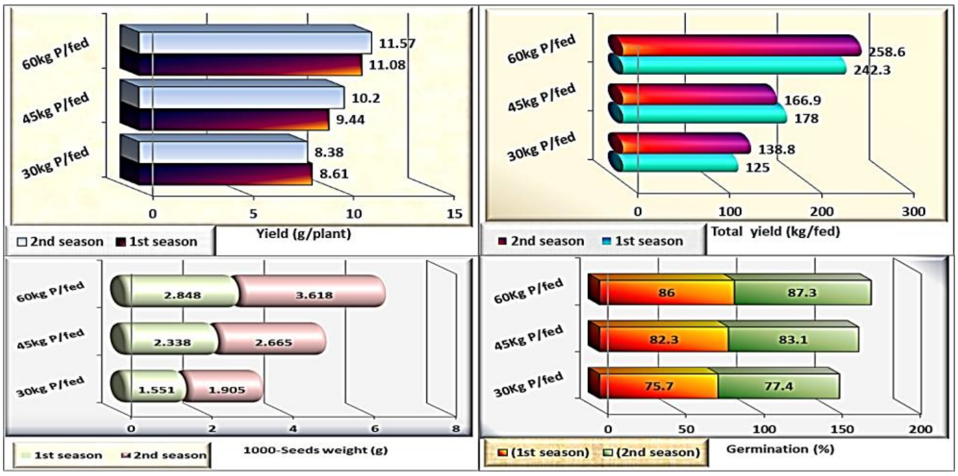

Figure 4. Effects of phosphorous fertilization rates on onion seed yield traits.

The application of 60 kg P/fed recorded significantly the highest values for the three traits followed by 45 kg P/fed and 30 kg P/fed, in descending order during the two study seasons. However, the demonstrated seed yield traits increased gradually with increasing P application rates, where fertilized plants with different phosphorus rates showed that 60 kg P/fed exhibited a highly significant increment in all seed studied traits on an average of both seasons **Figure 5**, i.e., percentage of seed germination (Germ., %), seed yield/plant (Syp, g.), 1000-seed weight (1000-SW, g.) and total seed yield (Tyf, kg/fed.) by 13.2%, 33.3%, 87.1% and 89.9%, respectively, over the application of 30 kg P/fed followed by 45 kg P/fed by 8%, 15.6%, 44.8% and 30.7%, respectively.

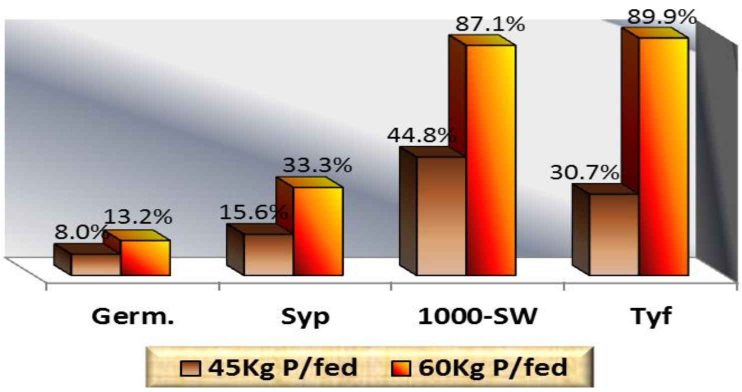

Figure 5. Changes percentage in seed yield traits (average of both seasons) as affected by 45 and 60 kg phosphorous rates application comparing to 30 kg P.

Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed. and Germ%: Germination%.

3.2. Stimulators foliar spray

3.2.1. Vegetative growth characteristics

The results presented in **Figure 6** indicate that foliar spraying with the stimulators (Nano-boron, Nano chitosan, and NAA) resulted in significant differences in the studied vegetative growth traits (Seed stalk height, number of seed stalk/plant, seed stalk diameter, and inflorescence diameter) compared to the control treatment which recorded the lowest values in all the characteristics. Maximum values of Seed stalk height, number of seed stalk/plant and seed stalk diameter were recorded to nano-chitosan followed by NAA and nano-boron in descending order in both seasons. However, the maximum value of inflorescence diameter was observed with nano-boron followed by nano-chitosan and NAA in descending order in both seasons.

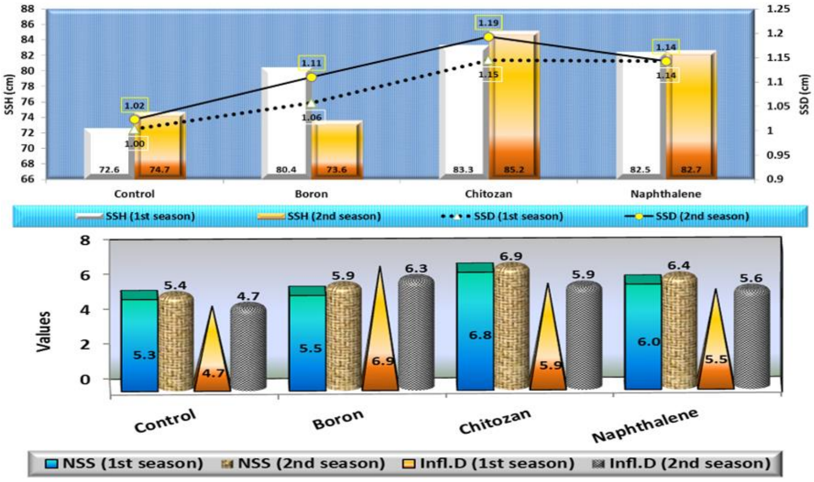

Figure 6. Main effect of stimulators foliar spray on some morphological properties.
SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter.

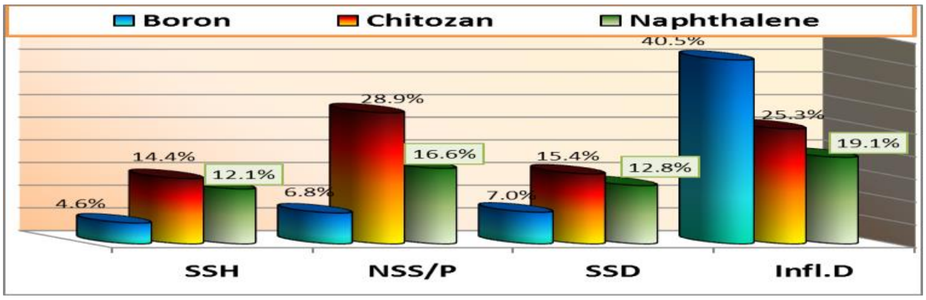

Figure 7. Changes percentage in vegetative growth (average of both seasons) as affected by boron, chitosan and NAA foliar spray comparing to control.
SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter.

Spraying plants with different stimulators showed that 50 ppm nano-chitosan exhibited a highly significant increment in most studied traits on an average of both seasons, i.e., Seed stalk height, number of seed stalk/plant, and seed stalk diameter by 14.4%, 28.9%, and 15.4%, respectively followed by NAA by 12.1%, 16.6% and 12.8%, respectively **Figure 7** compared to the control treatment which recorded the lowest values in all the characteristics. Moreover, maximum values of inflorescence diameter (6.893 & 6.263 cm) were recorded to nano-boron foliar spray compared to the other treatments in both seasons, whereas the minimum values (4.650 & 4.13 cm) were recorded to the control treatments in both seasons.

3.2.2. Seed yield and its attribute

Data demonstrated in **Figure 8** show that all foliar application significantly increased onion seeds and its parameters (Syp, 1000-SW, Tyf and Germ.) in both seasons. Maximum values of Syp, 1000-SW and Tyf were obtained from nano-boron foliar spray followed by nano-chitosan and NAA in descending order in both seasons. However, nano-chitosan exhibited the highest germination percentage followed by nano-boron.

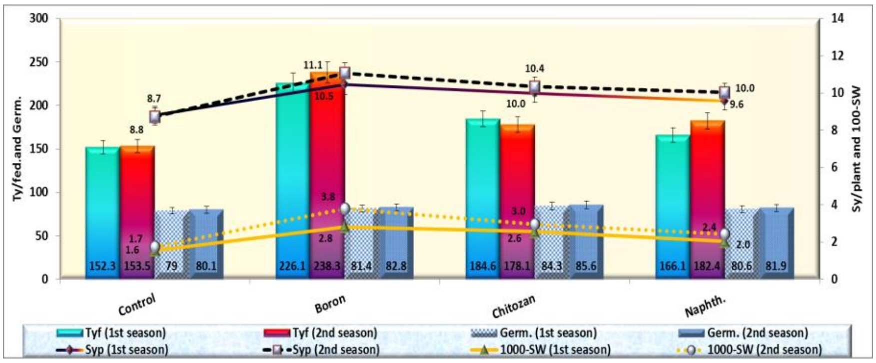

Figure 8. Effect of foliar treatment on yield and its parameters.

Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed. and Germ%: Germination%.

Spraying plants with different stimulators showed that nano-chitosan exhibited a highly significant increment in most seed studied traits on an average of both seasons, i.e., seed yield per plant, 1000-seed weight and total seed yield per feddan by 22.5%, 100.7% and 51.9%, respectively compared to the control treatment which recorded the lowest values in all the characteristics **Figure 9**.

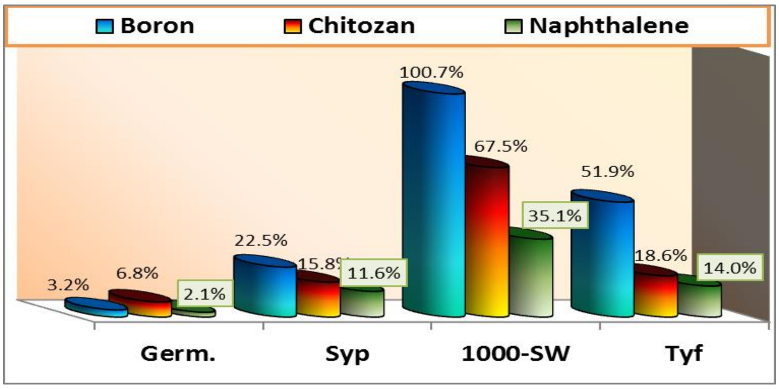

Figure 9. Changes percentage in seed yield traits (average of both seasons) as affected by boron, chitosan and NAA foliar spray comparing to control.

Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed. and Germ%: Germination %.

3.3. Phosphorous rates × foliar spray interaction effects

The obtained data in **Table 1** and **Figures 10** and **11** show highly responses of onion plants cultivated in loamy soil to both factories under the study, i.e., phosphorus fertilization and stimulators foliar spray and this led to a positive interaction and significant differences between the treatments. These results held true in growth parameters and inflorescence diameter (Infl.D) in both growing seasons.

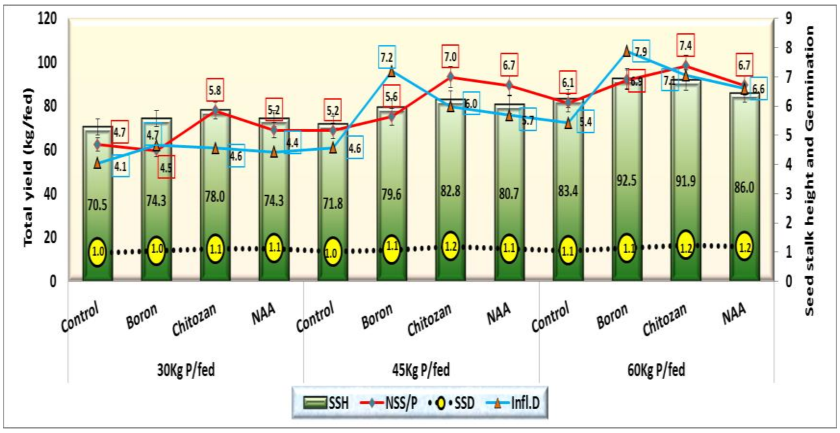

Figure 10. Interaction effect of phosphorus rates and stimulators foliar spray on some vegetative growth traits.

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter.

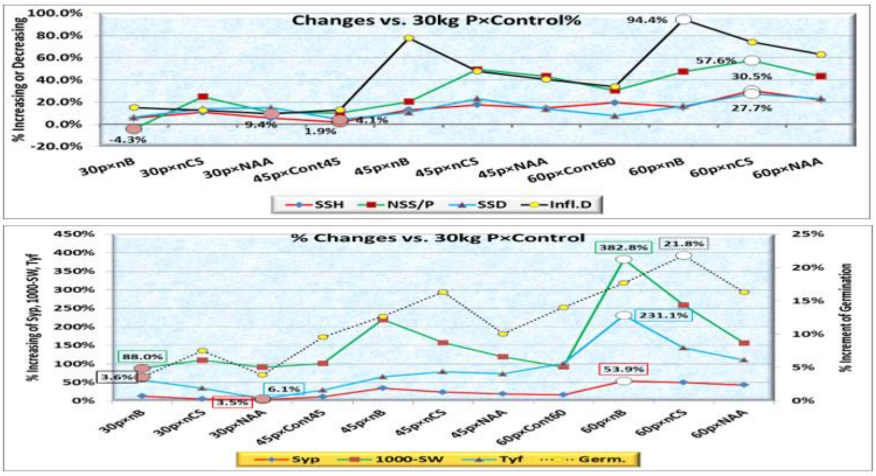

Figure 11. Changes percentage in growth (Up) and seed traits (Down) in average of both seasons as affected by interaction of phosphorus rates and stimulators foliar spray comparing to 30 kg P × water spray as control.

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter, Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed. and Germ%: Germination%.

It is clearly noted that onion plants as fertilized by any phosphorus rate (30, 45 and 60 kg P/fed) combined with any of the 4 foliar spray treatments gave statistically equivalent or increase values in all vegetative growth traits i.e., SSH, NSS/P, SSD, and Infl.D of plants compared to the corresponding control treatments (rated phosphorus × water spray) as shown in **Figure 10**, indicating the efficient role of the studied stimulator treatments. However, 60 kg P/fed., interacting with nano-chitosan or boron treatments exhibited the highest value in all the above-mentioned traits with no significant differences between them in NSS/P, SSD, and Infl.D.

Spraying plants with different stimulators showed that 50 ppm nano-chitosan interacting with 60 kg p/fed (60 p × nCS) exhibited a highly significant increment in most studied traits on an average of both seasons, i.e., seed stalk height, number of seed stalk/plant, and seed stalk diameter by 30.5%, 57.6% and 27.7%, respectively **Figure 11** compared to the control treatment (30 kg P/fed. × Water spray) which recorded the lowest values in all the characteristics. Moreover, the maximum increments of inflorescence diameter (94.4%) were recorded to nano-boron foliar spray (60 p × nB) compared to the other treatments in both seasons.

Seed and yield-related traits of onion plants **Table 1**, and **Figure 12** were significantly affected by interaction treatments. It is clearly noted that onion plants as fertilized by any phosphorus rate (30, 45 and 60 kg P/fed) combined with any of the 4 foliar spray treatments gave statistically equivalent or increase values in all traits i.e., seed yield per plant (Syp), 1000-seed weight (1000-SW), total seed yield per feddan (Tyf) and seed germination percentage (Germ.) compared to the corresponding control treatments (rated phosphorus × water spray), indicating the efficient role of the studied stimulator treatments. However, 60 kg P/fed. interacting with nano-boron followed by nano-chitosan treatments exhibited the highest value in all the above-mentioned traits with no significant differences between them in seed yield per plant (Syp).

Table 1. Interaction between phosphorous application rates and foliar application on growth a seed yield of onion plants.

Phosphorus	**Spraying**	**Seed stalk height(cm)**	**Number of seed stalk/plant**	**Seed stalk diameter (cm)**	**Inflorescence diameter (cm)**	**Average seed yield per/plant (gm)**	**Weight 1000 seed (gm)**	**Total yield kg/fed**	**Germination percentage (%)**
1st Season									
30 kg P/fed	Control	69.8	4.7	0.95	4.1	8.18	0.955	100.8	72.8
	Boron	73.8	4.25	1.01	4.72	9.1	1.43	157.2	75.47
	Chitosan	77.8	5.88	1.1	4.62	8.6	1.97	137.3	78.31
	Naphthalene	75.43	5.1	1.15	4.55	8.55	1.85	110.7	76.10
45 kg P/fed	Control	72.33	5.11	1.01	4.35	8.9	1.86	140.1	80.32
	Boron	78.4	5.5	1.06	8.1	10.12	3.03	211.0	83.70
	Chitosan	81.9	6.89	1.21	5.91	9.6	2.35	185.0	85.20
	Naphthalene	80.44	6.6	1.08	5.5	9.15	2.11	176.0	80.16
60 kg P/fed	Control	75.69	6.0	1.05	5.5	9.4	1.86	216.0	83.90
	Boron	90.11	6.65	1.1	7.86	12.15	4.03	310.0	85.10
	Chitosan	90.20	7.5	1.22	7.12	11.77	3.35	231.0	89.52
	Naphthalene	89.10	6.41	1.2	6.5	11	2.15	211.7	85.39
F-test		**	**	**	**	**	**	**	**
L.S.D. 0.05		0.96	1.98	0.057	1.52	0.64	1.22	4.25	1.25

Table 1. (*Continued*).

Phosphorus	Spraying	Seed stalk height(cm)	Number of seed stalk/plant	Seed stalk diameter (cm)	Inflorescence diameter (cm)	Average seed yield per/plant (gm)	Weight 1000 seed (gm)	Total yield kg/fed	Germination percentage (%)
2nd Season									
30 kg P/fed	Control	71.1	4.66	1	4	7.9	1.05	112.5	74.70
	Boron	74.77	4.71	1.06	4.6	9.12	2.34	177.3	77.33
	Chitosan	78.2	5.8	1.12	4.51	8.39	2.25	149.8	80.30
	Naphthalene	73.18	5.25	1.09	4.31	8.1	1.98	115.6	77.18
45 kg P/fed	Control	71.31	5.2	1.02	4.8	9	2.18	135.6	81.30
	Boron	80.72	5.77	1.1	6.3	11.5	3.38	141.3	82.50
	Chitosan	83.72	7.1	1.19	6.07	10.3	2.81	196.7	86.40
	Naphthalene	81.01	6.81	1.14	5.88	10	2.29	193.8	82.20
60 kg P/fed	Control	92.71	6.2	1.05	5.34	9.33	1.99	212.5	84.30
	Boron	72.31	7.15	1.17	7.89	12.6	5.65	396.2	88.50
	Chitosan	93.61	7.25	1.27	6.98	12.35	3.84	287.7	90.20
	Naphthalene	82.8	7	1.2	6.7	12	2.99	237.9	86.20
F-test		**	**	**	**	**	**	**	**
L.S.D. 0.05		0.87	1.78	0.051	1.39	0.54	1.09	3.88	1.07

Seed stalk height (SSH), Number of seed stalk/plant (NSS), Seed stalk diameter (SSD), Inflorescence diameter (Inf.D), Seed yield per/plant (Syp), 1000-seed Weight (1000-SW), Total yield kg/fed. (Tyf) and Germination (Germ%).

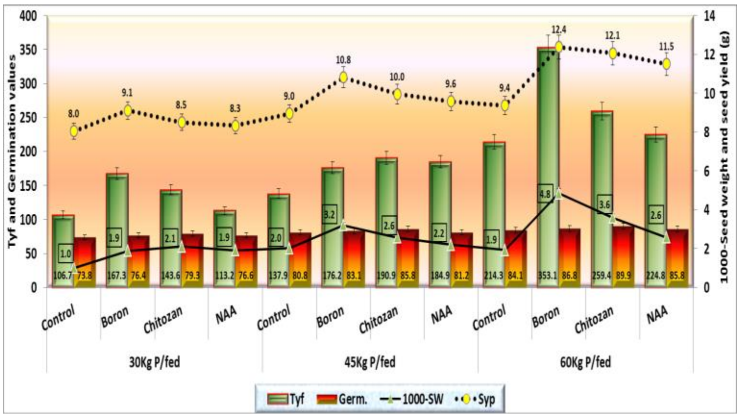

Figure 12. Interaction effects of P application rates and foliar treatments on seed and yield related traits of onion.

Seed yield per/plant (Syp), 1000-seed Weight (1000-SW), Total yield kg/fed. (Tyf) and Germination% (Germ).

Spraying plants with different stimulators showed that 50 ppm nano-boron interacting with 60 kg p/fed (60p × nCS) followed by nano-chitosan with the same rate of phosphorus (60 kg) exhibited a highly significant increment in most studied traits on an average of both seasons, i.e., seed yield per plant (Syp), 1000-seed weight (1000-SW) and total seed yield per feddan (Tyf) by 53.9%, 382.8% and 231.1%, respectively **Figure 11** compared to the control treatment (30kg P/fed. × Water spray) which recorded the lowest values in all the characteristics. Moreover, the maximum increments of seed germination percentage (21.8% & 17.7%) were recorded to nano-chitosan (60 p × nCS) and nano-boron (60 p × nB) foliar spray, respectively compared to the other interacted treatments.

3.4. Correlation between yield and yield contributing characters over two years

The relationships between total seed yield of onion cultivar Giza 6 Mohassan and yield contributing characters over two years are demonstrated in **Table 2**. Results indicated that associations between agronomic and yield contributing characters were highly significant. Greater values of yield contributing characters, including seed stalk height, number of seed stalk/plant, seed stalk diameter (cm), inflorescence diameter (cm), seed yield/plant (g), 1000-seed weight (g), and germination percentage (%) altogether. Inflorescence diameter **(**ID) gave significant and greater values of 0.893 for seed yield per/plant (Syp), 0.835 for 1000-weight (1000-SW), 0.808 for total seed yield (Tyf), and 0.824 for germination percentage (Germ%). Our findings potentially have valuable implications for improving the productivity of onion seed yield.

Table 2. Phenotypic correlations for yield and yield contributing characters over two years.

	SSH	NSS	SSD	Inf.D.	Syp	1000-SW	Tyf	Germ%
Seed stalk height (cm) (SSH)	1	0.768^{**}	0.719^{**}	0.605^{**}	0.662^{**}	0.379^{*}	0.413^{*}	0.713^{**}
Number of seed stalk/plant (NSS)		1	0.796^{**}	0.709^{**}	0.752^{**}	0.671^{**}	0.621^{**}	0.894^{**}
Seed stalk diameter (SSD)			1	0.544^{**}	0.627^{**}	0.569^{**}	0.405^{*}	0.704^{**}
Inflorescence diameter (Inf.D)				1	0.893^{**}	0.835^{**}	0.808^{**}	0.824^{**}
Seed yield per/plant (Syp)					1	0.866^{**}	0.771^{**}	0.843^{**}
1000-seed Weight (1000-SW)						1	0.819^{**}	0.761^{**}
Total yield kg/fed (Tyf)							1	0.720^{**}
Germination (Germ%)								1

Phenotypic correlation coefficients between onion yield and contributing characters were positively and significantly correlated with the productivity of onion seed yield.

3.5. Cluster analysis

Cluster analysis (based on 4 or 7 morphological traits) grouped 19 treatments (3 phosphorus, 4 stimulators and their 12 interactions) into four clusters as shown in **Table 3** and mean value of all traits in each cluster is presented in **Table 4**.

Concerning to the first pattern (based on 4 vegetative growth traits), first cluster having seven treatments accounting 36.84% of total treatments followed by cluster III having 6 treatments (31.58%) beside three treatments were classified in each of 2nd and 4th clusters accounting 31.58% of total treatments (15.79% each) as shown in **Table 3**. As for 2nd pattern (based on 7 traits), first cluster having six treatments accounting 31.58% of total treatments followed by cluster III having 5 treatments (26.32%) beside four treatments were classified in each of 2nd and 4th clusters accounting 42.10% of total treatments (21.05% each) as shown in **Table 3**.

Table 3. Clustering pattern s of 3 *Phosphorous*, 4 *Stimulators* treatments and their interactions based on onion traits.

Clusters		Treatments		
		No.	**Percentage**	**Included**
Vegetative growth traits (SSH, NSS/P, SSD and Infl.D)				
I	GROUP1 (Y1 ≥ 0, Y2 ≥ 0)	7	36.84%	T6, T7, T14, T15, T16, T18 and T19
II	GROUP2 (Y1 ≥ 0, Y2 < 0)	3	15.79%	T3, T13 and T17
III	GROUP3 (Y1 < 0, Y2 < 0)	6	31.58%	T2, T4, T5, T8, T9 and T12
IV	GROUP4 (Y1 < 0, Y2 ≥ 0)	3	15.79%	T1, T10 and T11
Vegetative growth, Syp, 1000-SW and Tyf traits				
I	GROUP1 (Y1 ≥ 0, Y2 ≥ 0)	6	31.58%	T6, T7, T14, T15, T18 and T19
II	GROUP2 (Y1 ≥ 0, Y2 < 0)	4	21.05%	T3, T5, T13 and T17
III	GROUP3 (Y1 < 0, Y2 < 0)	5	26.32%	T2, T4, T8, T9 and T12
IV	GROUP4 (Y1 < 0, Y2 ≥ 0)	4	21.05%	T1, T10, T11 and T16

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter, Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed. and Germ%: Germination%.

Table 4. Cluster-wise mean values and percentage contribution of different characters among the studied treatments.

Item	Based on	C-I		C-II		C-III		C-IV	
		Value	**difference***	**Value**	**difference**	**Value**	**difference**	**Value**	**difference**
SSH	4-Traits	84.6	5.11	82.3	2.74	74.2	–5.34	75.5	–4.00
	7-Traits	84.7	5.18	80.95	1.43	73.61	–5.90	77.69	–1.83
NSS/P	4-Traits	6.70	0.71	6.46	0.47	5.24	–0.75	5.35	–0.64
	7-Traits	6.80	0.81	6.26	0.28	5.15	–0.84	5.54	–0.45
SSD	4-Traits	1.16	0.05	1.12	0.02	1.04	–0.07	1.10	–0.01
	7-Traits	1.18	0.07	1.11	0.01	1.03	–0.08	1.09	–0.02
Infl.D	4-Traits	6.03	0.35	7.27	1.60	5.07	–0.61	4.47	–1.20
	7-Traits	6.13	0.45	7.10	1.42	4.77	–0.91	4.71	–0.97
Syp	4-Traits	10.4	0.47	11.5	1.62	9.25	–0.63	8.44	–1.44
	7-Traits	10.5	0.63	11.3	1.44	8.94	–0.94	8.67	–1.21
1000-SW	4-Traits	2.55	0.06	3.76	1.27	2.06	–0.43	1.92	–0.57
	7-Traits	2.66	0.17	3.65	1.16	1.81	–0.68	1.92	–0.57
Tyf	4-Traits	204.5	16.49	259.9	72.14	161.6	–26.2	129.5	–58.2
	7-Traits	202.6	14.83	253	65.22	147.4	–40.34	150.7	–37.04
Germ.	4-Traits	84.7	2.74	85.5	3.55	79.2	–2.74	77.5	–4.46
	7-Traits	84.81	2.84	84.66	2.70	78.64	–3.32	79.15	–2.81
High	4-Traits	50%		75%		0%		0%	
	7-Traits	62.50%		62.50%		0%		0%	
Moderate	4-Traits	50%		25%		37.50%		50%	
	7-Traits	37.50%		37.50%		37.50%		50%	
Low	4-Traits	0%		0%		62.50%		50%	
	7-Traits	0%		0%		62.50%		50%	

* Difference between value and the mean cluster for corresponding trait
SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter, Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed. and Germ%: Germination%.

As shown in **Table 4**, treatments of the clusters I and II of 1st pattern (based on 4 vegetative growth traits) were dominant in 50 and 75% of the traits studied, respectively compared to the rest of clusters. As for 2nd pattern (based on 7 onion traits), treatments were prevalent in 62.5% of the traits in each of the first and second clusters.

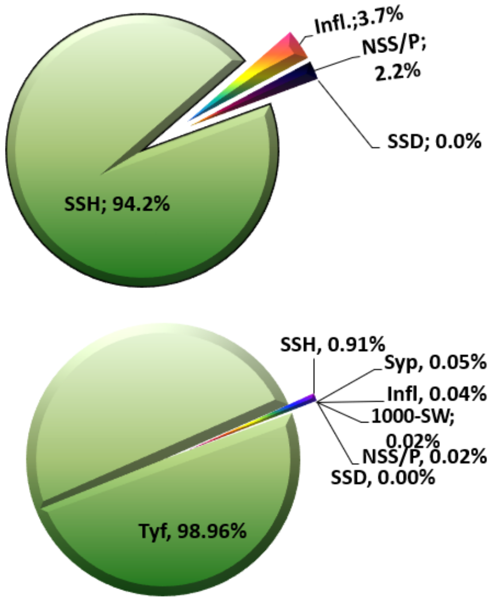

Figure 13. Graphical representation of the proportionate contribution of studied vegetative growth and seed traits toward different treatments in 1st (UP) and 2nd pattern (Down).

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter, Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed.

Cluster I had highest in cluster means values for SSH (84.63 & 84.70 cm), SSD (1.16 & 1.18 cm), Syp (10.35 & 10.51 g), Tyf (204.25 & 202.58 kg), Germ (84.71 & 84.81%) whereas cluster II exhibited the highest cluster means values for SSH (82.26 & 80.95 cm), Infl.D (7.27 & 7.10 cm), Syp (11.50 &11.32 g), 1000-SW (3.67 & 3.65 g), Tyf (259.90 & 252.98 kg), Germ (85.52 & 84.66%) based on 1st and 2nd pattern, respectively indicating that the presence of the most promising treatments in both clusters can be extensively used for further onion planting programs to obtain high seed-yielding with the heaviest 1000-seed weight and highest seed germination percentage. On the contrary, no remarkable feature was noticed in both III and IV clusters for most different characters and had the lowest mean values for most traits, i.e., SSH (74.18 & 75.52 cm), SSD (1.04 & 1.10 cm), Syp (9.25 & 8.44 g), Tyf (161.55 & 129.53 kg) and Germ (79.22 & 77.50%) in cluster III and IV, respectively based on the 4 vegetative growth traits (1st pattern) as well as SSH (73.61 & 77.69 cm), SSD (1.03 & 1.09 cm), Syp (8.94 & 8.67 g), Tyf (147.42 & 150.71 kg) and Germ (78.64 & 79.15%) in cluster III and IV, respectively base on the seven onion traits (2nd pattern) as compared to other clusters confirming that using any of the treatments in both III and IV clusters will, of course, lead to a significant reduction in the yield and quality of seeds. On the other hand, the current study found that out of the four vegetative growth and their contributing traits (pattern 1), the proportionate contribution of the SSH (cm) towards divergence was found 94.2% **Figure 13**. Therefore, this trait would be the important parameter for selecting divergent treatments based on the vegetative growth traits. As for pattern 2, it found that out of the seven onion traits and their contributing traits, the proportionate contribution of the total seed yield (kg/fed.) towards divergence was found 98.96% **Figure 13** whereas SSH did not contribute more than 0.91%. Therefore, the total seed yield (kg/fed.) trait would be the important parameter for selecting divergent treatments in this pattern.

3.6. Principal component analysis (PCA).

Principal components analysis (PCA) was conducted to determine which traits were the major sources of variation within the treatment groups. The results of the PCA of the onion treatment combinations based on 4 and 7 morphological traits are presented in **Table 5**.

Table 5. Principal component analysis (based on two patterns)) for different traits affected by 3 phosphorus fertilizer rates combined with 4 stimulator treatments.

Variables	PC1	PC2	PC3	PC4
1st pattern: Vegetative growth traits (SSH, NSS/P, SSD and Infl.D)				
SSH	**0.5187**	**0.5236**	**0.4995**	**0.4552**
NSS/P	0.1885	0.1184	**0.4623**	**-0.8583**
SSD	**–0.5662**	–0.3234	**0.7251**	0.2215
Infl.D	**–0.6124**	**0.7792**	–0.1049	–0.0833
2nd pattern: Vegetative growth, Syp, 1000-SW and Tyf traits				
SSH	**0.6569**	**0.6670**	**0.6321**	**0.6867**
NSS/P	0.1882	0.1287	0.2871	**–0.5125**
SSD	**0.4478**	0.2229	**–0.6009**	–0.1055
Infl.D	0.3305	**–0.5684**	–0.1453	0.3366
Syp	0.3357	**–0.4543**	**0.5111**	–0.3355
1000-SW	**0.5042**	–0.2033	–0.2271	–0.0421
Tyf	–0.2098	–0.3251	0.1036	**0.4633**

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter, Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed.

It is evident from **Figure 14** that 97.5% of the total variability present among the nineteen treatments is explained by the first three principal components based on 1st or 2nd analysis patterns. Out of four principal components, the first component axe **Figures 14** and **15** in the principal component analysis had an Eigenvalue up to above 1.0 (3.35 & 5.63), presenting 83.7% and 80.5% of the total variability based on 4 and 7 traits, respectively, while PC2, PC3, and PC4 with Eigenvalues of 0.40, 0.15 and 0.10 accounted for 10.12%, 3.66% and 2.51% of total variability, respectively based on 4 traits **Figure 14** as well as 0.94%, 0.25% and 0.17% of total variability, respectively based on 7 traits **Figure 15**.

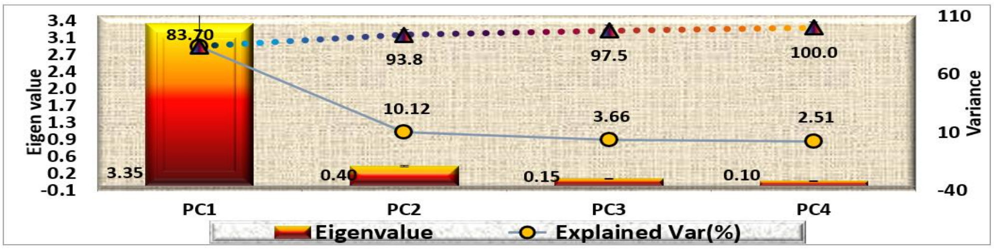

Figure 14. Scree plot of Eigen values, explained (%) and accumulative variability (%) for 4 vegetative growth parameters of fertilizer and stimulators treatments.

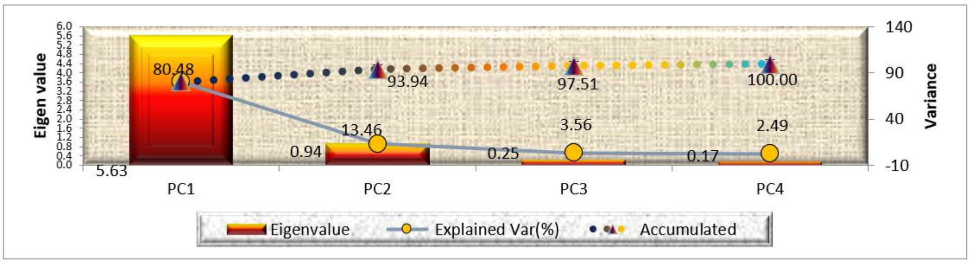

Figure 15. Scree plot of Eigen values, explained (%) and accumulative variability (%) for 7 morphological parameters of fertilizer and stimulators treatments.

The results of **Figures 16** and **17** and **Table 5** showed that both SSH and SSD (based on the two patterns) as well as Infl.D and 1000-SW (based on 1st and 2nd pattern, respectively) had the highest loadings in PC1.

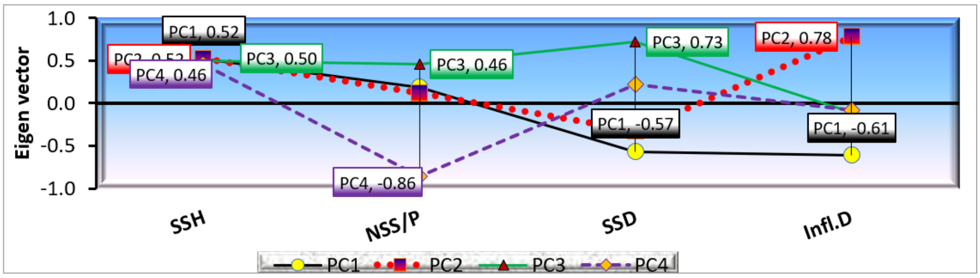

Figure 16. Scree plot of Eigen vector for 4 vegetative growth parameters of fertilizer and stimulators treatments.

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter

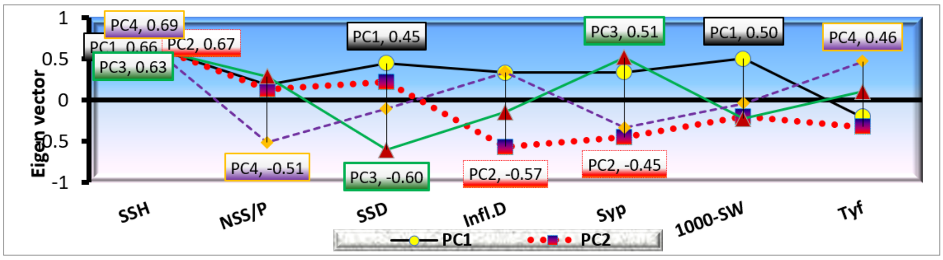

Figure 17. Scree plot of Eigen vector for 7 morphological parameters of fertilizer and stimulators treatments.

SSH: Seed stalk height, NSS: Number of seed stalk/plant, SSD: Seed stalk diameter, Inf.D: Inflorescence diameter, Syp: Seed yield per/plant, 1000-SW: 1000-seed Weight, Tyf: Total yield kg/fed.

The most important traits in the PC2 were seed stalk height (SSH) and inflorescence diameter (Infl.D) based on both patterns as well as seed yield per plant (Syp) in 2nd pattern. So, PC2 is a weighted average of these traits indicating their significant importance for this component. The PC_3 accounts for 3.6% of the total variance and traits which contributed higher eigenvectors value in PC3 as SSH and SSD based on the two patterns as well as NSS/P and Syp based on 1st and 2nd pattern, respectively. The fourth principal component explained 2.5% of total variability with SSH and NSS/P (based on the two patterns) as well as Tyf (based on the 7 traits) as the most important trait. Therefore, all PCs have a significantly positive association with SSH in both patterns. PC1 has a negative association with SSD and Infl.D of pattern 1 and also, a significantly positive association with SSD and 1000-SW in the 7 morphological traits pattern. PC2 has positive and negative associations with Infl.D in the 1st and 2nd pattern, respectively. The third PC has a positive association with both NSS/P and SSD in 1st as well as positive and negative association with Syp and SSD, respectively in 2nd pattern (7 traits). PC4 has a negative association with NSS/P of both patterns (4 and 7 traits) and a positive association with Tyf in 2nd pattern.

The results obtained from biplot-PCA **Figure 18** indicated the presence of high variations among the studied treatments based on the two data patterns of studied traits resulting in amplitude that may appear their effects the growth performance.

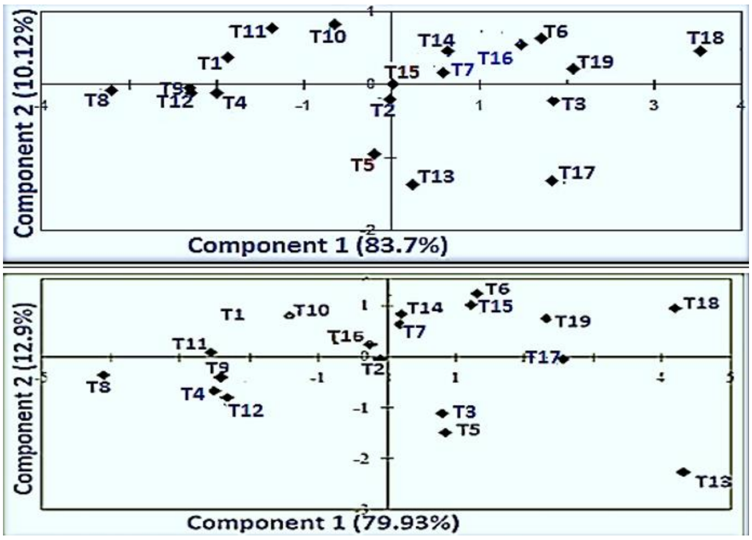

Figure 18. Principal component bi-plot of 19 treatments based on 4 onion vegetative growth traits (above) and 7 morphological traits (under).

Figure 19 presents the UPGMA tree diagram generated by cluster analysis. In general, it shows two large classes. In a hard selection, across the approved cut-off point, four groups were formed, T18 formed a single cluster (1st pattern) which has high values for the parameters taken into consideration (SSH, NSS/P, SSD, Syp, germination%, and total seed yield) whereas T17, also formed a single cluster (2nd pattern) which has high values for the parameters taken into consideration (Infl.D, Syp, 1000-SW, Tyf and Germination) and other eighteen treatments in the other class of which have fluctuated values. Interestingly, the distribution of nutrient and stimulate treatments by the dendrogram was comparatively consistent with the aggregation of these treatments obtained using cluster analysis and along the two axes in the PCA graph **Figure 18**.

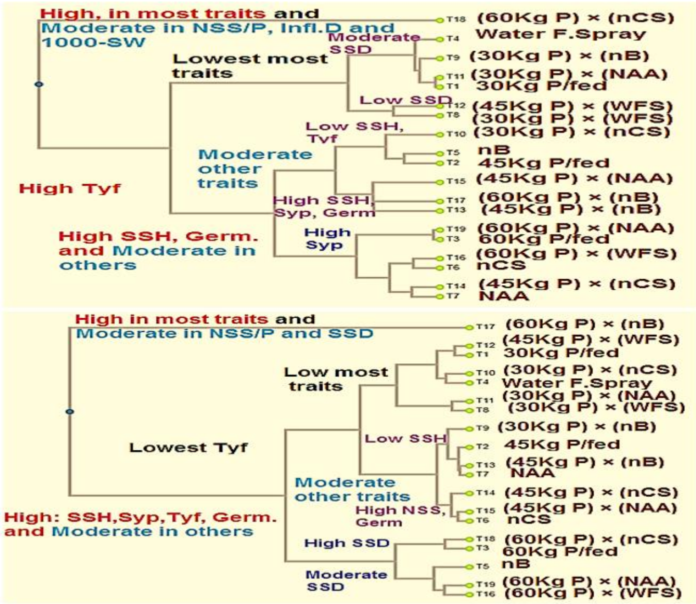

Figure 19. Dendrogram, using average linkage (Between Groups), for nineteen nutrients and stimulate treatments based on four growth traits (above) and seven onion morphological traits (lower).

WFS: Water foliar spray (Control)

T1: 30 kg P/fed, T2: 45 kg P/fed, T3: 60 kg P/fed, T4: Control, T5: nB, T6: nCS, T7: NAA,

T8: (30 kg P) × (Control), T9: (30 kg P) × (nB), T10: (30 kg P) × (nCS), T11: (30 kg P) × (NAA),

T12: (45 kg P) × (Control), T13: (45 kg P) × (nB), T14: (45 kg P) × (nCS), T15: (45 kg P) × (NAA),

T16: (60 kg P) × (Control), T17: (60 kg P) × (nB), T18: (60 kg P) × (nCS) and T19: (60 kg P) × (NAA)

4. Discussion

Phosphorus is an essential element for onion plants due to its role as a major building block of DNA molecules (Shaheen et al. 2017). The increase in morphological properties on onion plants due to P fertilization may be attributed to its important role in root growth and influences the vigorously of the plant in addition to its role in energy transfer compound (ATP and other nucleic protein) the genet information system cell membranes and phosphor protein (Brawas and Mukherge, 1993; El-Ezz, et al., 2022; Abdelkader et al., 2022). Moreover, such responses might be expected to influence the temporal patterns of dry matter accumulation under the varying conditions of phosphorus supply (Aisha et al., 2007).

Onion productivity increased with increasing P-rate fertilization. These results are in agreement with (Shaheen et al., 2017; Almading et al., 2000; Gebeyehu, 2018; Singh et al., 2010; Amare et al., 2000). They reported that the highest rates of Phosphorus (92 to 115 kg/ha) gave better growth and had a major effect on the productivity of the onion plants, hence increasing total yield and its components. Phosphorus and N fertilization play a great role in the seed germination percentage of onion seeds (Amjad et al., 1999; Ali et al., 2007; Ahmed and Abdalla, 1984). These roles occur in enhancing many aspects of plant physiology (Brady and Weil, 2002). The increase in plant growth, yield, and quality may occur through increasing the formation of chlorophyll, the rate of photosynthesis, and dry matter production or may be due to speeding nutrient absorption and penetration, synthesis, and movement among the high surface area and slow-releasing of nano-fertilizers. This increase may be caused by activating the photosynthesis process (Hopkins et al., 2007; Lal, 2008; Moosapoor et al., 2013; Singh et al., 2013; Schwab et al., 2015). The superiority of Nano boron foliar application might accelerate the flowering stage in the plant through sugar transport across plant cell walls which accelerating the flowering stage in the plant (Blevins and Lukaszewski, 1998; Herrea-Radriguez et al., 2010). The plant requirement of boron is more in the flowering stage and seed production than vegetative stage (Shkolnik, 1984). Moreover, nano-boron affects the reproductive organs of the plant such as stigmas, pollen, and ovaries, and consequently on seed onion yield. These results are in harmony with what findings by Bayar et al. (2024); Tewodros et al. (2005); Zayed et al. (2017) and Khalil et al. (2022). They found that spraying bean plants (*Phaseolus vulgaris* L.) with nano chitosan at the rate of 50 ppm gave the highest values of all growth characters, average bulb weight, marketable and total yields and bulb quality parameters (bulb diameter, TSS% and DM%) as compared with the other spraying treatments or the control. Also, El-Bassiony et al. (2020) explain the improvement of vegetative growth parameters and yield due to spraying amino acids by providing a ready source of substances that form the protein in the living tissues.

Phenotypic correlation coefficients between onion yield and contributing characters were positively and significantly correlated with the productivity of onion seed yield. Although correlation analysis helps in the determination of effective traits in order of indirect selection of superior treatments but on the other hand, principal component analysis is a suitable multivariate technique in identifying and determining independent principal components that are effective on plant traits separately. Therefore, the principal component analysis also helps in indirect selection for traits effective on yield (Leilah and Al-Khateeb, 2005; Alkharpotly 2023a, 2023b). The cumulative variance of >93% by the first two principal components indicated that the identified traits within these axes exhibited great influence on the phenotype of the onion plants and could effectively be used for selection among them. The bi-plot enabled the evaluation of the correlation level among the quantified variables, with treatments presenting the same direction being more closely correlated. The principal component analysis is important and could define most of the analyzed parameters, especially the morphological parameters. PC diagnosis is a multivariate approach providing a theoretical basis for further improvements in nutrients and/or stimulator diagnosis. Golparvar et al. (2006) reported that PCA reduces the number of interdependent variables into a smaller number of independent PCs that are linear combinations of original variants.

5. Conclusions

In spite of the positive effect of nano-chitosan on growth and yield components, results proved that spraying nano-boron at 50 ppm concentration three times; at 50, 65, and 80 days from transplanting with soil application of 60 kg phosphorus fertilization gave high effects, especially on onion seed yield. Phenotypic correlation coefficients between onion yield and contributing characters were proved to be positive and significant.

Author contributions: Conceptualization, ZFF, MAA; and KZG; methodology, MAAA, HAAH, ESD, MFMA, SMES and MNS; software, ZFF, HAAH, MMA, FMA, ESD and KZG; validation, HAAH, MMA, FMA and KZG; formal analysis, MAAA, HAAH, MMA, MFMA, SMES and MNS; investigation, ZFF, MMA, FMA and KZG; resources, MAAA, MAA, MNS and SMES; data curation, MAAA, FMA, MFMA and MNS. writing—original draft preparation, MAAA, ZFF, MAA, HAAH, ESD, MFMA, SMES and MNS; writing—review and editing, MAAA, MAA, HAAH, MFMA, KZG, SMES and MNS; visualization, MMA, FMA and SME; supervision, ZFF, MAA and ESD; project administration, ZFF, MAA and ESD; funding acquisition, MMA, FMA, ESD, KZG and MFMA. All authors have read and agreed to the published version of the manuscript.

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