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Response of wheat to cyanobacteria and compost tea applications as a tool to achieve bio-organic farming concept

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Abstract

Increasing wheat output while decreasing the usage of chemical fertilizers is a significant policy considering the current economic conditions the world is going through. Thus, there is necessity for encourage eco-friendly techniques to add benefits to wheat growth and productivity while also reducing chemical fertilizers requisite. The current study was carried out to evaluate the impact of a potent strain (*Nostoc calcicola*), its extract, and compost tea solely or in combination on growth and productivity of wheat plants. The results support our hypothesis that the combined treatment significantly enhanced wheat growth, nutrients uptake, photosynthetic pigments, yield, and its components as well as the nutritional value of wheat grains and straw by using 50% dose of the required quantity of chemical fertilizers. Our findings suggested that combining cyanobacteria and compost tea to improve wheat plant growth, productivity and yield quality attributes might be a simple and cost-effective strategy.

Keywords: Wheat; Cyanobacteria; *Nostoc;* Compost tea; Cyanobacterial extract; Nutrients uptake; Growth; Yield

1. Introduction

Bread wheat (*Triticum aestivum*, L.) has been considered the first strategic food crop in Egypt for more than 7000 years. It is used to make bread, as well as for some industrial purposes and as a major source of straw fodder for animal feed. Recently, an extraordinary consideration of a few studies has been coordinated to improve wheat efficiency in order to close the gap between Egyptian creation and utilization by expanding the developed region and wheat yield per unit region [1]. Wheat production per unit land area could be increased by using high yielding varieties and implementing some agronomic practices, particularly added nitrogen fertilization [2]. However, the excess of chemical fertilizers causes serious environmental problems such as alteration of pH and structure of soil as well as reduction in the enzyme activities of microbes [3]. Moreover, due to the low absorption rate of chemical fertilizers by plants, which is only about 50%, environmental issues such as leaching, runoff, emission, and eutrophication of waterways have become significant [4]. The World Health Organization (WHO) intends to use the "Green Revolution" to improve world food production by around 50% by 2029. This strategy will help to increase agricultural productivity and reduce the risks related with the use of chemical fertilizers to the environment and human health. Hence, the use bio and organic fertilizers is one of the majorities of alternative methods for sustainable agriculture [5].

Cyanobacteria, a group of photosynthetic gram-negative bacteria, are the most abundant group of microorganisms on the earth, especially in freshwater and marine environments [6, 7]. Cyanobacteria are beneficial for the production of eco-friendly biofertilizers which are costly low and easily available. These biofertilizers containing-cyanobacteria can improve nitrogen viability, improve soil properties such as soil aeration and water holding capacity, and provide vitamins such as B12 [8]. Cyanobacteria do not require a host in order to grow, develop, and produce useful products,

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whereas cyanobacteria's have several functions such as, improve soil aggregates via production of adhesive substances, excretion of plant hormones, vitamins, and amino acids, improve the soil's ability to retain water, decrease the salinity of soil, production of organic acids which increase P availability in soil, and adsorb heavy metals on their surface [7, 9]. Also, cyanobacteria can be used as a liquid fertilizer for hydroponic cultivation, this liquid fertilizer include growth substances such as growth hormones, enzymes, polysaccharides and antibiotic agents [10]. Several studies have reported that inoculation with cyanobacteria added values to plants especially rice plant, for instance Jaiswal et al. [11] found that inoculating rice crops with *Anabaena* sp. increased growth, productivity, and N/P economy via nitrogen fixation and P solubilization mechanisms of the potent cyanobacterial strain. However, few studies have used cyanobacteria as a biofertilizer in wheat fields.

Compost tea (CT) is an organic liquid fertilizer made from high-quality compost that contains beneficial microorganisms and chemicals capable of protecting and stimulating plant development. It is gaining popularity as a means of increasing the production of conventional and/or organic crops [12]. Compost tea contains many of microorganisms which contribute to growth of plant and pathogens depression through several mechanisms (direct and indirect) such availability of plant nutrients via biological nitrogen fixers, macro- and microelements dissolvers, and biocontrol of pathogens via biological antibiotic agents [13]. Previous researches indicated that extracts of compost improve plant health, both growth, yield and quality, whereas, Vanishri and Anil [14] mentioned that the application of compost tea improve growth and physiological response of rice.

In the same concept, the objective of the present work was to study the impact of cyanobacteria, its extract, and compost tea solely or in combination on growth and productivity of wheat plants. We hypothesized that treated wheat plant with a potent cyano-strain (*Nostoc calcicola*) and its extract as well as tea compost will be added benefits for the wheat growth and productivity as well as reduce chemical fertilizers requisite under the current global economic conditions.

2. Material and methods

2.1. Experimental design

A pot experiment was carried out at the greenhouse of Faculty of Agriculture, Mansoura University, during the winter season of 2019/2020 to study the comparison between bio-fertilization as inoculants of cyanobacterial strain (*Nostoc calcicola*) and its extract as well as tea compost on the wheat growth and yield. The experiment was arranged as a completely randomized block design (CRBD) with three replicates. Pots (35 cm height and 30 cm in diameter) were filled with 8 kg soil. Clay loam soil was used, some physicochemical and biological properties are shown in Table (1).

Table 1 Physicochemical properties of the experimental soil

Property		Value
Particle size distribution (%)	Coarse sand	2.24
	Fine sand	23.51
	Silt	42.00
	Clay	32.26
Chemical analysis	pH	7.97
	EC	0.7
Cations ($meq\ L^{-1}$)	Ca^{++}	68.01
	Mg^{++}	34.50
	Na^{+}	397.17
	K^{+}	8.33
Anions ($meq\ L^{-1}$)	CO_3^{-}	0.00
	HCO_3^{-}	725.17
	Cl^{-}	143.54
	SO_4^{-}	0.00

pH (1:2.5); EC (electrical conductivity dsm^{-1})

The treatments were performed as follows: T1=Control (100% N), T2= *Nostoc calcicola*, T3= Compost tea, T4= *Nostoc calcicola* **e**xtract, T5= *Nostoc calcicola* + Compost tea, T6= *Nostoc calcicola* extract + Compost tea. Wheat grains (*Triticum aestivum* L.) cv. Gemmiza12 were obtained from Wheat Research Institute, Agricultural Research Center (ARC), Kafr El-Sheikh, Egypt. Thereafter, the seeds were surface sterilized with 1% sodium hypochlorite for 5 min then washed with sterilized water. Ten seeds were cultivated in each pot, then, after germination, only three uniform plants/per pot were left by plants thinning. Pots were irrigated whenever demanded by adding amount of water fulfilling the capacity of field. Nitrogen fertilizer was added as urea (46% N) in two equal doses. Phosphorus fertilizer was added as calcium superphosphate (15.5% P_2O_5). Potassium fertilizer was added as potassium sulphate (48% K_2O). These chemical fertilizers were applied according to the recommendations and rules of the Egyptian Ministry of Agriculture, Cairo, Egypt. The bio and organic treatments received only 50% of the recommended doses of nitrogen fertilizer.

2.2. Cyanobacterial inoculum preparation

Nostoc calcicola was isolated and identified in our published study, and it was superior as nitrogen fixer and indole acetic acid producer [1]. To preparate the inoculum of *Nostoc calcicola*, BG-11_0 medium [15] was inoculated with a loopful of 21 days old culture, then incubated at 28-30ºC under illumination (5000 lux) for 30 days. One hundred ml of homogenous cyanobacterial growth (1.5x10^7 cfu/ml) was added and mixed into 1 kg of sieved clay soil as a carrier. The soil-based cyanobacterial inocula (SBI) were inoculated to pots 10 days after wheat sowing at the rate of 10 kg SBI/fed.

2.3. Compost Tea

Compost tea was kindly obtained from Agricultural Microbiology Department, Agricultural Research Center, Sakha, Kafr El-Sheikh, Egypt. Some physicochemical and biological properties of compost tea are shown in Table (2). Compost tea was applied as foliar spray in three equal doses at a rate of (1:5 v/v).

Table 2 Physicochemical and biological properties of compost tea

Property	**Value**
pH	8.20
EC	3.51
Total N (ppm)	148.50
Total P (%)	0.11
NH4-N (ppm)	69.9
NO3-N (ppm)	33.80
Total soluble-N (ppm)	103.7
Available P (ppm)	19.80
DTPA extractable Fe (ppm)	176.90
DTPA extractable Mn (ppm)	23.10
DTPA extractable Zn (ppm)	41.30
DTPA extractable Cu (ppm)	9.50
Total count of bacteria (cfu/ml)	8.7x10^7
Total count of fungi (cfu/ml)	1.3x10^6
Total count of actinomycetes (cfu/ml)	1.2x10^6

2.4. Cyanobacterial extract preparation

Cyanobacterial isolate, *N. calcicola,* was cultured in flasks (500 ml) containing BG-11_0 medium at 28-30°C with constant agitation for 14 days under continuous light (5000 lux), then, cyanobacterial growth was separated and washed with distilled water. Cyanobacterial extract was prepared by grinding the growth with a mortar blender in distilled water.

Five gram of fresh cyanobacterial material in 500 ml of distilled water is considered as 1% Cyanobacterial extract [16]. Cyanobacterial extract was applied as foliar spray in three equal doses.

2.5. Morphological and Yield traits

From each treatment, four plants were randomly collected at 90 days after wheat sowing. Then, different morphological characteristics of plant growth; plant height, root height, number of leaves/plant, plant (fresh & dry) weight, and root (fresh & dry) weight were assessed. Then, wheat yield and its components were determined at harvesting, number of tillers/plants, number of spikes/plants, and weight of 1000-grain. A random sample was taken from threshed grains to measure the 1000-grain weight (g), one thousand air dry wheat grains were weighed.

2.6. Chemical analyses

2.6.1. Photosynthetic pigments

Leaf photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) were extracted by methanol and spectrophotometrically estimated [17].

2.6.2. Mineral nutrients

To determine N, P and K concentrations in plant tissues, 0.2 g dried powder from each sample was digested with a mixture of concentrated sulphoric (H_2SO_4) and per chloric ($HClO_4$) acids, then heated until become clear solution. This solution was quantitatively transferred into 100 ml measuring flask and kept for determinations. Nitrogen was determined using micro Kjeldahl method [18]. Phosphorus was calorimetrically assessed as described by Mousa et al [19]. Potassium was estimated by using Jenway Flame photometer, Model corning 400 as the modified method of Peters et al. [20].

2.7. Statistical analysis

Data were subjected to statistical analysis by using COSTAT (2005) Software of analysis of variance according to Gomez and Gomez [21]. Duncan multiple range test have been used to compare means at p= 0.05 as outlined by Snedecor and Cochran [22]. The correlation between the tested traits was done using Pearson's correlation coefficient by Origin Pro 2021 (9.8.0.200) software.

3. Results

3.1. Wheat growth improved upon different bio and organic applications

For evaluation the effectiveness of the suggested bio and organic treatments on wheat growth and productivity, certain parameters such as shoot & root length, shoot & root fresh weight, shoot & root dry weight, leaves number, and tillers number were monitored in the designed pots experiment. Represented data of the morphological parameters as affected by different bio and organic applications are recorded in Table (3). Overall, shoots and root length as well as fresh and dry weights of wheat plant, were significantly improved by dual bio and organic treatments. Nonetheless, bio and organic treatment (*Nostoc calicola* + compost tea) significantly resulted in maximum shoot and root length (78.36 and 15.53 cm) with an increment of 10.05 and 18.91%, respectively compared with the control plants. As well as the maximum plant biomass (fresh and dry weights) was recorded also with the previous treatment with an increase of 18.91 and 29.20% for fresh weight of shoot and root as well as 26.98 and 53.73% for dry weight of shoot and root, respectively comparing with their corresponding control plants. Moreover, it was found that root/shoot ratio recorded significantly highest values with dual bio and organic treatments, both *Nostoc calicola* and its extract combined with compost tea (Fig.1). However, the number of leaves and tillers per plant did not show any significant improvement according to any of bio and organic applications compared with their corresponding control. Such findings indicate that the dual treatment of *Nostoc calicola* + compost tea can improve wheat growth by using 50% dose of the required quantity of chemical fertilizers.

Table 3 Growth parameters of wheat plants treated with cyanobacteria, extract, compost tea alone or in combination

Treatments	Shoot length (cm)	Root length (cm)	Shoot FW (g plant $^{-1}$)	Root FW (g plant $^{-1}$)	Shoot DW (g plant $^{-1}$)	Root DW (g plant $^{-1}$)	No. Leaves plant $^{-1}$	No. tillers plant $^{-1}$
Control	71.20±1.07c	13.06±0.11f	13.78± 0.19c	2.02±0.45e	6.04± 0.20f	0.67±0.02e	21.3±0.57a	4.3±0.57a
Nostoc	72.89±0.77c	13.75±0.09d	14.16± 0.25c	2.15±0.30d	6.34±0.31d	0.76±0.02d	21.3±0.57a	4.3±0.57a
Tea	75.56±1.04b	14.64±0.07c	14.98± 0.19b	2.38±0.35c	7.11±0.45c	0.88±0.02c	22.0±2.00a	5.0±2.00a
Extract	72.41±1.09c	13.36±0.10e	13.97± 0.18c	2.08±0.05e	6.16± 0.36e	0.71±0.03de	21.3±0.57a	4.3±0.57a
Nostoc+Tea	78.36±1.14a	15.53±0.09a	15.52± 0.21a	2.61±0.35a	7.67±0.40a	1.03±0.02a	22.7±0.57a	5.0±1.00a
Extract+Tea	76.89±0.94ab	15.09±0.08b	15.43±0.73a	2.47±0.35b	7.34±0.31b	0.93±0.02b	22.3±0.57a	5.0±2.00a

Data included are means ± SD; different letters within the same column indicate significant differences between means at P ≤ 0.05 according to Duncan's multiple-range test; FW, fresh weight; DW, dry weight.

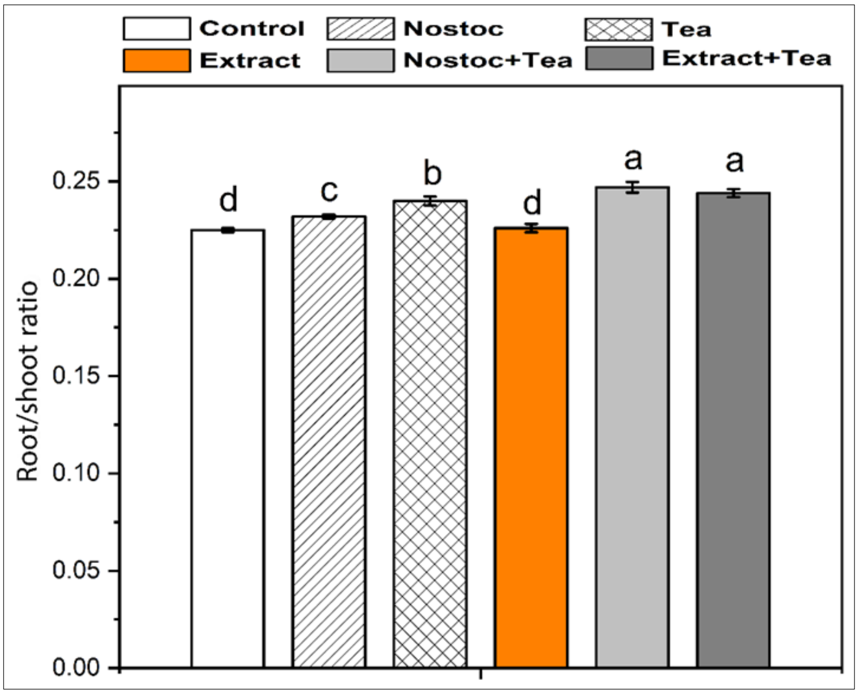

Figure 1 Interaction between bio and organic treatments on the root/shoot ratio on length basis of wheat plants. Different letters indicate significant differences between means at *P* ≤ 0.05 according to Duncan's multiple-range test

3.2. Leaf photosynthetic pigments were improved upon different bio and organic applications

Photosynthetic pigments (Chl a, Chl b, and carotenoids) content in the leaves of wheat plants were enhanced by the dual application of *Nostoc calicola* + compost tea followed by (*Nostoc calicola* extract + compost tea) with an increase of (11.26, 16.27, and 18.91%) and (8.45, 13.95, and 16.21%) for both treatments, respectively (Fig.2). As well as the other individual treatment of *Nostoc calicola*, compost tea, and *Nostoc calicola* extract had a positive effect on photosynthetic pigment contents in leaves of wheat comparing with the control plants.

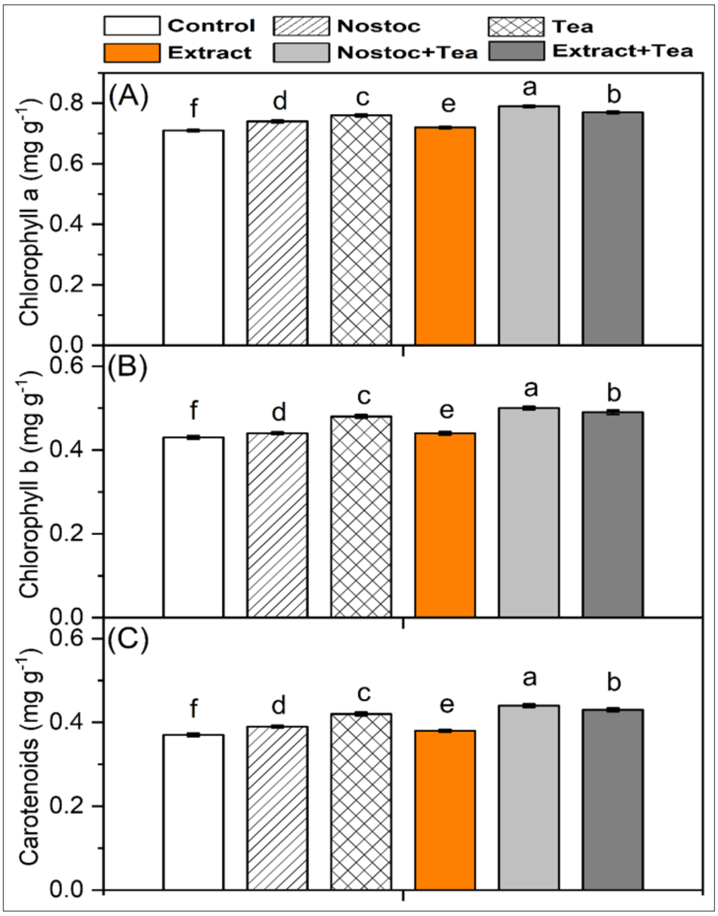

Figure 2 Changes in leaf photosynthetic pigments of wheat plants treated with cyanobacteria, extract, compost tea alone or in combination: (A) chl a, (B) chl b, and (C) carotenoids. Different letters indicate significant differences between means at $P \leq 0.05$ according to Duncan's multiple-range test

3.3. Nutrients uptake were improved upon different bio and organic applications

To ascertain the state of plant nutrition, the contents of essential plant nutrients, such as nitrogen (N), phosphorus (P), and potassium (K) in the shoots and roots of wheat plants were evaluated (Fig. 3). Results revealed that the application of bio and organic fertilizers significantly improved the of N, P, and K in wheat shoots and roots. The maximum value of N, P, and K contents in the shoots and roots of wheat plants those treated by the co-application of *Nostoc calicola* + compost tea with an increment of (17.37, 16.66, and 16.54%) and (20.09, 16.90, and 25.29%) for N, P, and K in shoots and roots, respectively comparing with the corresponding control plants. These results suggested that the applications of dual (bio and organic) fertilizers can increase the availability of essential nutrients to wheat plant and thus improve wheat growth and productivity.

3.4. Yield and its components were improved upon different bio and organic applications

Yield components of wheat plants co-treated with (*Nostoc calicola* + compost tea), as represented by spike weight, number of grains per spike, 100-grains weight, and straw weight were significantly higher compared with control plants with an increase of (21.11, 20, 16.45, and 35.52%), respectively (Table 4). However, the co-application (*Nostoc calicola* Extract + compost tea) resulted in a high number of grains per spike and there is no significant difference between it and the treatment of (*Nostoc calicola* + compost tea). In addition, the co-application (*Nostoc calicola* Extract + compost tea) and the individual treatment of compost tea resulted in a high 100-grains weight and there is no significant difference between them and the treatment of (*Nostoc calicola* + compost tea). Accordingly, these results explored that the bio and organic fertilizers treatments could improve wheat yield its traits.

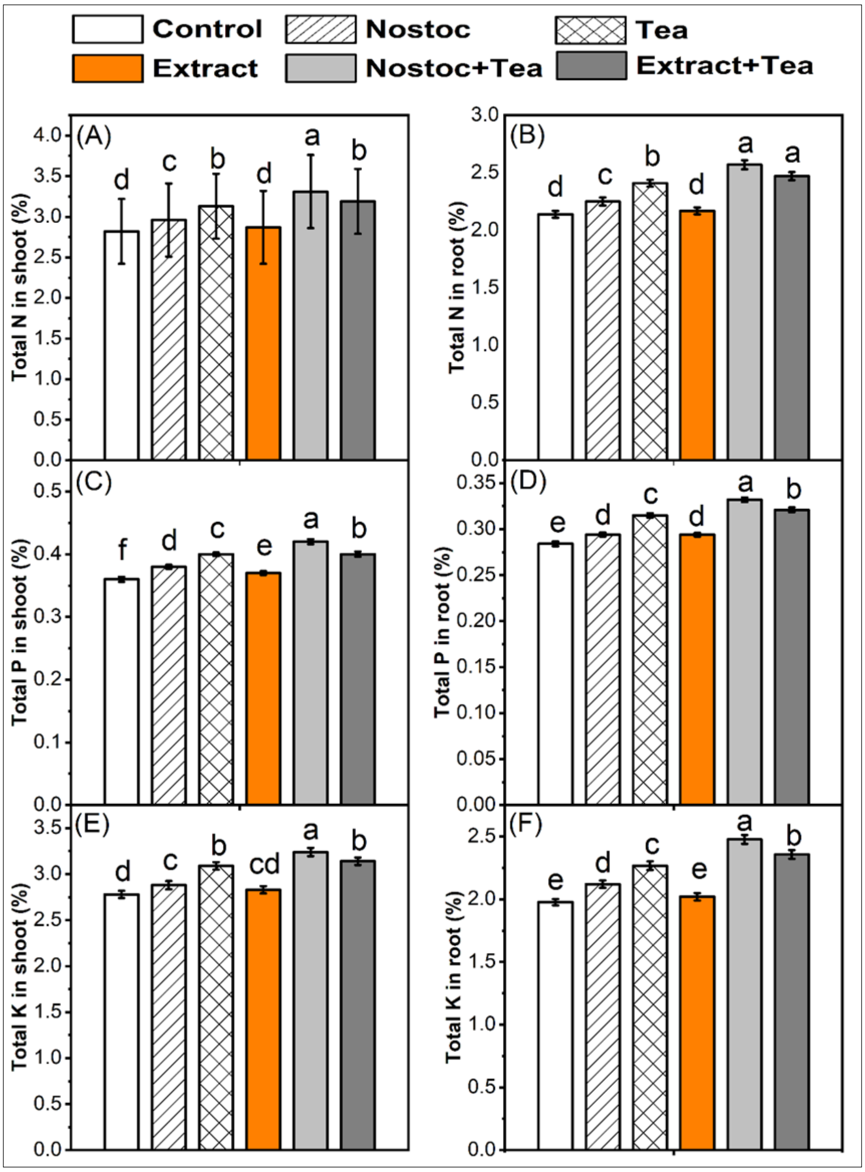

Figure 3 Nutrients (N, P, and K) contents in the shoots (A, C, and E) and in the roots (B, D, and F) of wheat plants treated with cyanobacteria, extract, compost tea alone or in combination. Different letters indicate significant differences between means at $P \leq 0.05$ according to Duncan's multiple-range test

Table 4 Yield parameters of wheat plants treated with cyanobacteria, extract, compost tea alone or in combination

Treatments	Spike weight (g)	No. grains spike $^{-1}$	Weight of 100 grains (g)	Straw weight (g plant $^{-1}$)
Control	3.22±0.040d	60.0±2.00c	4.68±0.070c	8.98±0.141e
Nostoc	3.39±0.050c	63.7±4.04bc	4.96±0.065b	9.86±0.140c
Tea	3.65±0.075b	68.0±2.00ab	5.34±0.075a	11.08±0.155b
Extract	3.28±0.075cd	62.3±2.52c	4.79±0.065c	9.31±0.125d
Nostoc+Tea	3.90±0.55a	72.0±2.65a	5.45±0.070a	12.17±0.155a
Extract+Tea	3.72±0.087b	70.0±2.00a	5.44±0.080a	11.34±0.166b

Data included are means ± SD; different letters within the same column indicate significant differences between means at $P \leq 0.05$ according to Duncan's multiple-range test; FW, fresh weight; DW, dry weight.

3.5. Grains and straw quality were improved upon different bio and organic applications

The nutritional value of wheat grains and straw also have been evaluated in this study. Mean data regarding N, P, and K contents in wheat grains and straw are shown in (Fig. 4). In general, the same trend was observed as the application of bio and organic fertilizers significantly improved the of N, P, and K in wheat grains and straw. The maximum value of N, P, and K contents in the grains and straw of wheat plants those treated by the co-application of (*Nostoc calicola* + compost tea) with an increase of (17.14, 16.50, and 16.29%) and (17.08, 16.41, and 16.44%%) for N, P, and K in grains and straw, respectively comparing with the corresponding control plants. These results indicated that the applications of dual (bio and organic) fertilizers can improve the value of wheat grains and straw, in addition to saving 50% of chemical fertilizers.

3.6. Pearson correlation between wheat yield and nutrients content

Pearson correlation analysis indicated numerous significant correlations between the traits scored (Fig. 5). The asterisks indicate whether the correlation is statistically significant or not for either positive or negative correlations. There are a highly positive correlations between growth parameters, nutrients content, yield and seed quality. A significant correlation was observed between N, P, and K contents of shoot, root, seed, and straw of wheat yield (Fig. 5).

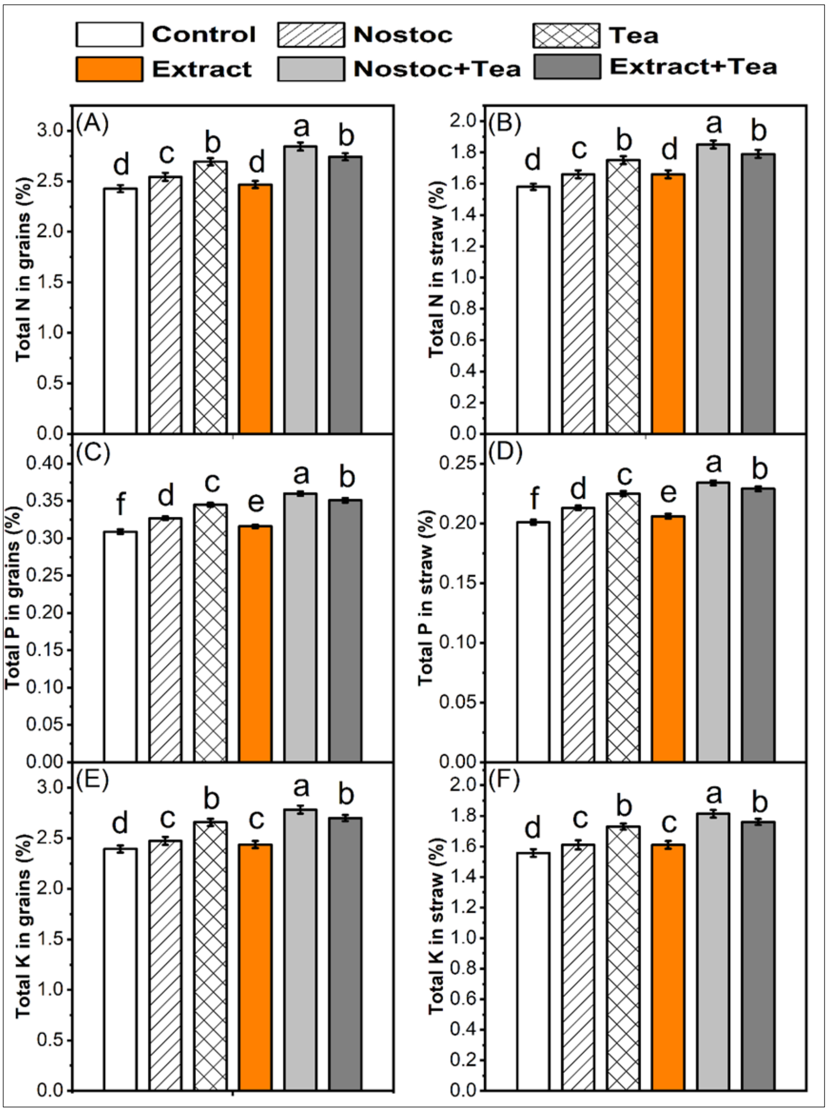

Figure 4 Nutrients (N, P, and K) contents in the grains (A, C, and E) and in the straw (B, D, and F) of wheat plants treated with cyanobacteria, extract, compost tea alone or in combination. Different letters indicate significant differences between means at $P \leq 0.05$ according to Duncan's multiple-range test

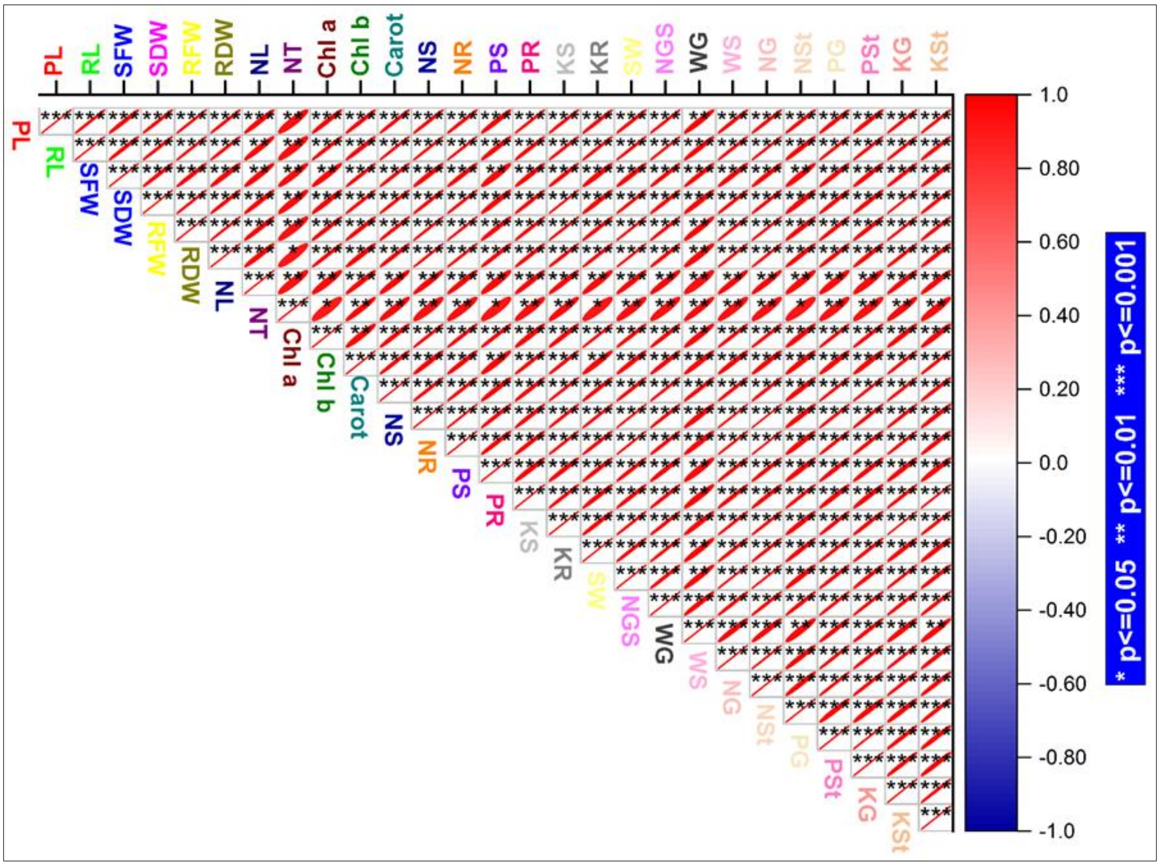

Figure 5 Pearson correlation analysis between wheat growth attributes, photosynthetic pigments, nutrients contents, and yield components (PL plant length, RL root length, SFW shoot fresh weight, SDW shoot dry weight, RFW root fresh weight, RDW root dry weight, NL number of leaves, NT number of tillers, Chl a chlorophyl a, Chl b chlorophyl a, Carot carotenoids, NS nitrogen in shoot, NR nitrogen in root, PS phosphorus in shoot, PR phosphorus in root, KS potassium in shoot, KR potassium in root, SW spike weight, NGS number of grains/spike, WG weight of 100 grains, WS weight of straw, NG nitrogen in grains, NSt nitrogen in straw, PG phosphorus in grains, PSt phosphorus in straw, KG potassium in grains, KSt potassium in straw

4. Discussion

In light of current global conditions, one of the most important strategies of the Egyptian state is to increase wheat yield while reducing the use of chemical fertilizers. In this line, lot of studies have reported the role of beneficial microorganisms to enhance wheat growth and productivity under low rates of chemical fertilizers [23-25]. While there are very few studies on the effective role of cyanobacteria on improving the growth and productivity of wheat plants. Hence, we hypothesized that treated wheat plant with cyanobacteria, its extract, and compost tea solely or in combinations will be given a value for the quantity and quality of wheat as well as reduce chemical fertilizers requisite. The present results confirmed our hypothesis and provided evidence for a synergistic interaction between *Nostoc calicola* and compost tea, which is obviously appeared by increment of wheat growth (Table 3) and yield (Table 4) of dual-treated wheat plants comparing with control plants. Similarly, previous studies have reported the enhance benefits of treatment with cyanobacteria to wheat plants either individually [26] or with plant growth promoting rhizobacteria when used as a consortium [27]. In addition, compost tea could enhance nutrients availability and plant growth [28]. Furthermore, employing cyanobacteria was more efficient than using their extracts in the current investigation. Several quantitative and qualitative mechanisms for cyanobacteria-induced plant growth and production have been postulated. Cyanobacteria have the ability for atmospheric nitrogen fixation [1], production some bioactive materials such as plant growth promotors, enzymes, and vitamins which enhance growth and productivity of plant [29].

Plant' roots traits mostly affect by physical and biological characterization of the soil and depend on concentration of nutrients [30-32]. In addition, plant root traits reported that root/shoot ratio is proportional to availability of nutrients and fertilization supply. The present study showed that response of bio and organic treatments on wheat plant, whereby significantly increment in root/shoot ratio, lead also to an enhancement in plant nitrogen uptake which could be contribute to mineral nitrogen shortage (Fig. 1). Nitrogen deficit increases root/shoot ratio [33, 34]. In free mineral nitrogen soil zones, elongation of roots enhanced and lead to a foraging development of roots [35, 36]. This data also indicates the vital role of bio and organic fertilization in more release of available nutrient elements to be absorbed by plant roots and this in turn increase dry matter content in the different wheat plant organs, in agreement with Radwan and Awad [37] on peanut, Bonifas et al. [39] on corn and velvetleaf, and Chen et al. [40] on cotton.

Bio and organic fertilizers significantly affect phytohormone levels while enhancing nutrient uptake, resulting in metabolic alterations in plants that add value to photosynthetic metabolism [40]. The present results revealed that nutrient elements (N, P, and K) were higher in plants treated with bio and organic fertilizers as well as, leaf photosynthetic pigments were improved due to bio and organic applications either individual or in combination comparing with the control plants (Figs.2-4). Cyanobacteria were shown to enhance the uptake of macro and micro contents in several plants such as tomato [41], wheat [26], mungbean [42], lettuce [43], and radish [44]. In the harmony of our results, Gao et al. [5] reported that chlorophyll content in maize plant was higher in bio and organic fertilizers treatments compared with control plants. In addition, Romanowska-Duda et al. [45] reported an improvement in chlorophyll content in Willow (*Salix viminalis* L.) plants due to the application of cyanobacteria and *Chlorella* sp. The increase in chlorophyll concentration in response to bio and organic fertilizers might be mediated by their stimulating effects on cytokinin production [45], nutrients uptake, particularly Mg [40], and enhancing the activity of ACC-deaminase [46].

The goal of agricultural plants inoculation with bio and organic fertilizers is to increase crop output. Our results indicated that bio and organic fertilizers especially, the co-application of (*Nostoc calicola* + compost tea) improve the yield of wheat plants as well as the quality of grains and straw (Tables 3 and 4). This improvement could be attributed to the ability of our potent cyanobacterial strain to fix nitrogen and produce growth promoting substances such as IAA [1] as well as compost tea which enhance nutrients availability. Thus, more nutrients were translocated to wheat plants which improve yield and quality of wheat (Figs. 3 and 4). Positive effects of cyanobacteria on the productivity of different crops were previously reported. Song et al. [47] demonstrated that biofertilizers of nitrogen-fixing cyanobacteria (NFC) have a great potential in improving fertility of the soil and increment yield of rice paddy. Furthermore, Karthikeyan et al., [48] mentioned to promising cyanobacterial strains; *Calothrix ghosei*, *Hapalosiphon intricatus* and *Nostoc* sp. Which enhanced wheat yield and its components.

5. Conclusion

Based on our findings, co-applying bio and organic fertilizers (*Nostoc calicola* + compost tea) has considerably increased wheat (*Triticum aestivum* L.) cv. Gemmiza12 growth and yield through improving nutrient uptake, photosynthetic pigments, and the nutritional content of wheat grains and straw. Furthermore, this application decreases the requirement for chemical fertilizers by half of the prescribed amount. As a result, this application might be a simple, cost-effective, and efficient method of increasing wheat output while using minimal chemical fertilizers. Nonetheless, further study is needed to enhance plant-microbe interactions and assure biofertilizer efficacy by establishing highly suitable plant genotypes and microorganism strains.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors have read and approved to submit it to World Journal of Advanced Research and Reviews. There is no conflict of interest of any author in relation to the submission.

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