Integrated effects of bacteria and fungi biofertilizers on morphological traits, antioxidants indices, and polyphenol compounds of quinoa (*Chenopodium quinoa Willd.*) under salinity condition

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Abstract

It is imperative to assess the potential of halophyte plant species, such as quinoa, in resisting high salinity levels in arid and semi-arid regions where the productivity of crops is dramatically affected. A factorial experiment based on a completely randomized design with three replications was conducted to explore the effect of integrated biofertilizer, on morphological traits, antioxidants, and polyphenol compounds of quinoa under salinity stress. The studied factors included NaCl salinity stress at three levels of 0, 150, and 300 mM (S_0 , S_{150} , and S_{300} , respectively), Trichoderma (T) fungus at two levels (its use and non-use), and biofertilizer at three levels (control, nitrogen (F_N), and phosphorus (F_P)). The means of the studied traits showed that the highest shoot length and dry weight was related to $S_0T_0F_N$, the highest root length to $S_{150}TF_N$, the highest root dry weight to $S_0T_0F_N$, and the highest phenol and flavonoid contents to $S_{300}TF_P$ and S_0TF_N treatments. Among polyphenols, the highest caffeic acid, rutin, coumaric acid, and quercetin were observed in S_0TF_P , and the highest levels of chlorogenic, rosmarinic, cinnamic acids, and apigenin (mg/kg) were observed in S_0TF_N . To sum up, Bacteria and fungi biofertilizers were effective on the studied traits at the three salinity levels.

Introduction

Quinoa (*Chenopodium quinoa willd*) is an annual dicotyledon pseudocereal from the sub-family spinach that is native to South America and the Andes where its cultivation dates back to thousands of years ago and it is used as an essential source of nutrient⁶⁷. The young leaves of quinoa are consumed fresh as a leafy vegetable like spinach⁴⁵. It is also used as an ingredient in the recipes of many foods. The seeds of quinoa are rich in free gluten and nutritional value, and their protein content is greater than corn and wheat. They also contain a great deal of methionine and lysine when compared to cereals³⁷. Quinoa is also known as a halophyte cereal that is more resistant to environmental stresses, including salinity and water deficit, than barley, wheat, and corn^{25,56}.

Saline soils severely inhibit crop growth and soil productivity⁴³. The best approach to combating soil degradation and saline water is the cultivation of halophyte plant species⁴⁸. Salinity hinders many metabolic processes in plants and affects crop production²⁰. A major adverse impact of salinity is the over-accumulation of Na^+ and Cl^- within cells, which leads to ion imbalance and physiological irregularities. Salinity stress brings about several biochemical, physiological, and morphological changes in plants and affects their growth, photosynthesis, protein synthesis, respiration, and energy production²⁶.

Today, researchers are increasingly paying more attention to the use of microorganisms, such as growth-promoting bacteria, to increase yields²³. Rhizobacters influence plant development and yields and mitigate the risks arising from salt stress in addition to contributing to nitrogen biosynthesis, siderophore production, the dissolution of mineral phosphate, and the production of plant hormones³⁷. As such, it is of crucial importance to develop such techniques as the use of biofertilizers that contain bacteria that biologically enhance stress resistance of plants⁴⁶. It was reported that quinoa had a high tolerance to

salinity in the germination stage, and the application of N and P biofertilizers increased its salinity tolerance so that all recorded morphological traits of the quinoa plants treated with biofertilizers were significantly increased compared to the control⁷. It has been found that biofertilizers, in addition to playing a role in the uptake of specific elements, contribute to absorbing other elements, reducing diseases, improving soil structure, further stimulating plant growth, increasing crop quantity and quality, and enhancing plant resistance to environmental stresses including drought and salinity⁴².

Trichoderma is a soil-borne microorganism, some species of which are known to stimulate plant growth³². (There is a report as to the increased growth of Trichoderma-treated quinoa plants⁴⁷. Trichoderma protects plants from environmental stresses such as salinity and improves their growth and development¹². The fungal strains of the genus Trichoderma are known to produce secondary metabolites with different biological activities. Trichoderma can produce fungal materials that are capable of stimulating plants to produce their own defense metabolites⁶². *Trichoderma* spp. also synthesizes many biologically active compounds, including cell wall-decomposing enzymes⁶³.

By establishing and abundantly sporing in the soil environment, especially in the root zone of most crops, Trichoderma species not only reduce pathogens in the soil but also stimulate the growth of plant roots and shoots by biochemical mechanisms³¹. Antioxidants are essential for coping with oxidative stress. A health benefit of quinoa is related to its nutritional properties, as well as the content of biologically active molecules such as phenolic compounds and their antioxidant activity⁵.

This study aimed to investigate the tolerance of quinoa to different salinity levels along with the effect of biofertilizers and Trichoderma on improving morphological parameters, antioxidants, and leaf polyphenolic compounds and to make some practical recommendations for the development of its cultivation in saline regions.

Materials And Methods

The study was conducted as a factorial experiment based on a completely randomized design with three replications under controlled conditions at the research greenhouse of Agriculture Faculty, Urmia University in 2018. The treatments included salinity at three levels (0, 150, and 300 μM NaCl), Trichoderma at two levels (no fungus and with fungus), and biofertilizer at three levels (0, N, P). The soil was sampled and analyzed before the experiment was initiated (Table 1). Fifty-four 6.5-kg pots containing sterilized soil and sand at a 3:1 ratio were prepared and the soil sample was tested for its composition. Trichoderma was added to each pot at a rate of 7.5 g, and the seeds of quinoa cv. 'Titicaca' were cultivated. The seeds that were supposed to be treated with biofertilizer were impregnated with fertilizer for half an hour. Azotobaror-1 biological fertilizer, which contains the bacteria of *Azotobacter vinelandii* strain O4, was used as N biofertilizer, which actively fixes atmospheric nitrogen in an absorbable form for plants. Barvar-2 phosphate biofertilizer was used as P biofertilizer. It contains two types of phosphate-solubilizing bacteria from the genus Pantoea (strain P5) and *Pseudomonas putida* (strain P13). After the seeds germinated, six plants were finally kept in each pot. The different rates of salt

stress were applied to the plants at the one-month (6-leaf) stage, and 10 days later, the plants were harvested. Total phenolic content was determined by Folin-Ciocalteu reagent⁶⁰. The flavonoid content of the extract was estimated by Zhishen et al.'s (1999)⁷¹ procedure. Also, the HPLC values were determined using a high-performance liquid chromatography device (model series 1100, Agilent, USA) equipped with a 20-µl injection loop, a four-solvent gradient pump, a degassing system, an oven stone, and a diode array detector, adjusted at 250, 272, and 310 nm⁵⁸. The data were statistically analyzed using SAS software version 9.4. The means were compared using the PLSD test at the $P < 0.05$ level, and MS-Excel software was used to draw the graphs.

Table 1
The physico-chemical characteristics
of the soil at the study site

Measure parameter	Value
Salinity (dS/m)	0.65
Soil texture	Loam-clay
pH	6.7
Clay (%)	36
Silt (%)	55
Sand (%)	9
Organic carbon (%)	0.20
OM (%)	0.34
CaCO ₃ (%)	27.5
P (mg/kg)	11
K (mg/kg)	290

Results

Morphological parameters

The analysis of data variance showed that the morphological and antioxidant parameters of quinoa were significant at the $P < 0.01$ level (Table 2).

Table 2

The results of the variance analysis for the effect of salinity, biofertilizer, and Trichoderma on morphological traits and antioxidant of quinoa

Sources of variations	df	Shoot length (cm)	Shoot dry weight (g)	Root Length (cm)	Root dry weight (g)	Phenols (mg gallic acid g DM ⁻¹)	Flavonoids (mg gallic acid g DM ⁻¹)
Replication	2	1.185 ^{ns}	0.014 ^{ns}	1.865 ^{ns}	0.003 ^{ns}	7.749 ^{ns}	0.00001 ^{ns}
A	2	284.129 ^{**}	1.753 ^{**}	61.99 ^{**}	0.067 ^{**}	1267.38 ^{**}	0.0041 ^{**}
B	1	4.16 ^{ns}	0.698 ^{**}	0.155 ^{ns}	0.006 ^{ns}	1615.18 ^{**}	0.0003 ^{**}
C	2	364.462 ^{**}	14.878 ^{**}	45.48 ^{**}	0.329 ^{**}	572.93 ^{**}	0.0012 ^{**}
AB	2	6.16 ^{ns}	3.209 ^{**}	31.28 ^{**}	0.043 ^{**}	1374.12 ^{**}	0.00004 ^{ns}
AC	4	100.462 ^{**}	5.889 ^{**}	37.71 ^{**}	0.145 ^{**}	1625.97 ^{**}	0.0001 ^{**}
BC	2	92.72 ^{**}	3.587 ^{**}	1.09 ^{ns}	0.053 ^{**}	3345.46 ^{**}	0.0002 ^{**}
ABC	4	72.38 ^{**}	4.598 ^{**}	178.55 ^{**}	0.058 ^{**}	365.43 ^{**}	0.0004 ^{**}
Experimental error	34	2.518	0.083	1.76	0.002	59.52	0.00002
Coefficient of variation		3.698	8.468	6.09	11.66	11.81	7.039
ns: non-significant; * and **: significant at the P < 0.05 and P < 0.01 levels, respectively.							

Shoot length

The highest shoot length (cm) was obtained from the treatment of S₀T₀F_N, which was different from the other treatments significantly. The lowest was related to S₃₀₀T₀F_P, but it did not differ from that of S₃₀₀T₀F_N and S₃₀₀T₀C significantly. The plants treated with P biofertilizer (F_P) at the salinity level of 300 µM grew longer shoot when they were exposed to Trichoderma than when they were not (Fig. 1).

Shoot dry weight

The highest shoot dry weight (g) was obtained from the plants treated with S₀T₀F_N, which was different from the other treatments significantly. The lowest one was related to S₀T₀C and S₃₀₀T₀C, but they did not differ from S₃₀₀T₀F_N and S₁₅₀T₀F_P significantly (Fig. 2).

Root length

The plants treated with $S_{150}TF_N$ grew the longest roots (cm) and differed from the plants exposed to the other treatments significantly. The lowest root length was observed in $S_{300}TF_N$. In the salinity levels of 0 and 300 μM treated with the biofertilizer F_N and T, root length was decreased (Fig. 3).

Root dry weight

The $S_0T_0F_N$ -treated plants showed the highest root dry weight (g), differing from the other treatments significantly, and the plants treated with $S_0T_0F_P$ and $S_{300}TF_N$ exhibited the lowest one. The plants treated with the biofertilizer N (F_N) at the salinity level of 300 μM (S_{300}) exhibited lower root dry weight when they were exposed to Trichoderma (T) than when they were not (Fig. 4).

Antioxidants

Phenol

The highest phenol content (mg gallic acid per g dry matter) was related to the treatment of $S_{300}TF_P$, but it did not differ from the treatments of $S_{300}TF_N$, $S_{150}T_0C$, and S_0T_0C significantly. The lowest was related to $S_0T_0F_N$ (Fig. 5).

Flavonoid

The treatment of S_0TF_N gave rise to the highest flavonoid content (mg gallic acid per g dry matter), not differing from S_0TF_P significantly. The lowest was obtained from $S_{150}T_0C$, which was not different from $S_{300}TC$ significantly (Fig. 6).

HPLC

The highest amounts of caffeic acid, rutin, coumaric, and quercetin were related to S_0TF_P and the highest amounts of chlorogenic, rosmarinic acid, cinnamic acid, and apigenin (mg/kg) were observed in S_0TF_N (Fig. 7).

Discussion

Morphological traits

The results show that salinity stress at the rate of 150 mM salt (S_{150}) increased quinoa growth, which is the normal halophytic behavior of this plant and is consistent with the report of Parvez et al. (2020)⁴⁸. But, at 300 mM salt (S_{300}) treatment, shoot growth was decreased, which is supported by the reports of Becker et al. (2017)¹⁰ and Parvez et al. (2020)⁴⁸. The significant reduction in shoot length at high salinity (S_{300}) seems to be associated with different responses, including changes in nutrient uptake, cellular

homeostasis, and metabolic pathways of plants exposed to salinity stress⁴⁹. Osmotic damage, ion toxicity, and changes in the balance of available nutrients are some factors involved in the loss of plant height in saline environments. The decline of plant height under salinity has also been ascribed to physiological dryness of the root zone and competition between the ions of chlorine, sulfate, and nitrate⁷⁰. Salinity stress in the early stages causes osmotic stress, which reduces the water content of cells and inhibits their elongation, and even after osmotic balance and cell turgor are restored, they expand and elongate slowly⁴¹.

The highest shoot and root length and dry weight were observed in the treatment of $S_0T_0F_N$ at the salinity level of 0 mM (S_0) and in the treatment of $S_{300}T_0F_N$ at the salinity level of 300 mM (S_{300}). The results indicate that at the salinity levels of 0 and 300 mM, the N biofertilizer increased growth when the plants were not treated with Trichoderma ($S_0T_0F_N$). The biofertilizer Azotobarvar-1 (containing *Azotobacter*) is a selective molecular nitrogen fixer that can synthesize and secrete some biologically active substances in the root zone and improve the root system, thereby influencing the uptake of water and nutrients, biological N fixation, crop yields, and soil properties². Shoot and root length and dry weight were significantly increased by the treatment of $S_{150}TF_N$ compared to other treatments at the salinity level of 150 mM. In addition to fixing N and making a balance in nutrient uptake, bacteria of biofertilizers synthesize plant growth promoters and different acids, thereby enhancing root and shoot growth and development, and this, in turn, contributes to more assimilation and its mobilization to other parts⁷.

Trichoderma seems to have an increasing effect on *Azotobacter* activity at the salinity level of 150 mM, which is normal salinity for quinoa as a halophyte plant, but Trichoderma at the salinity levels of 0 mM (S_0) and 300 mM (S_{300}) had an antagonistic effect on *Azotobacter* activity, which eventually reduced the growth of quinoa. The antagonistic ability of Trichoderma with bacteria has been reported⁶⁴. It has been suggested that the acidification of the buffer by Trichoderma inhibits plant growth⁵⁰. This can affect the interaction of Trichoderma with other organisms and bacteria and even with the plant itself too. At the salinity level of 0 mM, the application of P biofertilizer increased shoot dry weight and root length and decreased root dry weight compared to the control at the same salinity level. The interactive effect of Trichoderma and P biofertilizer was not significant on morphological characteristics at the salinity level of 0 mM. In summary, inhibition of plant growth and lack of lateral root growth during simultaneous cultivation of *C. quinoa* with biological control strains of Trichoderma under axenic conditions indicates that Trichoderma, especially growth regimes, can damage plants. The mechanisms of this injury may explain the exceptional cases of increased growth observed in the treated soil-grown crops⁵⁵.

However, at 150 mM salinity, the application of P biofertilizer reduced shoot length and dry weight and root dry weight and increased root length versus the control at the same salinity level. Biofertilizers have been reported to increase uptake by root through increasing root development⁶⁹. The application of Trichoderma along with P biofertilizer significantly reduced root length increase, had no significant effect on shoot length, but increased shoot dry weight significantly. It can be inferred from these results that at high salinity (300 mM), the application of Trichoderma along with phosphate-solubilizing bacteria

influenced plant growth positively, and this effect was significant on length. The phosphate biofertilizer Barvar-2 contains phosphate-solubilizing bacteria that secrete organic acids and acid phosphatase and convert insoluble phosphorus in soil (especially in areas with high soil calcium) into a plant-absorbable form²⁸. The interaction of a plant with beneficial microbes varies greatly depending on the genotypes and may range from growth inhibition to growth enhancement and vigorous growth⁵⁴. Different species of *Trichoderma* are used for their ability to enhance plant growth and development and their ability to grow in adverse conditions⁶⁶. It seems that *Trichoderma* in the salinity level of 300 mM salt had an increasing effect on the activity of phosphate-solubilizing bacteria and ultimately increased the growth of quinoa in high salinity.

Trichoderma treatment without the presence of bacteria at the salinity level of 150 mM salt ($S_{150}TC$) decreased root length significantly compared to the control ($S_{150}T_0C$). *Trichoderma* had no significant effect on shoot growth and root biomass. At 0 and 300 mM salinity levels, *Trichoderma* without the presence of bacteria ($S_{300}TC$) increased shoot length and dry weight significantly compared to the control treatment at the same salinity levels. There are reports as to the increased growth of some plant species, including quinoa, when they were treated with *Trichoderma*⁴⁷.

By secreting fungal metabolites, activating growth regulating signals and plant growth-responsible phytohormones, and increasing the solubility of soil nutrients, *Trichoderma* can increase plant growth^{6,16}.

Antioxidants

Total phenol

At the salinity level of 0 mM, the control treatment (S_0T_0C) and at the salinity level of 150 mM, the treatment of $S_{150}T_0C$ was related to the highest total phenol. This shows that at the salinity level of 0 mM, the application of biofertilizers and *Trichoderma* alone or in combination reduced total phenol content. It seems that the plant spent most of its photosynthates on the growth of plant shoots, which is consistent with the results of this study. Phenolic compounds are secondary plant metabolites that act as substrates for many antioxidant enzymes⁹ or indirectly alleviate the damages of oxidative stress by modulating the function of several proteins associated with this stress³⁰. The application of biofertilizers and *Trichoderma* alone or in combination reduced the amount of total phenol at the salinity level of 150 mM salt. Except for the treatment of $S_{150}T_0F_P$ in which biomass was significantly reduced, the plants spent most of their photosynthates on shoot growth. In the treatment of $S_{150}T_0F_P$, the P biofertilizer increased root length, which could be related to the non-selective uptake of elements by carriers and ion channels at low salinity conditions. Decreased pH due to the use of biosulfur biofertilizer can be the reason for the decline of polyphenols in this treatment¹⁵. In the treatment of $S_0T_0F_N$, total phenol shows the lowest quantity. It can be said that *Azotobacter* contributed to increasing nitrogen uptake and subsequently increasing protein synthesis and cell growth and proliferation, resulting in a significant increase in shoot and root length and biomass. It seems that an increase in nitrogen uptake is

the mechanism of the bacteria itself, which has led to no increase in Na^+ uptake, a reduction of stressful conditions for the cell, and the lack of a need for the increase in total phenol content of the leaves. Total phenol content was increased significantly and remarkably in the treatments of $\text{S}_{300}\text{TF}_\text{N}$ and $\text{S}_{300}\text{TF}_\text{P}$. The treatment of N or P biofertilizers with *Trichoderma* may have increased the uptake of Na^+ by the roots and its accumulation in the leaves. The absorption of nutrients by cation channels is not selective, and the interaction of *Trichoderma* and bacteria is likely to increase the activity of NH_4^+ carrier cation channels and subsequently, Na^+ uptake⁴⁴. Plants exposed to oxidative stress use special defense mechanisms, such as increasing the concentration of total phenol. Studies have shown that different levels of salinity treatment increased total phenol content by 8–35%⁴. Also, phenol compounds accumulated in the leaves of corn and chickpea to a much greater extent in the plants exposed to salinity stress than those not exposed^{29,39}. The use of a combination of seaweed and cyanobacteria as biofertilizer agents improved the growth and phenol content of fava beans⁵². In a study, it was found that an increase in phenol synthesis in *Trichoderma*-inoculated tomato plants improved their⁴⁰. growth under drought stress, thereby protecting them against oxidative stress by ROS scavenging. The increased synthesis of phenols and flavonoids is involved not only in the formation of cell walls, which protects plants against biotic stresses but also in antioxidant activity directly⁶¹.

The increase in phenolic compounds is due to the fact that free hydroxyl groups attached to the aromatic ring alleviate the oxidative damages caused by ions through scavenging radicals and other mechanisms, e.g. singlet oxygen reduction and metal chelating by bonding to toxic ions, thereby protecting cytoplasm and chloroplast structures against the negative impacts of salinity⁸. It seems that in the treatment of $\text{S}_{300}\text{TF}_\text{P}$, proper Na^+ compartmentation was performed in leaf cells so that the phenols were chelated with Na^+ and transferred it into the vacuole. By the reduction of cytosolic Na^+ and the creation of suitable cellular conditions, photosynthetic materials were used to synthesize proteins and materials necessary for growth and increased shoot and root length, as well as shoot and root biomass in this treatment. There are reports as to Na^+ compartmentation and transfer of cytosolic Na^+ into the vacuole to prevent the destructive effects of sodium in the cytosol of plant cells²⁴. Unlike the treatment of $\text{S}_{300}\text{TF}_\text{P}$, in the treatment of N biofertilizer along with *Trichoderma* at high salinity ($\text{S}_{300}\text{TF}_\text{N}$), there was no increase in shoot and root length and biomass, but root growth was significantly reduced. It seems that most photosynthates are used to synthesize secondary metabolites, the major of which are phenols. The increase in phenol content under osmotic stress in different tissues of many plants can occur due to the role of total phenols in regulating the important mechanism of plant metabolic processes, the overall result of which is the effect on plant growth¹.

Total flavonoid

The results showed that flavonoid content did not increase under stress and the production of flavonoids from photosynthates was decreased. Although the application of *Trichoderma* and biofertilizer alone or in combination reduced the amount of flavonoid reduction in salinity (150 mM salt), an increase was observed in flavonoid content in all treatments of the 150 mM salinity level versus the control of this

salinity level. This increase was more significant and pronounced in the treatments of $S_{150}TF_P$ and $S_{150}T_0F_N$. It seems that quinoa's defense system in salinity stress was more based on the increase in other phenols. The highest amount of flavonoids was observed in the treatments of S_0TF_N and S_0TF_P . Accumulation of phenolic compounds in salinity-tolerant plants is a solution to inhibit the activity of reactive oxygen radicals and protect cell membranes from salinity stress damage⁵⁹. Flavonoid content can be increased by applying biological fertilizers alone or a combination with chemical fertilizers such as nitrogen fertilizers²². Factors such as genotype (cultivar), soil, and environment seem to influence biochemical processes that happen during germination versus the primary and secondary metabolites and phenol compounds profile of quinoa¹⁴. By imposing salinity stress on *Chichorium spinosum*, researchers observed that it increased flavonoid content and antioxidant activity⁵¹. Flavonoids are often induced by abiotic stress and are involved in plant protection³⁸. Accumulation of flavonoids due to salinity can indicate that the plant needs large amounts of flavonoids to counteract the harmful effects of salinity³. Flavonoids make membranes resistant to oxidative agents by reducing fluidity and preventing the release of free radicals³⁸. Organic-grown cabbage, spinach, and green peppers generally had higher levels of flavonoid and antioxidant activity¹⁹. The increased synthesis of flavonoids by Trichoderma-inoculated plants act as endogenous regulators of auxin motions and growth regulator, and these plants may exhibit fine-regulation of growth hormone and photoprotection in photosynthesis pathway¹³.

Polyphenols (HPLC)

Quinoa leaf is a potentially rich source of phenolic and flavonoid compounds³³. Gawlik-Dziki et al. (2013)²¹, who analyzed HPLC to identify ChL aglycones of quinoa leaves, detected ten main phenolic acids and four flavonoids in the chemical polyphenolic fraction. The main phenolic acids included ferulic, sinapinic, and gallic acids, whereas kaempferol and isoramentine were the most abundant flavonoid. Also, a great deal of rutin was observed. Quercetin has been reported in the shoot of *C. album*³⁶. Among the phenolic compounds studied in this research, rosmarinic and coumaric acids were the predominant phenolic compounds in quinoa leaves. Caffeic acid was observed in lower amounts. The amounts of cinnamic and chlorogenic acids were slight, all of which showed a significant increase in the treatments of S_0TF_N and S_0TF_P . Apigenin was present in small amounts in all treatments but showed a large increase in the treatments of S_0TF_N and S_0TF_P . Rutin was found in almost the same amount and quercetin in different amounts in all treatments, but the amount of these two flavonoids was also increased significantly in the treatments of S_0TF_N and S_0TF_P . Apigenin content was also increased slightly in these two treatments. On the other hand, total flavonoid content was remarkably enhanced in these two treatments. The results are consistent with one another. The stressful conditions along with F_P and F_N and Trichoderma were effective in increasing total phenol. The results seem to depend upon not only the plant's response to different levels of salt but also the interaction among antioxidants. Phenolic compounds can influence one another antagonistically. These changes in the amount of the studied phenols can indicate the different antioxidant potential of various compounds in dealing with salinity

stress and the interaction between microorganisms. Phenolic compounds encompass a wide range of compounds, including phenolic acids, flavonoids, and tannins³⁵. The increase in total phenol in the treatments of S₃₀₀TF_N and S₃₀₀TF_P could be related to other phenolic compounds that have not been studied and measured in this study. In plants, the biological synthesis of polyphenols and their accumulation is generally stimulated in response to biotic/abiotic stress such as salinity. Plants exposed to salinity stress may provide potential sources of polyphenols by increasing the concentration of polyphenols in their tissues and limiting biomass production. The optimal performance of polyphenols has been suggested to be accomplished by using stress-tolerant species⁵³. An increased level of phenolic acids has been reported with increasing NaCl concentrations in barley⁵⁷. El-Din et al. (2009)¹⁸ reported that salinity stress exposure of thyme increased such compounds as caffeic, chlorogenic, ferulic, and rosmarinic acids. In *M. chamomilla*, the accumulation of phenolic acids such as chlorogenic and caffeic acids was increased with increasing salinity³⁴. In *Nigella sativa*, salinity stress increased the biosynthesis of some specific phenolic compounds such as quercetin, apigenin, and trans-cinnamic acid¹¹. There is another report that salinity stress can cause the accumulation of phenolic compounds in plant tissues⁶⁸. A study on artichoke revealed that the amount of polyphenolic compounds was decreased with increasing salinity²⁷. The results on olives showed that the use of Trichoderma increased the concentration of polyphenols in olive leaves¹⁷.

Conclusions

The present study investigated the effect of salinity stress, bacteria biofertilizers, and Trichoderma on morphological traits, antioxidants, and polyphenol compounds of quinoa. The results showed that the application of biofertilizers and Trichoderma under salinity stress influenced morphological traits, antioxidants, and polyphenol compounds of this plant species. At the salinity level of 300 mM, the application of Trichoderma had an increasing impact on the activity of phosphate solubilizing bacteria and finally induced resistance and increased the growth of the quinoa plants under severe salinity levels. The results revealed that at severe salinity levels, biofertilizers along with Trichoderma were effective in improving total phenols. Flavonoid content was not increased in stressful conditions, and the defensive system of this plant in salinity stress is more based on increasing other phenols. In total, it is recommended to apply bacterial biofertilizers along with Trichoderma to increase quantitative and qualitative traits of quinoa.

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Figures

Figure 1

Means comparison for the shoot length of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 1

Means comparison for the shoot length of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 2

Means comparison for the shoot dry weight of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 2

Means comparison for the shoot dry weight of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 3

Means comparison for the root length of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 3

Means comparison for the root length of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 4

Means comparison for the root dry weight of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 4

Means comparison for the root dry weight of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 5

Means comparison for the phenol content of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 5

Means comparison for the phenol content of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 6

Means comparison for the flavonoid content of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 6

Means comparison for the flavonoid content of quinoa affected by salinity stress, biofertilizers, and Trichoderma. Unsimilar letters show significant difference at the $P < 0.01$ level. (S0T0C: no salinity $\times$ no Trichoderma $\times$ no biofertilizer; S0T0FN: no salinity $\times$ no Trichoderma $\times$ N biofertilizer; S0T0FP: no salinity $\times$ no Trichoderma $\times$ P biofertilizer; S0TC: no salinity $\times$ Trichoderma $\times$ no biofertilizer; S0TFN: no salinity $\times$ Trichoderma $\times$ N biofertilizer; S0TFP: no salinity $\times$ Trichoderma $\times$ P biofertilizer; S150T0C: 150 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S150T0FN: 150 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S150T0FP: 150 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S150TC: 150 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S150TFN: 150 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S150TFP: 150 mM salinity $\times$ Trichoderma $\times$ P biofertilizer; S300T0C: 300 mM salinity $\times$ no Trichoderma $\times$ no biofertilizer; S300T0FN: 300 mM salinity $\times$ no Trichoderma $\times$ N biofertilizer; S300T0FP: 300 mM salinity $\times$ no Trichoderma $\times$ P biofertilizer; S300TC: 300 mM salinity $\times$ Trichoderma $\times$ no biofertilizer; S300TFN: 300 mM salinity $\times$ Trichoderma $\times$ N biofertilizer; S300TFP: 300 mM salinity $\times$ Trichoderma $\times$ P biofertilizer).

Figure 7

HPLC for the (caffeic acid , rosmarinic acid, chlorogenic acid, coumaric acid, cinnamic acid, rutin, quercetin and apigenin) of quinoa affected by salinity stress, biofertilizers, and Trichoderma. (S0T0C: no salinity × no Trichoderma × no biofertilizer; S0T0FN: no salinity × no Trichoderma × N biofertilizer; S0T0FP: no salinity × no Trichoderma × P biofertilizer; S0TC: no salinity × Trichoderma × no biofertilizer; S0TFN: no salinity × Trichoderma × N biofertilizer; S0TFP: no salinity × Trichoderma × P biofertilizer;

S150T0C: 150 mM salinity × no Trichoderma × no biofertilizer; S150T0FN: 150 mM salinity × no Trichoderma × N biofertilizer; S150T0FP: 150 mM salinity × no Trichoderma × P biofertilizer; S150TC: 150 mM salinity × Trichoderma × no biofertilizer; S150TFN: 150 mM salinity × Trichoderma × N biofertilizer; S150TFP: 150 mM salinity × Trichoderma × P biofertilizer; S300T0C: 300 mM salinity × no Trichoderma × no biofertilizer; S300T0FN: 300 mM salinity × no Trichoderma × N biofertilizer; S300T0FP: 300 mM salinity × no Trichoderma × P biofertilizer; S300TC: 300 mM salinity × Trichoderma × no biofertilizer; S300TFN: 300 mM salinity × Trichoderma × N biofertilizer; S300TFP: 300 mM salinity × Trichoderma × P biofertilizer).

Figure 7

HPLC for the (caffeic acid , rosmarinic acid, chlorogenic acid, coumaric acid, cinnamic acid, rutin, quercetin and apigenin) of quinoa affected by salinity stress, biofertilizers, and Trichoderma. (S0T0C: no salinity × no Trichoderma × no biofertilizer; S0T0FN: no salinity × no Trichoderma × N biofertilizer; S0T0FP: no salinity × no Trichoderma × P biofertilizer; S0TC: no salinity × Trichoderma × no biofertilizer; S0TFN: no salinity × Trichoderma × N biofertilizer; S0TFP: no salinity × Trichoderma × P biofertilizer;

S150T0C: 150 mM salinity × no Trichoderma × no biofertilizer; S150T0FN: 150 mM salinity × no Trichoderma × N biofertilizer; S150T0FP: 150 mM salinity × no Trichoderma × P biofertilizer; S150TC: 150 mM salinity × Trichoderma × no biofertilizer; S150TFN: 150 mM salinity × Trichoderma × N biofertilizer; S150TFP: 150 mM salinity × Trichoderma × P biofertilizer; S300T0C: 300 mM salinity × no Trichoderma × no biofertilizer; S300T0FN: 300 mM salinity × no Trichoderma × N biofertilizer; S300T0FP: 300 mM salinity × no Trichoderma × P biofertilizer; S300TC: 300 mM salinity × Trichoderma × no biofertilizer; S300TFN: 300 mM salinity × Trichoderma × N biofertilizer; S300TFP: 300 mM salinity × Trichoderma × P biofertilizer).