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GROWTH AND YIELD OF RICE UNDER VARIABLE APPLICATION METHODS OF ZINC WITH AND WITHOUT ARBUSCULAR MYCORRHIZAE IN NORMAL AND SALINE SOILS

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Abstract

Salinity is a major abiotic stress that adversely affects the crop's growth, especially cereals. It caused an ionic imbalance in soils, resulting in poor uptake of micronutrients. Among these micronutrients, zinc (Zn) is essential when cultivating cereals like rice. On the other hand, application methods of micronutrients, i.e., Zn, can over this issue in salt-affected soils. Scientists also recommend the inoculation of arbuscular mycorrhizae (AMF) to improve Zn uptake and alleviate salinity stress. That's why the current study was conducted to enhance rice production in salt-affected soils using different application methods of Zn with and without AMF. For that, 12 treatments were applied in 3 replications following a randomized complete block design (RCBD). Results showed that AMF inoculation under ZnS performed significantly best in normal soil for the enhancement in shoot fresh weight (47.14%) and dry weight (46.36), photosynthetic rate (47.09%), transpiration rate (50.76%) and stomatal conductance (67.44%) over SS. A significant improvement in Zn grains concentration also validated the efficacious functioning of ZnS over No Zn and ZnF with AMF+SS. In conclusion, ZnS with AMF is a good approach for the alleviation of salinity stress and improvement in Zn grains concentration in rice. More investigations at the field level are suggested on other cereal crops in different climates to proclaim ZnS with AMF as the best treatment for mitigating salinity stress and enhancing Zn concentration in cereals grains.

Key words: Growth attributes; Yield; Gas exchange attributes; Grains Zn concentration; Electrolyte leakage.

Introduction

In variable soil degrading factors, salinization is a major concern. Both humans and natural actions are responsible for the development of salinity under variable climatic conditions. Mostly limited rainfall-carrying areas, i.e., arid and semi-arid regions, suffer from the problem of soil salinity (Shahid *et al*., 2018). Weathering of parent material is considered the major source of salt accumulation (Boudjabi & Chenchouni, 2022). A higher concentration of salts in the rhizosphere causes deterioration of soil fertility and complicates biodiversity's survival. It also adversely affects the health of the rhizosphere in 20% of irrigated land due to excessive accumulation of water-soluble salts (Qadir *et al*., 2014; Zhang *et al*., 2019). Mostly salinity stress restricts the growth of plants in 2 major ways, i.e., less water uptake due to changes in irrigation water osmotic potential and cell internal injury due to the flow of excessive salts in the transpiration stream (Greenway & Munns, 1980). Furthermore, specific ion toxicity in the plants also played an essential role in decreasing the growth and yield of crops (Javed *et al*., 2022).

In soil fertility, salinization primarily causes plants' limited availability of micronutrients. The less uptake of micronutrients in saline soils is directly associated with ionic competition (Grattan & Grieve, 1998). Among these micronutrients, zinc (Zn) is prime in importance (Tahir *et al*., 2018). It is required in humans, animals, and plants to regulate biochemical and physiological processes. In plants, Zn controls more than 300 enzymes that actively play a role in the functioning and structural development (Samreen *et al*., 2017; Bibi *et al*., 2020). Under Zn deficient conditions, plants' photosynthesis becomes restricted due to reduced chlorophyll contents. It also restricts the biosynthesis of proteins due to limited carbonic anhydrase activities (Xing *et al*., 2016).

To overcome this critical problem, inoculation of AMF is an efficacious technique (Saboor *et al*., 2021a; c). These AMF are soil-borne fungi belonging to the phylum Mucoromycota and sub-phylum Glomeromycotina (Wahid *et al*., 2020; Saboor *et al*., 2021b). These fungi produce arbuscules, a tree-like structure in plant root cortical cells that act as food-storing vesicles in roots (Smith & Read, 2008). Symbiosis of AMF with plants increases the surface area of roots. Improvement in the rhizosphere due to the elongation of roots caused better uptake of water and nutrients in the plants (Jiang *et al*., 2017). The prominent essential nutrients are P, Zn, Fe, Cu, and K (Coccina *et al*., 2019). Better uptake of water and nutrients resulted in a significant increase in biomass and yield of AMF-inoculated plants (Wahid *et al*., 2020; Saboor *et al*., 2021b; a). On the other hand, application methods of micronutrients like Zn also overcome its deficiency or limited uptake in plants (Mohsin *et al*., 2014; Ahmad *et al*., 2018). So far, some scientists suggest soil application of Zn to achieve maximum benefits. However, others suggest the foliar application methods as an efficacious technique for better uptake of Zn in plants (Yilmaz *et al*., 1997; Bahadur *et al*., 1998; Gurmani *et al*., 2012; Ahmed *et al*., 2020; Khan *et al*., 2021).

That's why the importance of Zn application methods and AMF current study was conducted. The study aimed to explore AMF inoculation impact with (soil and foliar application) and without Zn on rice in salt-affected soils. This study covers the knowledge gap regarding a better method of Zn application in rice when AMF is inoculated under saline conditions. It is hypothesized that soil application methods might be better than the foliar application method of Zn in AMF inoculation in rice under salinity stress.

Material and Methods

Experimental location and design: A field study was conducted in the research area of the Department of Soil Science, Bahauddin Zakariya University Multan. Under two factorial treatment arrangements, the experimental design was completely randomized (CRD).

Treatment plan: A total of 12 treatments were applied in 3 replications on rice cultivated in naturally salt-affected soils. Three Zn application methods were examined, i.e., no Zn application, soil application (ZnS = 4 mg $ZnSO_4$/kg soil), and foliar application (ZnF = 0.5% Zn foliar spray at panicle and tillering stages) with and without AMF inoculation in normal (2.11 dS/m) and saline soils (5.95 dS/m). The treatment plan includes control (No Zn+ No AMF+normal soil), AMF+normal soil, Zn+ No AMF+saline soil (SS), AMF+SS, soil Zn application (ZnS)+AMF, ZnS+AMF+SS, ZnS+No AMF, ZnS+SS, foliar Zn application (ZnF)+AMF, ZnF+AMF+SS, ZnF+No AMF and ZnF+SS.

Soil characterization and pots preparation: Clay pots having 45 cm width and 60 cm depth were utilized in the study. After 8 kg of soil was filled in each pot. The soil was passed through a sieve, i.e., 2mm, to remove residues and stones. Analysis of the composite sample is provided in Table 1.

Table 1. Analysis of pre-experiment soil composite sample

Attributes	Units	Saline soil values	Normal soil value	References
Sand		55	65	(Bouyouces, 1962)
Silt	%	15	10	
Clay		30	25	
Texture		**Sandy clay loam**	**Sandy clay loam**	
pH*s*	-	8.49	8.15	(Page *et al*., 1983)
EC*e*	dS/m	5.95	2.11	(Rhoades, 1996)
Total nitrogen	%	0.02	0.02	(Bremner, 1996)
Available phosphorus		2.13	5.61	(Kuo, 1996)
Extractable potassium	mg kg^{-1}	101	148	(Pratt, 1965)
Extractable zinc		0.11	0.17	(Estefan *et al*., 2013).

Seed purchasing and nursery development: SUPER BASMATI rice seeds were collected from the certified seed dealer of the government of Punjab, Pakistan. Initially, the nursery was grown for 25 days. Seedlings were transplanted into the pots after 25 days of seed germination.

AMF inoculation and Zinc application: Clonex® (Root Maximizer; 158 propagule $gram^{-1}$; 5711 Enterprise Drive, Lansing, MI, USA) 2.5 g mycorrhizal inoculum was incorporated in 10 kg soil. Zinc was directly applied in soil = 4 mg $ZnSO_4$ kg^{-1} of soil. As per treatment, plant foliar of 0.5%, Zn solution was done at the panicle and tillering stages.

Fertilizer and irrigation: Macronutrients, i.e., 0.84g N, 0.54g P, and 0.36g K using urea, DAP, and SOP were applied. Nitrogen was added in 3 splits (Rehman *et al*., 2020), i.e., sowing, tillering, and spike initiation. In each pot, 100% FC was maintained (Wang *et al*., 2008).

Gas exchange attributes: Assessment of photosynthetic, transpiration rate, and stomatal conductance were performed as described by Danish & Zafar-ul-Hye (2019) on IRGA [CI-340; Photosynthesis system; CID, Inc. USA].

Chlorophyll contents and electrolyte leakage: Examining of chlorophyll contents was done by the method of Arnon (1949). The extract was prepared in 80% acetone. To explore chlorophyll a and chlorophyll b, absorbance was noted at 663 and 645 nm wavelengths.

$$\text{Chlorophyll a}\left(\frac{\text{mg}}{\text{g}}\right)=\left(\frac{(12.7\ (\text{Optical density }663)-2.69\ (\text{Optical density }645)\text{V})}{1000\ (\text{Leaf weight})}\right)$$

$$\text{Chlorophyll b}\left(\frac{\text{mg}}{\text{g}}\right)=\left(\frac{(22.9\ (\text{Optical density }645)-4.68\ (\text{Optical density }663)\text{V})}{1000\ (\text{Leaf weight})}\right)$$

$$\text{Total Chlorophyll}\left(\frac{\text{mg}}{\text{g}}\right)=(\text{Chlorophyll a}+\text{Chlorophyll b})$$

V = Final volume made

Electrolyte leakage (EL) was assessed per Saeed *et al*., (2014) methodology. The final value of EL was calculated using the equation:

$$\text{Electrolyte Leakage (\%)}=\left(\frac{\text{EC1}}{\text{EC2}}\right)\times 100$$

Morphological and yield traits: Plants were harvested manually at the time of maturity. Morphological attributes, i.e., plant height, shoot dry weight, 1000 grains weight, and grain yield, were computed soon after crop harvesting.

Nutrient accumulation: For zinc (Zn) concentration in grains, digestion was performed with HNO_3:$HClO_4$ = 2:1 (Miller, 1998). For the final Zn assessment, the atomic absorption spectrophotometer was unitized (Seregin *et al*., 2011).

Statistical analysis

Statistical analysis was performed according to standard procedure (Steel *et al*., 1997). Treatments were compared by Fisher LSD test; $p \leq 0.05$. Pearson correlation and parallel plots were also performed on OriginPro2021 software (OriginLab Corporation, 2021).

Results

Plant height: Different zinc application methods (Zn) with and without AMF significantly affected the plant height of rice cultivated under normal and saline soils. Results showed that AMF caused significant improvement in plant height of rice over control (No AMF) under No Zn, soil zinc application (ZnS), and foliar zinc application (ZnF) in normal and saline soils (SS). Compared to normal soils, SS caused a significant decrease in plant height. Treatment ZnS with and without AMF remained significantly better than ZnF for enhancement in rice plant height (Fig. 1A). However, ZnF performed significantly better for increasing rice plant height than no Zn. A maximum significant increase of 47.31, 33.69 and 44.34% in rice plant height was noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 1B shows plant height data-value-ranges and relationships between the different variables, i.e., AMF (Fungi) and Zn application. It was observed that ZnS with AMF was more dominant among all for the improvement. However, SS with no Zn was the most recessive combination (Fig. 1B).

Shoot fresh weight: Variable application methods of zinc (Zn) with and without AMF effect were significant on shoot fresh weight of rice grown under normal and saline soils. It was noted that AMF caused a significant enhancement in shoot fresh weight of rice than control (No AMF) under ZnS and ZnF in normal and saline soils. However, AMF and no AMF remained statistically alike under no Zn for shoot fresh weight (Fig. 2A). Rice shoot fresh weight was significantly decreased in SS over normal soils. Treatment ZnS with and without AMF differed significantly over ZnF for the increase in rice shoot fresh weight. However, ZnF caused a significant enhancement in the fresh shoot weight of rice compared to no Zn with and without AMF. A maximum significant increase of 21.31, 47.14, and 32.39% shoot fresh weight was noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 2B shows data value ranges of shoot fresh weight and relationships between the different variables, i.e., AMF (Fungi) and Zn application. It was observed that ZnS with AMF was more dominant among all for the improvement. However, SS with no Zn was the most recessive combination (Fig. 2B).

Shoot dry weight: Results showed that under No Zn, ZnS, and ZnF in normal and saline soils AMF inoculation induced a significant increase in the shoot dry weight of rice compared to the control (No AMF). However, AMF+SS and SS remained statistically similar under ZnF for shoot dry weight. Treatment AMF+SS caused significant improvement in shoot dry weight than SS when applied under no Zn and ZnS. Rice shoots dry weight was significantly improved in AMF, AMF+SS, and SS under ZnS over No Zn (Fig. 3A). Treatment ZnS with and without AMF differed significantly over ZnF for an increase in rice shoot dry weight. However, ZnF and ZnS caused no significant change in the shoot dry weight of rice cultivated in SS. A maximum significant increase of 48.96, 46.36 and 30.95% in shoot dry weight was noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 3B shows data-value ranges of shoot dry weight and relationships between the different variables, i.e., AMF (Fungi) and Zn application.

Number of tillers: The impact of applied treatments was significant on the number of tillers of rice cultivated in normal and saline soils. It was noted that AMF and AMF+SS under no Zn and ZnS showed no significant change in the number of tillers. However, a significant increase was noted in several tillers where ZnS and ZnF were applied over SS. In No Zn, ZnS, and ZnF, AMF+SS caused a significant enhancement in the number of tillers than SS. Furthermore, AMF+SS and no AMF remained statistically alike for the number of tillers under no Zn, ZnS, and ZnF (Fig. 4). A maximum significant increase of 60.00, 42.86, and 46.15% in the number of tillers was noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 4B shows data value ranges of the number of tillers and relationships between the different variables, i.e., AMF (Fungi) and Zn application.

1000 grains weight: A significant increase in 1000 grains weight was noted where AMF was inoculated over no AMF under ZnS. Both AMF and no AMF remained statistically alike to each other under ZnF and no Zn. On the other hand, significant improvement in 1000 grains weight was noted in AMF+SS compared to SS under no Zn and ZnF (Fig. 5). It was also observed that AMF+SS and SS did not differ significantly under ZnS for 1000 grains weight. However, ZnS and ZnF performed significantly better for enhancement in 1000 grains weight in SS than no Zn. Significant increases of 25.16, 18.32 and 19.97% in 1000 grains weight were noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 5B shows data value ranges of 1000 grains weight and relationships between the different variables, i.e., AMF (Fungi) and Zn application.

Yield: It was noted that under ZnS and ZnF, AMF did not differ significantly from noAMF for the enhancement in rice yield. A significant change was noted between AMF and no AMF under no Zn. However, AMF caused a significant improvement in rice yield compared to AMF+SS under no Zn, ZnS, and ZnF. On the other hand, AMF+SS and SS remained statistically similar for rice yield under no Zn, ZnS, and ZnF (Fig. 6). On average, ZnS-cultivated rice plants gave significantly better yields than those with no Zn. The maximum increase of 22.64, 16.31 and 19.97 % in yield were noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 6B shows data value ranges of yield and relationships between the different variables, i.e., AMF (Fungi) and Zn application.

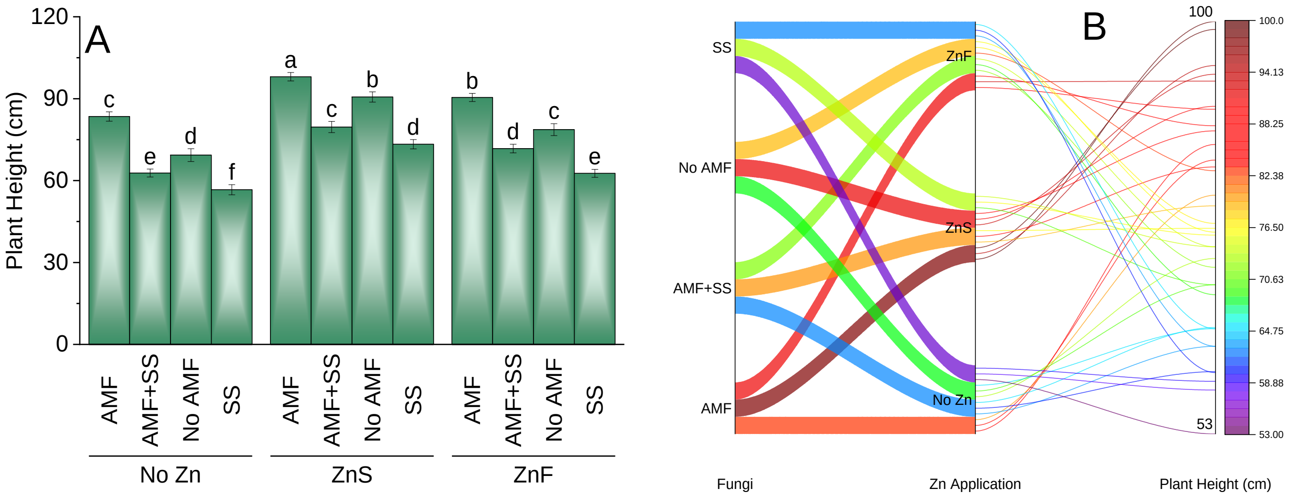

Fig. 1. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice plant height under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the data range of studied attributes with the interaction between AMF treatment and Zn application rates.

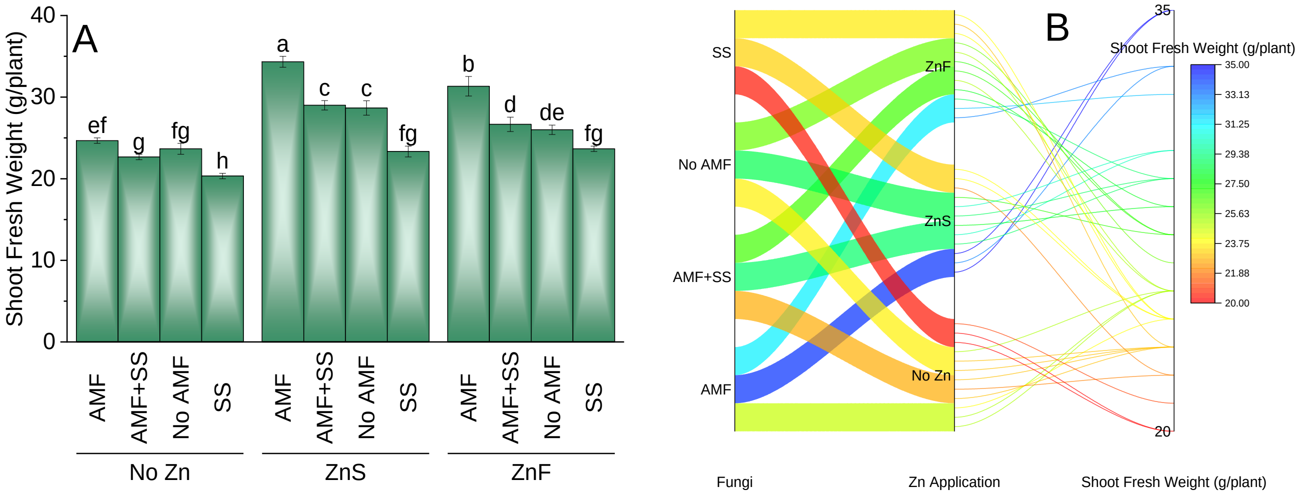

Fig. 2. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice shoot fresh weight under normal and saline soil conditions. Different letters on the bars are showing significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots are showing the data range of studied attributes with the interaction between AMF treatment and Zn application rates.

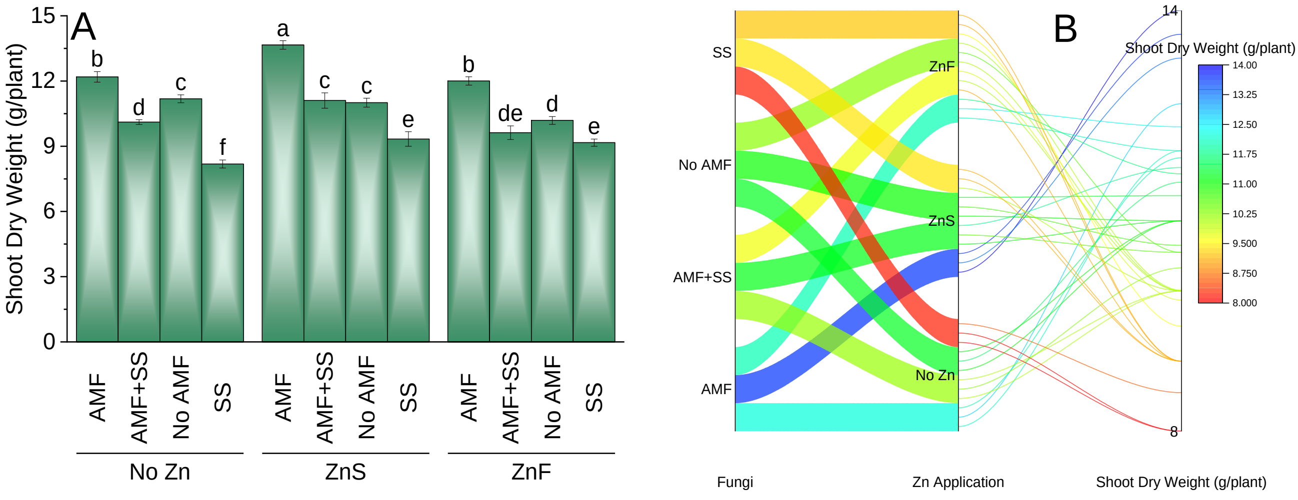

Fig. 3. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice shoot dry weight under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes' data range with the interaction between AMF treatment and Zn application rates.

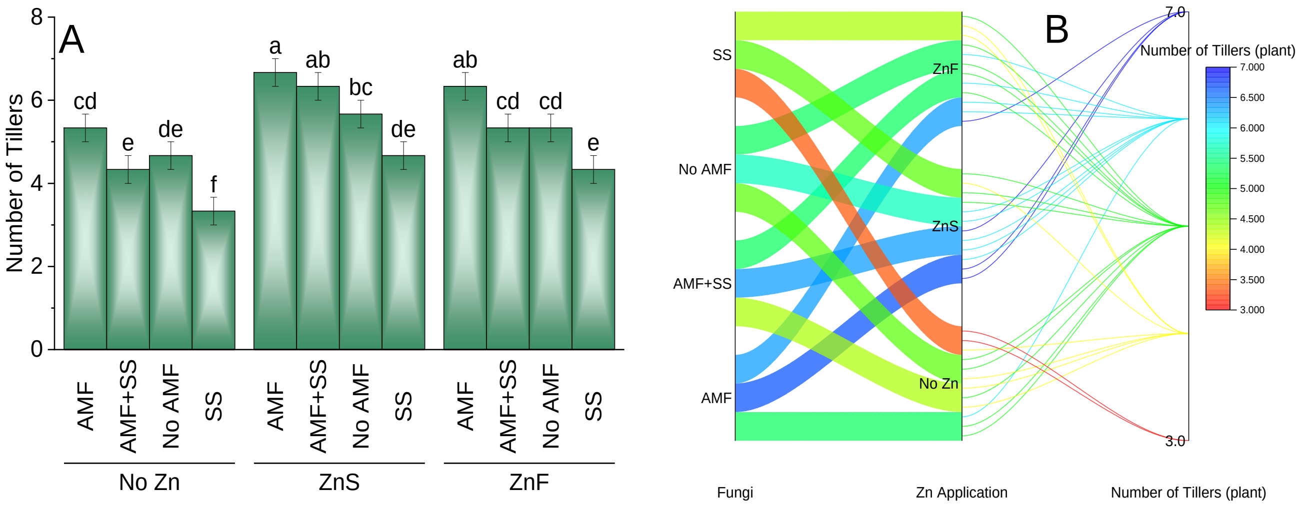

Fig. 4. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice number of tillers under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes data range with the interaction between AMF treatment and Zn application rates.

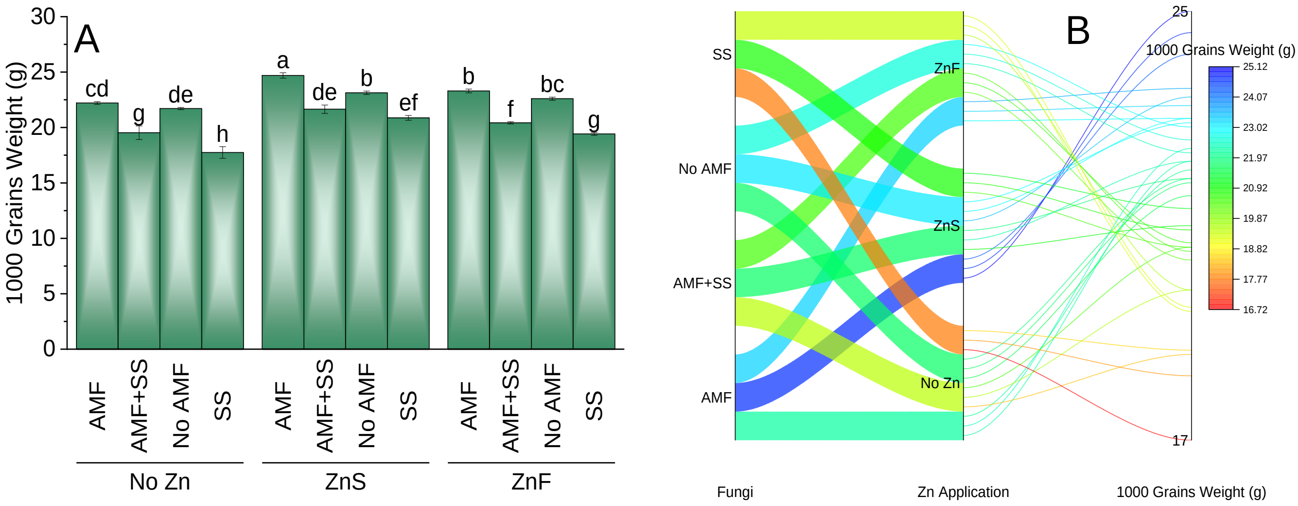

Fig. 5. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice plant height under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes data range with the interaction between AMF treatment and Zn application rates.

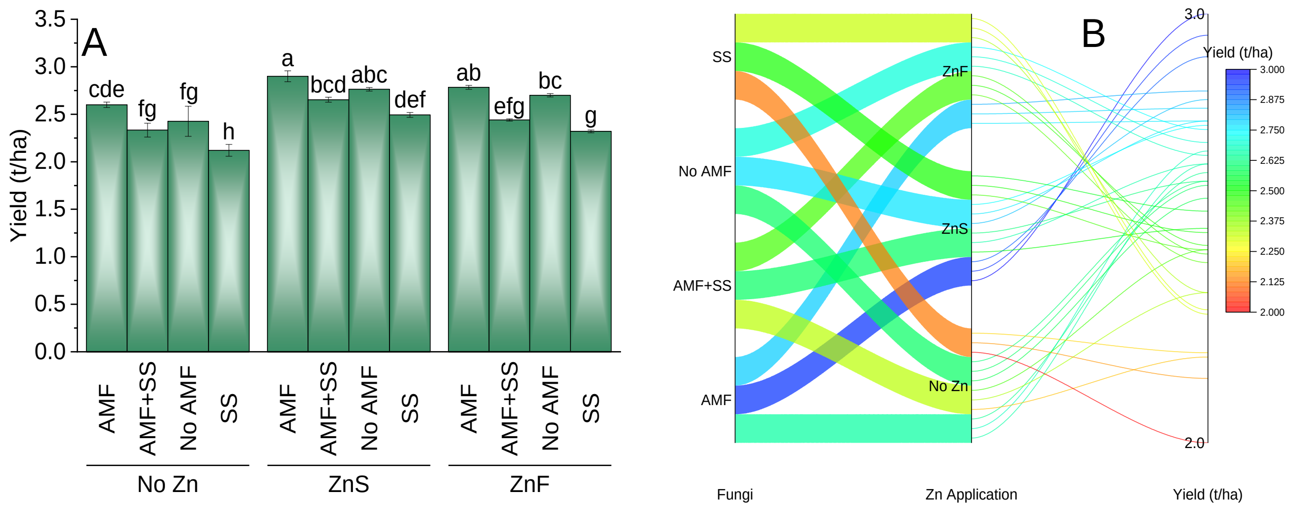

Fig. 6. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice yield under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes data range with the interaction between AMF treatment and Zn application rates.

Gas exchange attributes: The effect of treatments was significant on the photosynthetic rate (Pn), transpiration rate (E), and stomatal conductance (gs) of rice cultivated in normal and saline soils. Treatment AMF showed a significantly higher photosynthetic rate than no AMF under no Zn, ZnS, and ZnF. It was also observed that AMF+SS remained significantly better for improvement in photosynthetic rate than SS under ZnS and ZnF. However, no significant change in photosynthetic rate was observed between AMF+SS and SS under no Zn (Fig. 7A). The maximum increase of 27.15, 47.09, and 44.33% in photosynthetic rate were noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. In the case of transpiration rate, inoculation of AMF caused significant enhancement compared to no AMF under No Zn, ZnS, and ZnF. Treatment AMF+SS under No Zn, ZnS, and ZnF also differed significantly better than SS for improvement in transpiration rate. Furthermore, No AMF showed a significantly higher transpiration rate over SS under No Zn and ZnS. However, No AMF and SS did not differ significantly under ZnF for transpiration rate (Fig. 7B). The maximum increase of 38.17, 50.76 and 39.81% in transpiration rate were noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. For stomatal conductance, AMF differed significantly better than no AMF under No Zn, ZnS, and ZnF. Similarly, AMF+SS showed significantly higher stomatal conductance than SS under No Zn, ZnS, and ZnF. On average, ZnF and ZnS showed a significant increase in stomatal conductance than No Zn with and without AMF (Fig. 7C). The maximum increase of 69.53, 67.44 and 59.13% in stomatal conductance was noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 7D shows data value ranges of gas exchange attributes, i.e., Pn, E, and gs, and relationships between the different variables, i.e., AMF (Fungi) and Zn application.

Electrolyte leakage: No AMF and AMF did not differ significantly for electrolyte leakage under No Zn. However, AMF performed significantly better for decreasing electrolyte leakage in rice leaves than No AMF under ZnS and ZnF. It was noted that AMF+SS also caused a significant decrease in electrolyte leakage compared to SS under no Zn, ZnS, and ZnF. However, on average ZnS and ZnF performance was better than No Zn for a significant decrease in electrolyte leakage in rice leaves (Fig. 8). Figure 8B shows data value ranges of electrolyte leakage and relationships between the different variables, i.e., AMF (Fungi) and Zn application.

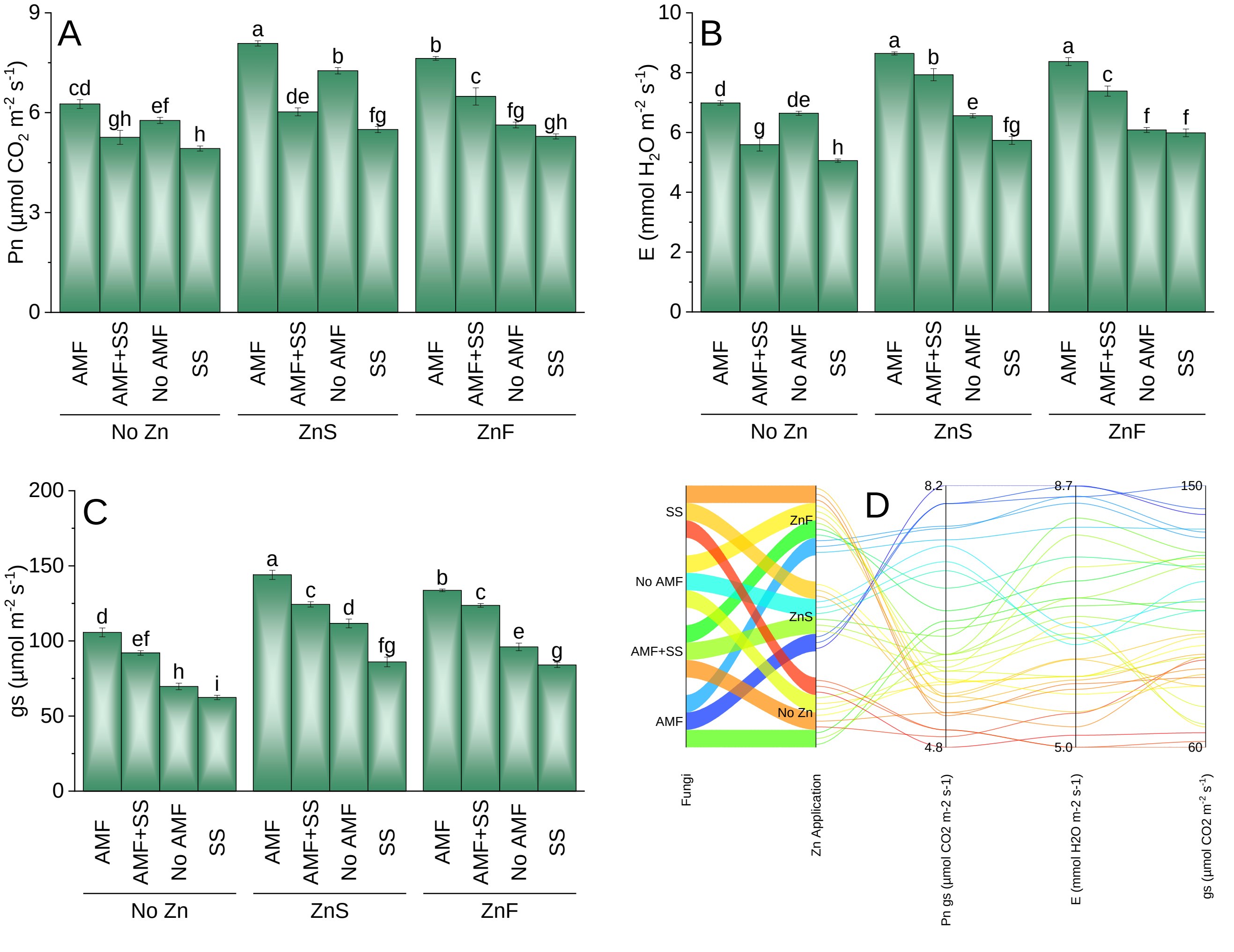

Fig. 7. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice photosynthetic rate; Pn (A), transpiration rate; E (B) and stomatal conductance; gs (C) under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes data range with the interaction between AMF treatment and Zn application rates.

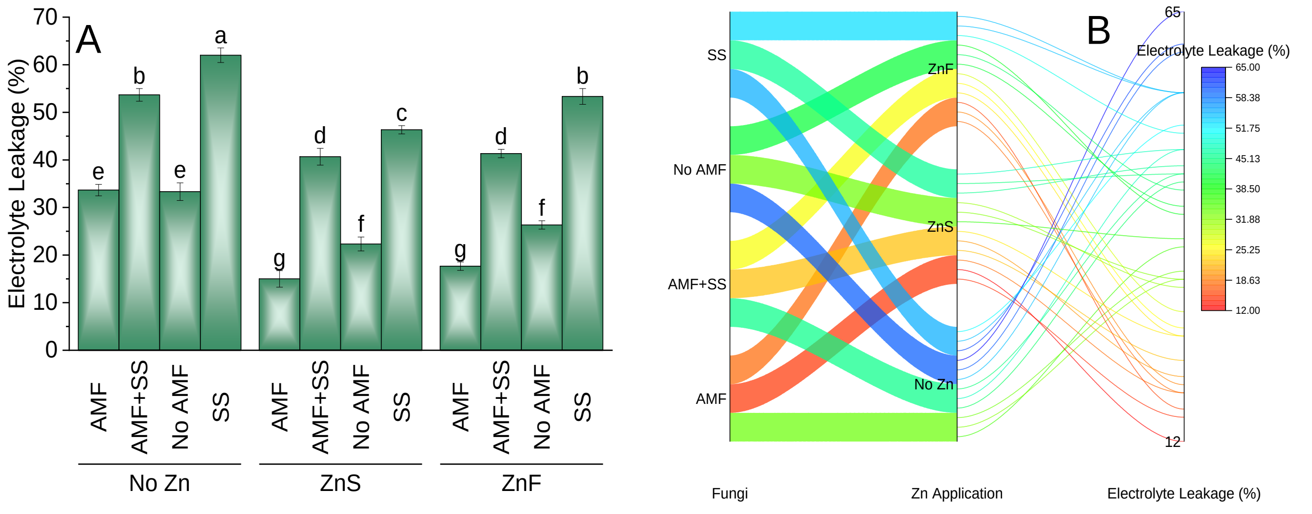

Fig. 8. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice leaves electrolyte leakage under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes data range with the interaction between AMF treatment and Zn application rates.

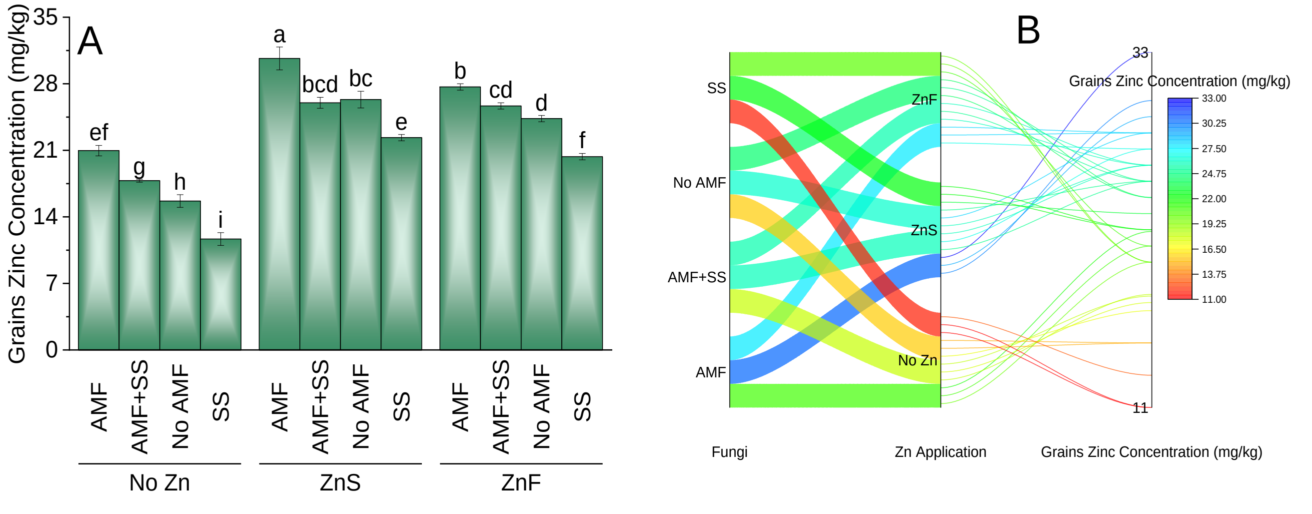

Fig. 9. Effect of different application methods (soil and foliar) of zinc (Zn) with and without AMF on rice grains Zn concentration under normal and saline soil conditions. Different letters on the bars show significant differences at $p \leq 0.05$ (Fisher LSD). Bars are means of 3 replicates ± SE. Parallel plots show the studied attributes data range with the interaction between AMF treatment and Zn application rates.

Grains Zn concentration and Pearson correlation: In the case of grains Zn concentration, AMF inoculation caused significant enhancement compared to no AMF under No Zn, ZnS, and ZnF. In AMF and SS, ZnS differed significantly better for the enhancement in Zn grains concentration than ZnF and No Zn. Similarly, ZnF also caused significant improvement in Zn grains concentration over No Zn in SS and AMF. It was also observed that AMF+SS showed significantly higher grains Zn concentration over SS under No Zn, ZnS, and ZnF (Fig. 9). The maximum increase of 79.71, 37.32 and 36.07% in grains Zn concentration were noted in AMF over SS under no Zn, ZnS, and ZnF, respectively. Figure 9B shows data value ranges of grain's Zn concentration and relationships between the different variables, i.e., AMF (Fungi) and Zn application. Pearson correlation showed that all the studied growth attributes' impact was significantly positive in correlation with each other except electrolyte leakage (Fig. 10).

Discussion

Higher level of salinity usually causes poor growth and productivity of crops. Imbalance uptake of salts deteriorates the health of roots and creates an ionic imbalance in the plants (Ahmad *et al.,* 2011). Such ionic imbalance and specific ion toxicity of Na and Ca resulted in poor crop productivity. It has also been observed that a higher concentration of water-soluble salts in the soil also restricted the availability of micronutrients, especially Zn (Quijano-Guerta *et al.,* 2002). Higher electrolyte leakage due to salt injury also played a notorious role in crop growth (Shareef *et al.,* 2020). It has also been well-documented that plant salt stress enhances the reactive oxygen species (ROS). These ROS also negatively affect plants' regular functioning, which subsequently causes chlorophyll degradation (Taïbi *et al.,* 2016; Naz *et al.,* 2019). The current study also observed similar results, where electrolyte leakage was significantly higher in control treatment plants. The current study showed that inoculation of AMF caused significant improvement in plant height, shoot fresh and dry weight, number of tillers, 1000 grains weight, and rice yield. The improvement in rice yield and growth attributes was directly associated with better uptake of Zn in the plants. Inoculation of AMF was imperative in extending root surface area (Saboor *et al.,* 2021b; c). This increase in the rhizosphere due to the elongation of roots provides a chance to plant for better uptake of nutrients and water (Huang *et al.,* 2021). Optimum uptake of water plays an important role in increasing plants' fresh biomass (Kano-Nakata *et al.,* 2013). Similarly, an improvement in the uptake of macro and micronutrients due to better root health caused a significant increase in grain weight and yield of crops (Yan *et al.,* 2022). Similar improvements were also noted in the current study, where shoot fresh and dry weight was enhanced when AMF was inoculated with ZnS and ZnF.

However, the performance of ZnS was relatively better than ZnF. Such improvements might be associated with the better activity of AMF in soil with applied ZnS compared to ZnF. When AMF is inoculated in plants, they enhance glomalin-related soil protein secretion. This protein secretion plays an imperative role in regulating activities responsible for the optimum uptake of Zn (Wamberg *et al.,* 2003; Saboor *et al.,* 2021c). Furthermore, under salt stress K+/Na+ ratio in plants becomes decreased, which eventually minimizes the regulation of stomata and other metabolic activities in the plants (Tester & Davenport, 2003). In the current study, a significant improvement in photosynthetic rate, transpiration rate, and stomatal were conducted to validate the effectiveness of AMF inoculation with ZnS and ZnF against salinity stress. Rapid inhibition of ROS due to better Zn uptake induced positive effects in the plants (Zhao & Wu, 2017). It also improved the chlorophyll contents, optimizing the plant's photosynthetic rate (Liu *et al.,* 2016). Our results also confirmed the above argument. The Pearson correlation showed that the photosynthetic rate was significantly positive in correlation with the Zn concentration in rice plants.

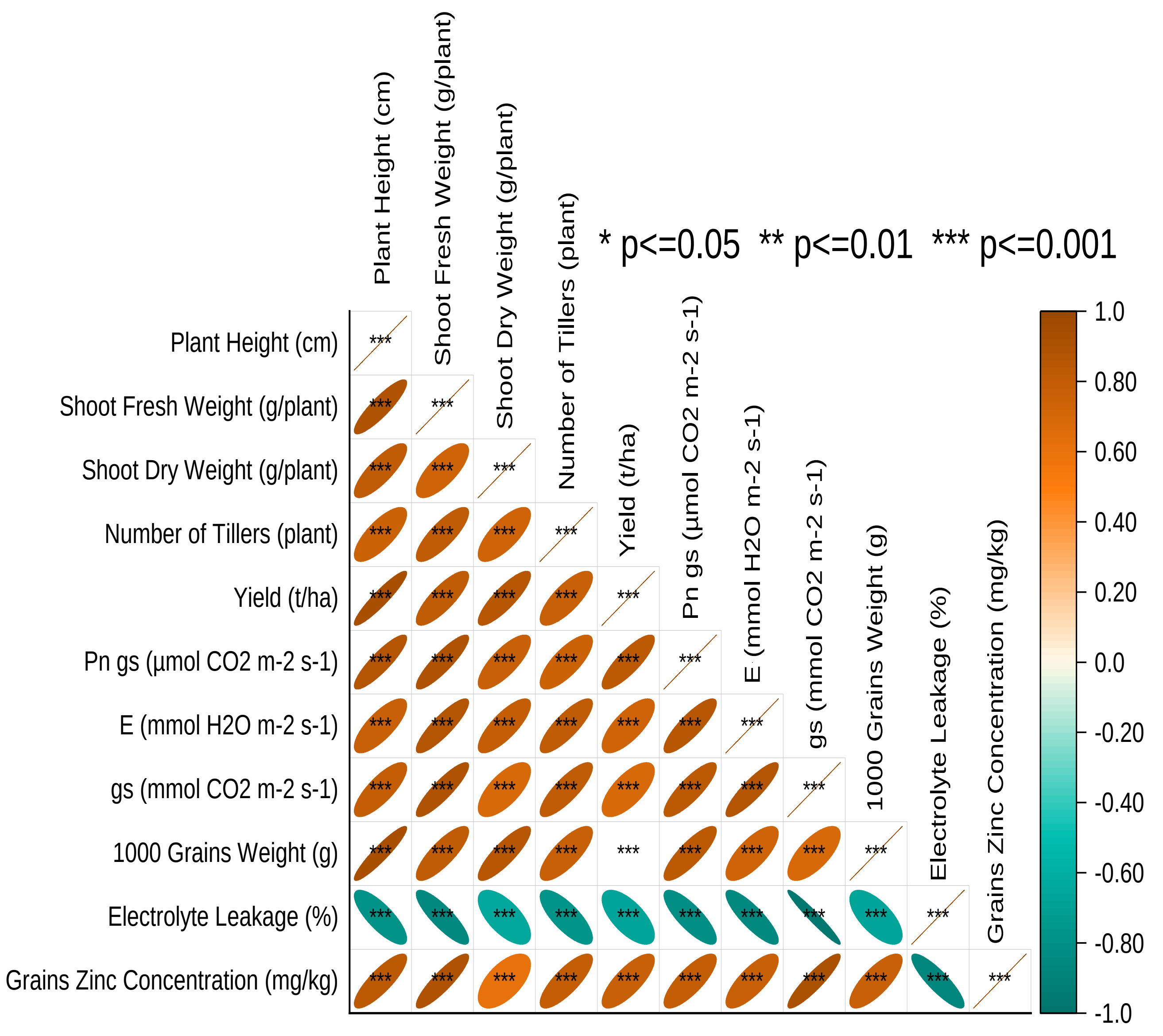

Fig. 10. Pearson correlation for studied attributes of rice cultivated in normal and saline soils amended with different application methods of Zn with and without AMF. The green color indicates a negative, while the brown color shows a positive correlation. The intensity of the color shows the strength of the correlation. Darker color has high while light color has low strength.

Conclusion

It is concluded that AMF can potentially alleviate salinity stress in rice plants. The application of ZnS and ZnF both effectively increase Zn uptake in rice. However, ZnS application is better when combined with AMF in rice cultivated in salt-affected soil. Growers are suggested to apply ZnS in combination with AMF better achieve rice growth and yield in saline soils. At the field level, more investigations are suggested under different climatic conditions on different cereal crops to declare ZnS and AMF as the best combination to mitigate salinity stress.

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