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NANO FERTILIZERS WITH ALGAE EXTRACT AS BIOSTIMULANT AFFECTING GROWTH, BULB YIELD, AND QUALITY OF ONION (*ALLIUM CEPA* L.)

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SUMMARY

Biostimulants (nano fertilizers, algal extract) are synthetic or natural compounds for application to seeds, plants, and soil to increase crops, particularly onion yields. These substances cause changes in vital structural processes to influence plant growth through improved tolerance to abiotic stresses and enhance seed and grain yield and quality. The presented study aims to determine if biostimulants beneficially increase onions' vegetative growth, harvest, and quality of onions (*Allium cepa* L.). A randomized complete block design with three replications helped compare various rates of Nano NPK fertilization (0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 g/L Nano NPK + 0.5 g/L algae extract, 1.0 g/L mineral NPK + 0.5 g/L algae extract, 1.0 g/L mineral NPK, 1.0 g/L Nano NPK, and 0.5 g/L algae extract) with the control treatment (spraying distilled water only). The results showed as the Nano NPK + 0.5 g/L algae extract levels decreased, all studied parameters gradually declined. Foliar application of Nano NPK 1.0 g/L combined with 0.5 g/L algae recorded the highest significant effects, followed by 1.0 g/L mineral NPK + 0.5 g/L algae and 0.8 g/L Nano NPK + 0.5 g/L algae compared with the control. The highest values of bulb diameter (10.1 cm/plant), plant height (108.7 cm/plant), plant fresh weight (254.7 g/plant), and fresh yield (25.67 t/ha) emerged with foliar application of Nano NPK 1.0 g/L combined with 0.5 g/L algae, and the lowest values, obtained from the control treatment, were 4.2 cm/plant, 62.3 cm/plant, 100.23 g/plant, and 10.09 t/ha, respectively. The results suggested that using the algae extract combined with nano fertilizer treatment as a biostimulant will maximize onion growth parameters, yield production, and nutrient contents.

Keywords: Onion (*Allium cepa* L.), vegetative growth, nanotechnology, NPK fertilization, algae extract, nutrient content and yield

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Key findings: Applying nanofertilizers in conjunction with the algae extracts' usage as a biostimulant is crucial for maximizing the growth characteristics, yield production, and nutrient contents of onions.

INTRODUCTION

Allium is a genus of flowering plants that contains garlic, shallots, leeks, chives, and onions. It has gained attention for its biological features and possible use in treating and preventing various disorders aside from being rich in numerous phytonutrients acknowledged as essential components of the Mediterranean diet (Lim, 2016; Marrelli *et al.,* 2019). Another typical vegetable people eat for flavor and health benefits is onion (*Allium cepa* L.). Among many other potential health benefits, onions may lower the risk of obesity, heart disease, and cancer. Minerals, i.e., phosphorus, calcium, magnesium, iron, manganese, and carbohydrates, are abundant in the bulb of this plant. In addition, it is a good source of protein, vitamin C, vitamin B6, antioxidants, and sulfur amino acids (Ware, 2017). A wide range of secondary metabolites, including flavonoids (especially flavonols and anthocyanins), phytosterols, and saponins, have been found in this species (Marrelli *et al.,* 2019). In Egypt, onion is one of the most important vegetables for the local market and for exports, fresh or dried. With an onion production of approximately 3.08 million tons at 87,948 ha of crops in 2019, Egypt ranked fourth among the world's largest onion exporters after the Netherlands, India, and China in the last three years. Over the past decades, significant technological and agricultural advancements have helped grow this crop, potentially opening up vast new export opportunities (FAOSTAT, 2020).

Biostimulants are natural or synthetic substances that can be alternative enhancers to seeds, plants, and soil. These substances cause changes in vital and structural processes to influence plant growth through improved tolerance to abiotic stresses and increase seed and grain yield and quality, reducing the need for fertilizers (Du Jardin, 2015). Biostimulants can be promising since the nutrients can transfer from plant leaves to their roots in a very short time (Afify *et al.,* 2019; El-Nwehy *et al.,* 2021; Afify and El-Nwehy, 2022; Bakry *et al.,* 2022). Some algal extracts and nanofertilizers can become foliar sprays under biostimulants classification. Algae extracts, unlike chemical fertilizers, are decomposable, non-toxic, non-contaminating, and non-harmful to humans and other living organisms (Yarnpakdee *et al.,* 2019). Algae exist in almost all terrestrial environments and are the most distinctive organisms on the planet, having potential applications, such as, biofertilizers and soil conditioning agents to improve soil fertility and plant productivity (Chapman, 2013; Duarte *et al.,* 2018).

The creation of macronutrient nanofertilizers remains a primary focus of fertilizer research to ensure that plants get the proper quantity of nutrients while simultaneously reducing transportation costs and improving food output. Furthermore, compared with conventional fertilizers, the macronutrient (N, P, and K) nanofertilizer considerably increases crop growth and yields, showing enhanced efficiency. Utilizing macronutrient nanofertilizers may help avoid nutrient loss while having a negligible environmental effect. These nanofertilizers with macronutrients had one or more nutrients encapsulated in nanoparticles (NPs) and were sprayed on crops (Liu and Lal, 2015; Zulfiqar *et al.,* 2019; Hayyawi *et al.,* 2022). Nanofertilizers control the nutrients in the nanostructure, increase the availability of nutrients, reduce soil toxicity, and reduce environmental protection costs (Sekhon, 2014; Rameshaiah *et al.,* 2015; Bakry *et al.,* 2022). It is necessary to use new cultivation techniques to increase food production. Therefore, novel changes should contribute to environment-friendly, economical, and sustainable farming systems, such as, nanofertilizers and slow or controlled-release fertilizers (El-Ramady *et al.,* 2018). Many studies have cropped up on nanofertilizers as nitrogen, phosphorus, and potassium-releasing agents and their effects on green beans (Hasaneen and Abdel-Aziz, 2016), wheat

(Abdel-Aziz *et al.,* 2016), and peanut beans (Afify *et al.,* 2019; Bakry *et al.,* 2022). A study conducted by Chemistry (2017) showed the effect of nanofertilizers on plant growth, yield, and quality of vegetables and other crops, which opens up new directions for growing food. The promising study objective was to determine if biostimulants beneficially increase vegetative growth, yield, and quality of onions.

MATERIALS AND METHODS

Two field experiments carried out at the experimental farm in El-Giza Governorate (El-Badrasheen area), Egypt, used a randomized complete block design with three replications to evaluate the effect of biostimulants (nanofertilizers plus algae extracts) on the vegetative growth, yield, and quality of onions (*Allium cepa* L.; Shandwell 1 spp.) throughout the 2020–2021 and 2021–2022 winter seasons. The onion cultivar planting commenced on 5 November in the two winter seasons. The trial area is 10.5 m^2 (3.5 m long and 3 m wide), with five ridges; the distance from the ridges is 60 cm, with the ridges' direction from north to south. Planting continued on both sides of the 7 cm row between the seedlings. Superphosphate (15.5% P_2O_5) proceeded to equal use during soil preparation, with potassium sulfate (48% K_2O) and ammonium nitrate (33.5% N) after one and two months from the planting date, as approved by the Ministry of Agriculture (288 kg N + 108 kg P_2O_5 + 120 kg K_2O/ha). Nano NPK fertilizer: (20-20-20 NPK) introduced by the Nanoway Technology Company in Egypt, emitted as foliar fertilizer spray with 480 litters of water per ha, 30 days and 60 days after planting. The chemical composition of the Nano NPK Fertilizer comprised total nitrogen (N)-20%, phosphate (P_2O_5)-20%, soluble potassium (K_2O)-20%, magnesium (Mg)-zero, iron-zero, sulfur (S)-zero, inert materials-40%, and the water-soluble mineral NPK fertilizer (20-20-20).

The preparation of algae extract consisted of the *Spirulina platens* algae used in the study was a photosynthetic and multicellular blue-green microalgae that grows in a wide range of fresh, marine, and brackish water (Marrez *et al.,* 2014). The source of algae was the Algal Biotechnology Unit, NRC, Egypt. The chemical composition, mineral content, HPLC chromatogram hormones, and amino acid content of the algae extract are available in Tables 1 and 2.

The 11 foliar treatments were the different rates of nano (0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 g/L), with a combination of 0.5 g/L algae extract, mineral NPK 1.0 g/L + 0.5 algae extract, mineral NPK 1.0 g/L, Nano NPK 1.0 g/L, algae extract 0.5 g/L, and control (sprayed with fresh water). Other standard practices of growing onion proceeded as per the recommendation. The initial physicochemical properties (Table 3) of the experimental field soil having clay loam texture incur analysis following the procedure described by Piper (1950) and Jackson (1967).

Plants harvested from each plot after 70 days from cultivation served as samples to determine plant height (cm) (measured from the base of the broad sheath to the top of the longest leaf) and the chlorophyll a, b, and β-carotene content, as estimated by Nagata and Yamashita (1992). Afterward, all collected plants in each plot maintained storage in the standard field for 15 days. Each parcel had dry leaves and bulbs taken with 2 cm length as randomized samples from each replicate, cleaned, dried at 70 °C, and prepared for chemical analysis according to Cottenie *et al.* (1982). The protein percentage calculation had the nitrogen content multiplied by 6.25.

Soluble sugars in the collected extract's determination employed the enthrone method, according to Seifter *et al.* (1950). Plant fresh weight (g/plant) and total fresh yield (t/ha) from each net treatment have weights measured with the help of a digital balance. All data collected underwent an analysis of variance, according to Snedecor and Cochran (1967). Treatment means' comparison ensued using Duncan's Multiple Range Test (Duncan, 1955).

Table 1. Chemical composition and mineral of algae extract and HPLC chromatogram hormones of algae extract.

Elements	%						ppm			
	N	P	K	Mg	Na	Ca	Fe	Zn	Mn	Cu
Concentrations	13.30	2.22	2.13	0.22	0.01	0.33	1936.00	68.00	21.00	18.00
HPLC chromatogram hormones of algae extract sample, $mg.g^{-1}$										
Indole acetic acid				Indole butyric acid				Gibberellic acid		
13.66				3.25				1.19		

Table 2. Amino acids content of the used algae extract.

Amino acid	Abbreviation	Concentration (%)	Amino acid	Abbreviation	Concentration (%)
Aspartic	ASP	1.85	Threonine	THR	0.83
Serine	SER	0.70	Glutamic	GLU	2.24
Proline	PRO	0.67	Glycine	GLY	1.07
Alanine	ALA	1.55	Valine	VAL	1.11
Methionine	MET	0.33	Isoleucine	ISOL	0.71
Leucine	LEU	0.29	Tyrosine	TYR	0.53
Phenylalanine	PHE	0.87	Histidine	HIS	0.24
Lysine	LYS	0.70	Arginine	ARG	0.98
Cysteine	CYC	0.22			
Total amino acids		15.89			

Table 3. Some chemical and physical properties of the experimental soil.

Characteristics	pH (1:2.5)	EC (1:5)	CaCO3 (%)	O.M (%)	Available nutrients (ppm)			Particle size distribution (%)			Textural Class
					N	P	K	Sand	Silt	Clay	
El-Giza El-Badrasheen area	7.2	1.5	4.3	1.7	127	42	164	26.30	38.50	35.20	Clay Loam

RESULTS

Effect of nano NPK and algae extract on vegetative growth characteristics

The results in Table 4 illustrated that onion spraying with nano NPK and algae extract as biostimulants significantly affected all the vegetative growth characteristics (plant height, fresh weight, bulb diameter, and fresh yield). The mentioned properties were substantially improved by increasing the concentration of biostimulants nano NPK from 0.1 to 1.0 g/L combined with the algae extract.

Plant height

As mentioned in Table 4, all treatments significantly increased the plant height, with the maximum increase achieved at foliar application of Nano NPK at a rate of 1.0 g/L + 0.5 g/L algae (108.7 cm/plant), followed by minerals NPK of 1.0 g/L + 0.5 g/L algae (95.7 cm/plant), and 0.8 g/L Nano NPK + 0.5 g/L algae (88 cm/plant). Spraying with water (control treatment) gave the lowest value (62.3 cm/plant).

Plant fresh weight

The highest plant fresh weight of the onion was evident with foliar application of 1.0 g/L Nano NPK plus algae extract (Table 4). The highest values of plant fresh weight (254.70 g/plant and 233.68 g/plant) were gainful when sprayed with Nano NPK at a rate of 1.0 g/L + 0.5 g/L algae and minerals NPK at 1.0 g/L + 0.5 g/L algae, respectively, but the lowest value (100.23 g/plant) emerged when sprayed with water (control treatment).

Table 4. Effect of biostimulants (Nano NPK with Algae extract) on growth parameters of onion (combined analysis of two successive winter seasons of 2020–2021 and 2021–2022).

Biostimulant Treatment	Bulb diameter (cm/plant)	Plant height (cm/plant)	Plant fresh weight (g/ plant)	Fresh yield (t/ha)
0.1 g NPK nano + 0.5 g Algae	5.5h	70.0i	113.61i	11.45i
0.2 g NPK nano + 0.5 g Algae	6.3g	73.7h	118.43h	11.94h
0.4 g NPK nano + 0.5 g Algae	7.0f	77.0g	129.60g	13.06g
0.6 g NPK nano + 0.5 g Algae	7.7e	80.7f	157.04f	15.80f
0.8 g NPK nano + 0.5 g Algae	8.6c	88.0c	203.13c	20.47c
1.0 g NPK nano + 0.5 g Algae	10.1a	108.7a	254.70a	25.67a
1.0 g NPK mineral + 0.5 g Algae	9.0b	95.7b	233.68b	23.55b
1.0 g NPK mineral	8.0d	83.7e	181.29e	18.28e
1.0 g NPK nano	8.3c	86.7d	186.52d	18.79d
0.5 g Algae	5.0i	66.3j	108.86j	10.97j
Control	4.2j	62.3k	100.23k	10.09k

Table 5. Effect of biostimulants (Nano NPK with Algae extract) on quality parameters of onion (combined analysis of two successive winter seasons of 2020–2021 and 2021–2022).

Biostimulant Treatment	Carotene	Chl a	Chl b	Protein	Starch	Sugar
	mg/g f w			%		
0.1 g NPK nano + 0.5 g Algae	0.062i	0.378f	0.124de	9.56i	3.75i	5.33i
0.2 g NPK nano + 0.5 g Algae	0.068h	0.353h	0.116g	9.88h	3.94h	6.30h
0.4 g NPK nano + 0.5 g Algae	0.072g	0.366g	0.120f	11.36g	4.23g	6.64g
0.6 g NPK nano + 0.5 g Algae	0.075f	0.395e	0.127d	13.15f	4.39f	6.87f
0.8 g NPK nano + 0.5 g Algae	0.083c	0.419c	0.139c	16.58c	6.73c	7.69c
1.0 g NPK nano + 0.5 g Algae	0.090a	0.451a	0.178a	18.38a	8.25a	10.72a
1.0 g NPK mineral + 0.5 g Algae	0.087b	0.437b	0.148b	17.23b	7.05b	8.75b
1.0 g NPK mineral	0.077e	0.395e	0.121ef	15.44e	4.86e	7.12e
1.0 g NPK nano	0.081d	0.401d	0.148b	16.01d	5.34d	7.40d
0.5 g Algae	0.054j	0.334i	0.112h	8.01j	3.19j	4.86j
Control	0.046k	0.292j	0.084i	5.96k	2.87k	3.83k

Bulb diameter

The study noted that foliar application of nano NPK with algae extract significantly affected bulb diameter (Table 4). Spraying with Nano NPK at a rate of 1.0 g/L + 0.5 g/L algae recorded the maximum diameter (10.1 cm/plant), followed by minerals NPK at 1.0 g/L + 0.5 g/L algae (9 cm/plant). In contrast, the control treatment appeared with the lowest value (4.2 cm/plant).

Effect of nano NPK and algae extract on yield

A perusal of Table 4 indicates the effect of different nano NPK concentrations on the onion yield. The 1.0 g/L Nano NPK + 0.5 g/L algae extract produced the highest crop yield of onions, at about 25.67 t/ha, with the lowest output obtained from the control treatment (10.09 t/ha).

Effect of nano NPK and algae extract on chemical compositions

Table 5 shows that in various chemical compositions (carotene, Chl a, Chl b, protein, starch, and sugar), the treatment of 1.0 g/L Nano NPK + 0.5 g/L algal extract outperformed the other treatments. The properties of onions gained considerable enhancement with increased application rates of Nano NPK from 0.1 to 1.0 g/L + 0.5 g/L algae.

Carotene, Chl a, and Chl b

From Table 5, foliar application of Nano NPK + 0.5 g/L of algae extracts significantly increased β-carotene, Chl a, and Chl b in onion plants compared with the control. Spraying with Nano NPK at a rate of 1.0 g/L + 0.5 g/L algae extract resulted in the highest concentrations of β-carotene (0.09 mg/g f.w.), Chl a (0.45 mg/g f.w.), and Chl b (0.17 mg/g f.w.) in onion leaves.

Protein

The spraying with various biostimulant treatments notably improved protein content in onion plants compared with the control. The higher protein content was apparent in Nano NPK 1.0 g/L + 0.5 g/L algae (18.38%), followed by mineral NPK 1.0 g/L + 0.5 g/L algae (17.23%), whereas the lowest protein content was with the control treatment (5.96% protein) (Table 5).

Starch and sugar

As shown in Table 5, adding biostimulant foliar treatments enhanced the onion plants' starch and sugar contents. The increment indicated a steady increase from treatment 0.1 to 1.0 g/L Nano NPK + 0.5 g/L algae extracts. The Nano NPK at a rate of 1.0 g/L + 0.5 g/L of algae marked a higher value for starch and sugar (8.25% and 10.72%, respectively) than the other treatments, followed by 1.0 g/L mineral NPK + 0.5 g/L algae (7.05% and 8.75%, respectively), then 0.8 g/L Nano NPK + 0.5 g/L algae (6.73% and 7.69%, respectively). The control treatment gave the starch and sugar values of 2.87% and 3.38%, respectively.

Effect of nano NPK and algae extract on nutrients content

The estimated nutritional status of plants measured the effect of adding biostimulants NPK, whether foliar (nano or mineral with or without algae). All biostimulant treatments improved the onions' nutrient (macro and micronutrients) content, thus improving their properties for export and local marketing.

Macronutrients

All treatments significantly improved onion nitrogen percent. The nitrogen concentration ranged from 0.95% (control treatment) to 2.94% (1.0 g/L Nano NPK + 0.5 g/L algae extract). The decreasing order of phosphorus content under different treatment was visible as: 0.93% > 0.75% > 0.70% > 0.67% > 0.64% > 0.61% > 0.58% > 0.56% > 0.51% > 0.43% > 0.38%% for 1.0 g/L Nano NPK + 0. 5 g/L algae, 1.0 g/L mineral NPK + 0.5 g/L algae, 0.8 g/L Nano NPK + 0.5 g/L algae extract, 1.0 g/L Nano NPK and 1.0 g/L mineral NPK, 0.6 g/L Nano NPK + 0.5 g/L algae, 0.4 g/L Nano NPK + 0.5 g/L algae, 0.2 g/L Nano NPK + 0.5 g/L algae, 0.1 g/L Nano NPK + 0.5 g/L algae, 0.5 g/L algae, and the control treatment, respectively. Potassium plays an essential role in transmitting sugars and proteins in the plant, thus affecting the storage of carbohydrates in storage organs (whether roots or tubers), and it was an imperative guide for understanding and discussing the nano NPK activity.

Table 6 details a wide variation in potassium concentration between fertilization treatments; it takes the same arrangement of nitrogen and phosphorus. The treatment of 1.0 g/L Nano NPK + 0.5 g/L algae extract recorded the maximum potassium content (4.71%), followed by 1.0 g/L mineral NPK + 0.5 g/L algae extract, and the control treatment gave the minimum percent (1.93%). Calcium has invigorating effects with many enzymes, such as, triphosphate adenosine, arginine, and phospholipase; calcium proves necessary to absorb nitrate nitrogen. As shown in Table 6, the plant under treatment with 1.0 g Nano NPK + 0.5 g/L algae extract and mineral NPK 1.0g/L + 0.5 g/L algae provided better calcium concentrations (2.2% and 1.78%, respectively) compared with the control (0.85%).

Micronutrients

Applying all biostimulant treatments promotes micronutrients to a different degree in onion plants. But Nano NPK + 0.5 g/L algae extracts significantly increased the concentration of all studied parameters: Fe, Mn, Zn, and Cu (Table

Table 6. Effect of biostimulants (Nano NPK with Algae extract) on macronutrient content of onion (combined analysis of two successive winter seasons of 2020–2021 and 2021–2022).

Biostimulant Treatment	Ca	N	P	K	Na
	%				
0.1 g NPK nano + 0.5 g Algae	1.28i	1.53i	0.51i	2.38h	0.22c
0.2 g NPK nano + 0.5 g Algae	1.36h	1.58h	0.56h	2.66g	0.21d
0.4 g NPK nano + 0.5 g Algae	1.45g	1.81g	0.58g	2.91f	0.20e
0.6 g NPK nano + 0.5 g Algae	1.53f	2.11f	0.61f	2.96f	0.19f
0.8 g NPK nano + 0.5 g Algae	1.70c	2.66c	0.70c	4.03c	0.16i
1.0 g NPK nano + 0.5 g Algae	2.20a	2.94a	0.93a	4.71a	0.14k
1.0 g NPK mineral + 0.5 g Algae	1.78b	2.75b	0.75b	4.36b	0.15j
1.0 g NPK mineral	1.60e	2.47e	0.64e	3.03e	0.18g
1.0 g NPK Nano	1.62d	2.56d	0.67d	3.29d	0.17h
0.5 g Algae	1.19j	1.28j	0.43j	2.14i	0.24b
Control	0.85k	0.95k	0.38k	1.93j	0.28a

Table 7. Effect of biostimulants (Nano NPK with Algae extract) on micronutrient content of onion (combined analysis of two successive winter seasons of 2020–2021 and 2021–2022).

Biostimulant Treatment	Fe	Mn	Zn	Cu
	ppm			
0.1 g NPK nano + 0.5 g Algae	65.73i	36.9i	90.80h	19.67i
0.2 g NPK nano + 0.5 g Algae	67.10h	37.7h	92.60g	20.53h
0.4 g NPK nano + 0.5 g Algae	76.53g	41.8g	93.53f	23.27g
0.6 g NPK nano + 0.5 g Algae	89.67f	42.3f	95.43e	26.47f
0.8 g NPK nano + 0.5 g Algae	196.10c	62.5c	97.93c	28.47c
1.0 g NPK nano + 0.5 g Algae	219.10a	76.4a	104.23a	32.27a
1.0 g NPK mineral + 0.5 g Algae	206.73b	69.1b	101.80b	30.80b
1.0 g NPK mineral	159.40e	58.9e	96.53d	27.27e
1.0 g NPK nano	165.60d	59.5d	97.70c	27.73d
0.5 g Algae	64.50i	35.4j	88.57i	17.33j
Control	42.77j	33.6k	81.43j	16.40k

7). For example, iron increased from 42.77 ppm of control treatment to 219.10 ppm at the highest rate of 1.0 g/L Nano NPK + 0.5 g/L algae, and manganese rose from 33.6 ppm of control treatment to 76.4 ppm at the highest rate of 1.0 g/L Nano NPK + 0.5 g/L algae. Zinc and copper increased from 81.43 and 16.40 ppm of the control treatment to 104.23 and 32.27 ppm, respectively, at the maximum rate of 1.0 g/L Nano NPK + 0.5 g/L algae.

Rank correlation coefficients

Table 8 mentions the values of the simple correlation coefficient (r) for the interactions of Chl a, Chl b, carotene, plant height, bulb diameter, fresh weight, fresh yield, protein, starch, and sugar in onions. The correlation coefficients (r) between fresh yields and all examined characteristics were positive and significant ($P < 0.05$). A favorable and substantial ($P < 0.05$) association between fresh yields and nutritional content was also prominent. Furthermore, there was a positive and significant ($P < 0.05$) association between fresh yields and protein, starch, and sugar levels (0.959, 0.973, and 0.943, respectively). On the other hand, substantial negative associations appeared between Na % and Chl a, Chl b, carotene, plant height, bulb diameter, fresh weight, fresh yield, protein, starch, and sugar. It could be detectable that the rest of the characters correlated positively with each other, indicating that the agronomist should consider these factors when choosing the biostimulant (nano NPK and algae extract) therapies to increase onion plant outputs.

Table 8. Correlation coefficients among various parameters.

Characters	Chl a	Chl b	Carotene	Plant height	Bulb diameter	Fresh weight	Fresh yield	Protein	Starch	Sugar
Chl b mg/g f w	0.932									
Carotene mg/g f w	0.959	0.892								
Plant height cm/plant	0.932	0.937	0.939							
Bulb diameter cm/plant	0.949	0.901	0.987	0.970						
Fresh weight	0.918	0.885	0.915	0.975	0.953					
Fresh yield	0.919	0.885	0.915	0.975	0.953	1.000				
Protein %	0.954	0.883	0.975	0.946	0.984	0.959	0.959			
Starch %	0.916	0.910	0.905	0.972	0.932	0.973	0.973	0.923		
Sugar %	0.931	0.940	0.946	0.991	0.967	0.943	0.943	0.928	0.954	
N %	0.954	0.883	0.975	0.945	0.984	0.959	0.959	1.000	0.922	0.927
P %	0.939	0.945	0.948	0.993	0.970	0.950	0.950	0.938	0.963	0.995
K%	0.925	0.899	0.930	0.971	0.948	0.969	0.969	0.930	0.993	0.961
Na %	-0.975	-0.913	-0.994	-0.937	-0.979	-0.918	-0.918	-0.976	-0.911	-0.945
Ca %	0.954	0.955	0.952	0.977	0.969	0.929	0.929	0.940	0.937	0.989
Fe ppm	0.892	0.846	0.893	0.927	0.921	0.977	0.977	0.957	0.951	0.888
Mn ppm	0.887	0.865	0.893	0.956	0.930	0.986	0.987	0.951	0.961	0.919
Zn ppm	0.974	0.936	0.982	0.953	0.974	0.920	0.920	0.959	0.913	0.966
Cu ppm	0.947	0.872	0.975	0.959	0.991	0.963	0.963	0.987	0.924	0.943

DISCUSSION

The results confirmed that adding biostimulants (nano NPK and algae extract) increased vegetative growth characteristics significantly (plant height, fresh weight, bulb diameter, and fresh yield), chemical compositions (carotene, Chl a, Chl b, protein, starch, and sugar), and nutrients content (Tables 4-7). The best result came from the treatment of 1.0 g/L Nano NPK plus 0.5 g/L algae in most of the measured parameters, which have a positive and significant ($P < 0.05$) correlation coefficient (r). Biostimulants offer new ways to modify and alter physiological processes in plants to promote growth, reduce stress, and increase yields. They can affect plant productivity as direct plant or soil responses to the effects of biostimulants or as indirect responses of biostimulants to soil and plant microbiomes (Yakhin *et al.,* 2017). It already had verifications that dimension reduction by physical or chemical methods increased the surface mass ratio of fertilizers, indicating a significant increase in nutrient absorption. Two main mechanisms have been recognized in biostimulation by way of nanomaterials. The first consists of the preliminary interactions of the nanomaterials with the cell surface, inducing signals that trigger positive responses in plants. The second mechanism is due to the internalization of nanomaterials, where their content becomes available for different metabolic functions of plants (Gonzales-Morales *et al.,* 2022). In that way, slow, targeted and more efficient nutrient release becomes possible, allowing (i) a discount of dosages and application costs, (ii) a significant reduction of nutrient losses, and consequently, (iii) an extension of nutrient use efficiency. An estimate implies that to achieve nutrient use effectively, using nano-agrochemicals rather than conventional products could be 20%–30% more effective (Kah *et al.,* 2018).

The previous explains the results obtained, especially for the macro- and micronutrients shown in Tables 6 and 7. Spraying onions with biostimulants significantly affected the percentage of some macro and micronutrients in the onion plant. Applying Nano NPK at a rate of 1.0 g/L + 0.5 g/L algae, followed by mineral NPK at a rate of 1.0 g/L + 0.5 g/L algae resulted in the highest nutrient values, whereas spraying with water (the control treatment) gave the lowest values. Nitrogen, phosphorus, and potassium concentrations ranged from 0.95%, 0.38%, and 1.93% (control treatment) to 2.94%, 0.93%, and 4.71% (1.0 g/L Nano NPK + 0.5 g/L algae extract), respectively, and the micronutrients Fe, Mn, Zn, and Cu concentrations ranged from 42.77%, 33.6%, 81.43%, and 16.40% (control treatment) to 219.10%, 76.4%, 104.23%, and 32.27% (1.0 g/L Nano NPK + 0.5 g/L algae extract), correspondingly. The smaller size, the higher the specific surface area, and the reactivity of biostimulants (nanofertilizers) may affect nutrient solubility, diffusion, and availability to plants (Singh *et al.,* 2013; Nemtinov *et al*., 2021; Billa *et al*., 2022; Maharijaya *et al*., 2023). The use of nanoscale fertilizers may additionally assist in minimizing nutrient loss through leaching or run-off, restricting its speedy degradation and volatility, improving the nutrient quality and fertility of the soil, and promoting crop productivity in the long run (Rautela *et al.,* 2021).

Nutrients, especially NPK, are essential for the growth and improvement of plants, specifically during the cell division and enlargement phases of progress. Therefore, improving the plant's nutritional status using biostimulants continued with significant growth in characteristics compared with the control. Foliar application with biostimulants had a remarkable enhancement in vegetative parameters compared with the control treatment. The highest values of plants' height were 108.7 and 95.7 cm/plant, and plants' fresh weight were 254.70 and 233.68 g/plant at 1.0 g/L Nano NPK + 0.5 g/L algae and 1.0 g/L mineral NPK + 0.5 g/L algae, compared with 62.3 and 100.23 g/plant in the control treatment (Table 4). These results agree with Mahmoud and Swaefy (2020), who mentioned that the onion plant height significantly increased as nitrogen fertilizer rates intensified.

This positive impact of biostimulants on growth parameters as a result of nutritional balance also came from increased chlorophyll content, photosynthetic rate, and rate of assimilation (Saleh *et al.,* 2010), increasing most vegetative parameters and an extended yield per head, while the previous increase in vegetative plant growth may also be due to more nitrogen and other nutrients at low doses (nanofertilizer foliar application) compared with standard nitrogen referring to the importance of nitrogen as a building block of amino acids, proteins, nucleic acids, pigments, and many enzymes. Gosavi *et al.* (2017) said the beneficial effects of N, P, and K in the leaf on maintaining leaf quality and carbon balance and improving photosynthetic capacity are well-documented. The resulting improvement in the content of chlorophyll and other pigments, as well as an increase in the rate of photosynthesis from biostimulants' use, caused an increase in the production of sugars and starch. There was a solid rise in some chemical composition (quality parameters) of onion content with amplifying nano NPK concentrations plus algae extract. It gave the highest starch and sugar content when applied with 1.0 g/L Nano NPK + 0.5 g/L algae at 8.25% and 10.72%, respectively. It was 2.87% and 3.83% in the control treatment, respectively (Table 5). Nanofertilizers and algae distillates increase the availability of plant nutrients for a longer duration and slow release with plant growth, increasing the composition of chlorophyll, photosynthesis, and dry matter production, improving overall plant growth (Al-juthery *et al.,* 2018).

The different significant effects of the levels of growth biostimulants on the plant's nutritional status, the chlorophyll and protein contents, the rate of photosynthesis, and the production of sugar and starch finally manifested in the onion yield. As shown in Table 4, the highest fresh yield (25.67 t/ha) emerged at 1.0 g/L Nano NPK + 0.5 g/L algae, while spraying with the control treatment gave the lowest value at 10.09 t/ha. The positive impact of nano NPK and algae extract as biostimulants on the composition of onion plant content may refer to the presence of macronutrients, suggesting that nano-engineered N, P, and K fertilizers appeared to enhance the uptake and effective use of nutrients by the plants (Abdel-Aziz *et al.,* 2016). In line with these outcomes, Ekinci *et al.* (2014) reported the foliar application of liquid nanofertilizer improved plant growth and cucumber yield. These results align with findings by earlier workers (Kole *et al.,* 2013; Sirisena *et al.,* 2013) who studied the importance of nanofertilizers to improve the plant's properties and concluded that applying Nano-K fertilizer increased rice grain yield. These results also agree with Ekinci *et al.* (2014), Liu and Lal (2014), Aryanpour *et al.* (2017), Afify *et al.* (2019), Merghany *et al.* (2019), and Bakry *et al.* (2022).

As shown in Table 8, positive and significant (*P* < 0.05) correlation coefficients (r) among fresh yields and all studied characters were 0.959 in protein, 0.973 in starch, 0.943 in sugar, 0.959 in N, 0.950 in P, and 0.969 in K, and the negative correlation with Na was -0.918. The increase in growth rate does affect the photosynthetic process with the overuse of nanoparticles, raising productivity, followed by an increase in dry matter in the tank water and increased gain. These effects are comparable to those that occur together via Al-juthery and Al-Maamouri (2020), who determined that nanofertilizers increase the availability of nutrients for plants; they have released longer and more appropriately according to the growth of plants, thus increasing the production of chlorophyll, the rate of photosynthesis, and overall plant growth. Finally, these results confirmed that biostimulants (nanofertilizers with algae extracts) enhanced vegetative growth, yield, and quality of onion. However, further research is necessary to validate the presented findings in other crop species.

CONCLUSIONS

The nano NPK application with algae extract as biostimulants has clear advantages for improving the growth, yield, and chemical composition of onion plants. It works together with traditional fertilizers to enhance nutrient uptake for optimum growth. With this, it is impossible to foresee how long-term use of biostimulants may affect ecosystems and food chains.

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