Cultivos Tropicales, Vol. 46, No. 2, April-June 2025, e-ISSN: 1819-4087, p-ISSN: 0258-5936, https://ediciones.inca.edu.cu

Cu-ID: https://cu-id.com/2050/v46n2e05

Original article

Nutritional effects of salt stress on mycorrhized tomato (*Solanum lycopersicum* L.) plants

Efectos nutricionales del estrés salino en plantas de tomate (*Solanum lycopersicum* L.) micorrizadas

Laura R. Medina García*, **Yakelin Rodríguez Yon**, **Nicolás Medina Basso**

Instituto Nacional de Ciencias Agrícolas (INCA), carretera San José-Tapaste, km 3½, Gaveta Postal 1, San José de las Lajas, Mayabeque, Cuba. CP 32700, Gaveta Postal 1.

ABSTRACT: Soil salinity is one of the most widespread agricultural problems, inhibiting plant growth and productivity. Arbuscular mycorrhizal fungi (AMF) are considered an effective alternative for the biological improvement of salinity stress, the objective of this work being to determine the effect of inoculation with different strains of AMF on the nutritional status of tomato plants under salt stress conditions. In the experiment tomato plants (*Solanum lycopersicum* L.) of the Vyta variety were used, studying the effect of the inoculation of different strains of AMF and three different levels of salinity on the nutritional status of the plants. It was observed that the plants inoculated with the AMF strains had a better nutritional status, both under normal conditions and under salinity stress, with a notable decrease in sodium content in plants colonized by said strains under salinity stress conditions.

Key words: salinity, arbuscular mycorrhizae, nutrition.

RESUMEN: La salinidad de los suelos es uno de los problemas agrícolas más extendidos, inhibiendo el crecimiento de las plantas y su productividad. Los hongos micorrízicos arbusculares (HMA) se consideran una alternativa eficaz para la mejora biológica del estrés por salinidad, siendo el objetivo del presente trabajo determinar el efecto de la inoculación con diferentes cepas de HMA sobre el estado nutricional de plantas de tomate en condiciones de estrés salino. En el experimento se utilizaron plantas de tomate (*Solanum lycopersicum* L.) de la variedad Vyta, estudiándose el efecto de la inoculación de diferentes cepas de HMA y tres niveles diferentes de salinidad sobre el estado nutricional de las plantas. Se observó que las plantas inoculadas con las cepas de HMA tuvieron un mejor estado nutricional, tanto en condiciones normales como sometidas a estrés salino, siendo notable la disminución de los contenidos de sodio en las plantas colonizadas por dichas cepas bajo condiciones de estrés por salinidad.

Palabras clave: salinidad, Micorrizas arbusculares, nutrición.

INTRODUCTION

In nature, plants are exposed to numerous stress conditions that retard their development and reduce their yields. One of the most widespread agricultural problems is the accumulation of salts on the soil surface (1). In general, salinity inhibits plant growth and productivity by inducing imbalances in the osmotic relationships between soil and plants and in plant metabolism (2).

There is a group of factors that increase plant tolerance to salinity, such as osmotic adjustment, synthesis of organic solutes, exclusion of ions at the root level, retention of ions in root vacuoles, and elimination of excess salts directly through glands or specialized structures (3). The incorporation or application of these can provide plants with better resistance to salt stress and can help improve crop productivity under these conditions.

*Author for correspondence. laura@inca.edu.cu

Received: 29/05/2023

Accepted: 30/01/2025

Conflict of interest: Authors declare that they have no conflict of interest.

Authors' contribution: Conceptualization- Laura R. Medina, Yakelin Rodríguez Yon, Nicolás Medina Basso. **Methodology-** Laura R. Medina, Yakelin Rodríguez Yon, Nicolás Medina Basso. **Supervision-** Laura R. Medina, Nicolás Medina Basso. **Initial draft writing-** Laura R. Medina, Yakelin Rodríguez Yon, Nicolás Medina Basso. **Final writing and editing-** Laura R. Medina, Nicolás Medina Basso. **Data curation-** Laura R. Medina, Yakelin Rodríguez Yon, Nicolás Medina Basso.

Stress tolerance in plants is a complex phenomenon involving numerous changes at the biochemical and physiological levels; however, the mechanisms behind stress tolerance appear to be affected by the colonization of arbuscular mycorrhizal fungi (AMF) (4).

AMF are considered an effective alternative for biological amelioration of salinity stress. They deploy a number of biochemical and physiological mechanisms that act in concert to provide enhanced salinity tolerance to plants. Some of these mechanisms include improved nutrient uptake and maintenance of ionic homeostasis, superior water use efficiency and osmoprotection, enhanced photosynthetic efficiency, preservation of cell ultrastructure, and enhanced antioxidant metabolism (5).

Considering the above, the objective of the present work was to determine the effectiveness of inoculation with different AMF strains on the nutritional status of tomato plants under salt stress conditions.

MATERIALS AND METHODS

The experiment was carried out in the experimental areas of the National Institute of Agricultural Sciences during the months of February and March under semi-protected growing conditions. Tomato (*Solanum lycopersicum* L.) plants of the Vyta variety were used. Seeds used were sterilized with a 10 % sodium hypochlorite solution for 10 minutes (6). Plants were sown in plastic pots of 5 L capacity, at a rate of 5 seeds per plant and, subsequently, a thinning was performed, leaving two plants per container. The tomato plants were grown under environmental conditions of temperature and relative humidity, as well as natural photoperiod. The substrate used was leached Ferrallitic Red soil, according to the New Version of the Cuban Soil Classification (7).

Treatments were distributed in a completely randomized design with a bifactorial arrangement (3x3), where the factors studied were AMF strains and salinity levels. The experiment consisted of nine treatments, with ten replicates each.

In one of the treatments of the strain factor, a certified inoculum based on *Glomus cubense* (Y. Rodr. & Dalpé) (INCAM - 4) from the mycorrhizae laboratory of the National Institute of Agricultural Sciences (INCA, San José de las Lajas, Mayabeque) was used. In another treatment of this same factor, a conglomerate of 28 AMF species was used, obtained by reproducing the species found in a soil affected by high salt content in the area of Las Caobas in Holguín province. Both AMF inocula had an average titer of 50 spores-g^{-1} of fresh soil and were certified at the Mycorrhizae Laboratory of INCA. Inoculation was carried out at a rate of 5 g per plant (approximately 250 spores per container). For the control treatment, only the composition of resident strains existing in the original substrate was maintained.

In none of the treatments was the soil sterilized, in order to maintain the characteristics of the microbiota associated with the crop.

The saline treatments were imposed with different concentrations of NaCl in the irrigation water: 50 and 100 mM. The solutions were prepared with commercial common salt with 99.97 % NaCl and 0.03 % potassium iodate. Treatments began 15 days after plant emergence, for 45 days, and irrigation with the different solutions was carried out once a week until the pots reached their maximum moisture retention level.

Determinations performed

The evaluations were carried out 60 days after plant emergence. In leaves, stems and roots, the percentages of N, P, K and Na were determined, in all cases by wet digestion (H_2SO_4 + Se), evaluating N by Nessler's method, P by molybdenum blue formation, K by flame photometry and Na by extraction of exchangeable cations with ammonium acetate (8).

RESULTS AND DISCUSSION

Sodium

Figure 1 shows the Na contents, by organs and total, in tomato plants subjected to salt stress. The reduced values exhibited by leaves, stems and total of plants inoculated with the strain conglomerate and *Glomus cubense*, compared to the non-inoculated control, are remarkable.

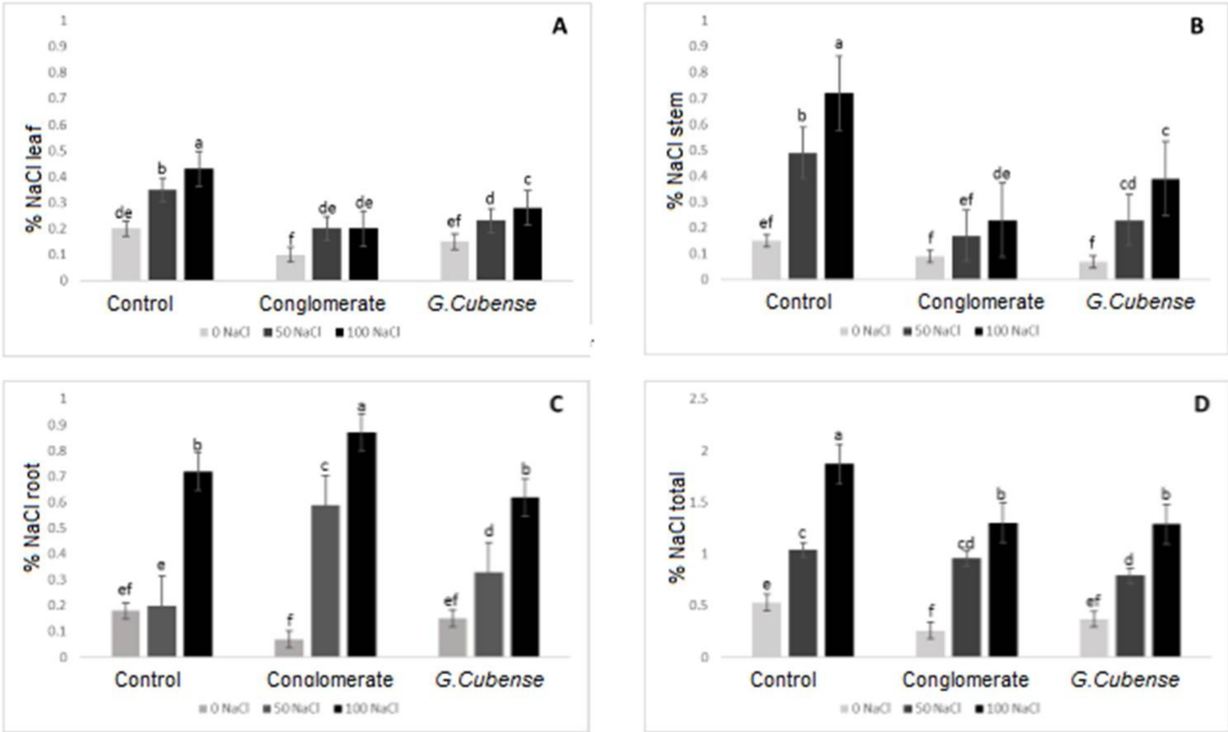
However, it can be observed that the same effect does not occur in the roots, with significant increases in Na content in the root system of plants inoculated with the conglomerate, at NaCl concentrations of 100 mM, in relation to the rest of the treatments. Similarly, for 50 mM NaCl concentrations, both plants inoculated with the conglomerate and with the *Glomus cubense* strain showed higher Na contents than the salinized treatments and not in the uninoculated variant (control).

There is evidence that, apparently, elements toxic to plants at high concentrations (Na, Cd, Pb, Ni, Ba, As) are sequestered in polyphosphate granules inside the hyphae of AMF, not being transferred to other plant organs (9, 10), and this could be the reason for the high Na concentrations found in the colonized roots.

Based on the above, a possible mechanism could be proposed to explain the role of AMF in the reduction of salt stress in plants, based on the reduction of Na absorption and its translocation to plant tissues, by accumulation of the element in the hyphae. As can be seen in Figure 1, mycorrhizal plants show less Na in their aerial organs than non-mycorrhizal plants.

Nitrogen

Figure 2 shows the nitrogen contents, by organs and total, in tomato plants under different levels of salinity and shows a notable and significant decrease in nitrogen contents in all organs, except the root of the plants, both mycorrhizal and non-mycorrhizal, as salt concentrations increased. This effect is of interest, since it can also be seen that the nutrient contents were significantly higher in the mycorrhizal treatments, indicative of a greater absorption of the element, especially in the variant inoculated with the conglomerate of strains.



Bars with common letters do not differ from each other according to Duncan = 0.05. The error bars represent the standard error of the mean per treatment

Figure 1. Effect of mycorrhization on the Na content in leaves (**A**), stems (**B**), roots (**C**) and total (**D**) of tomato plants subjected to saline stress

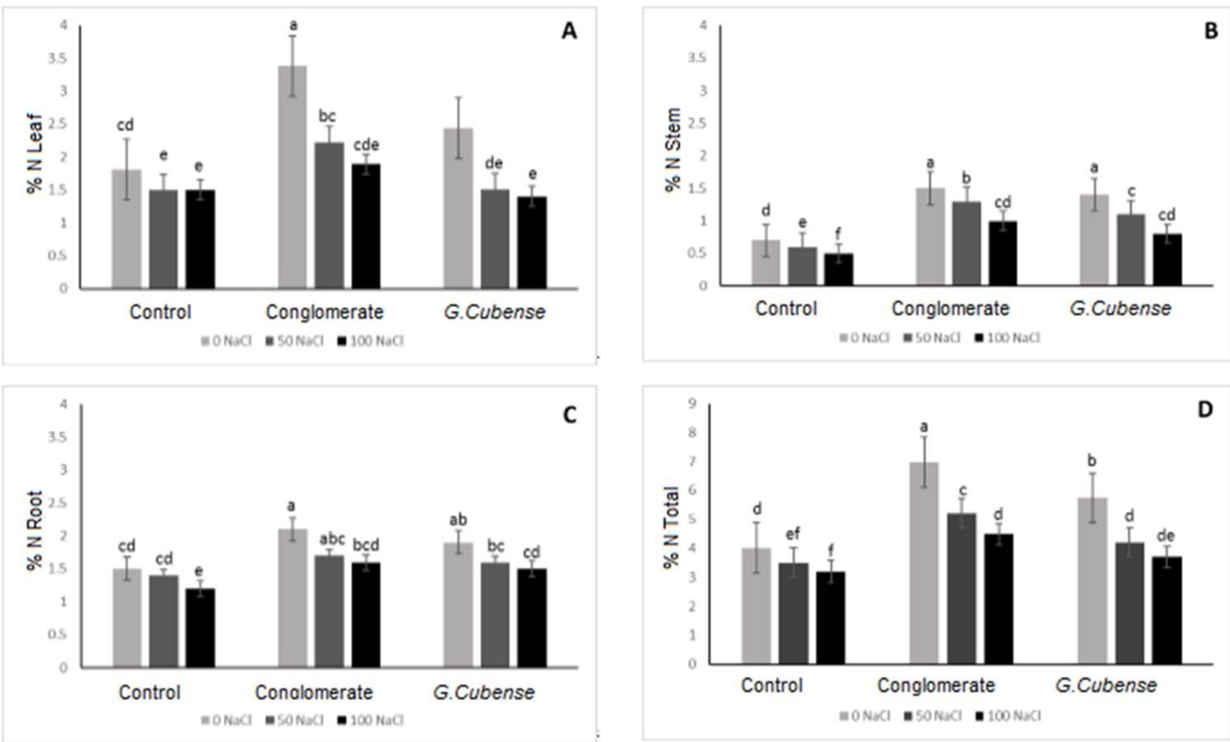


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Figure 2. Effect of mycorrhization on the N content in leaves (**A**), stems (**B**), roots (**C**) and total (**D**) of tomato plants subjected to saline stress

In the case of N acquisition, an increase of this element has also been reported in mycorrhizal plants, although in more discrete values than in the case of other nutrients. In an experiment on *Chrysanthemum morifolium* (Ramat.) under moderate salinity conditions, root N concentration was higher in mycorrhizal plants than in non-mycorrhizal plants, with enhanced root N uptake being the main mechanism underlying the increase in salt tolerance (11). It has been determined that this mechanism may help reduce the toxic effects of Na+ ions by regulating their uptake and indirectly helping to maintain plant chlorophyll content (12).

Phosphorus

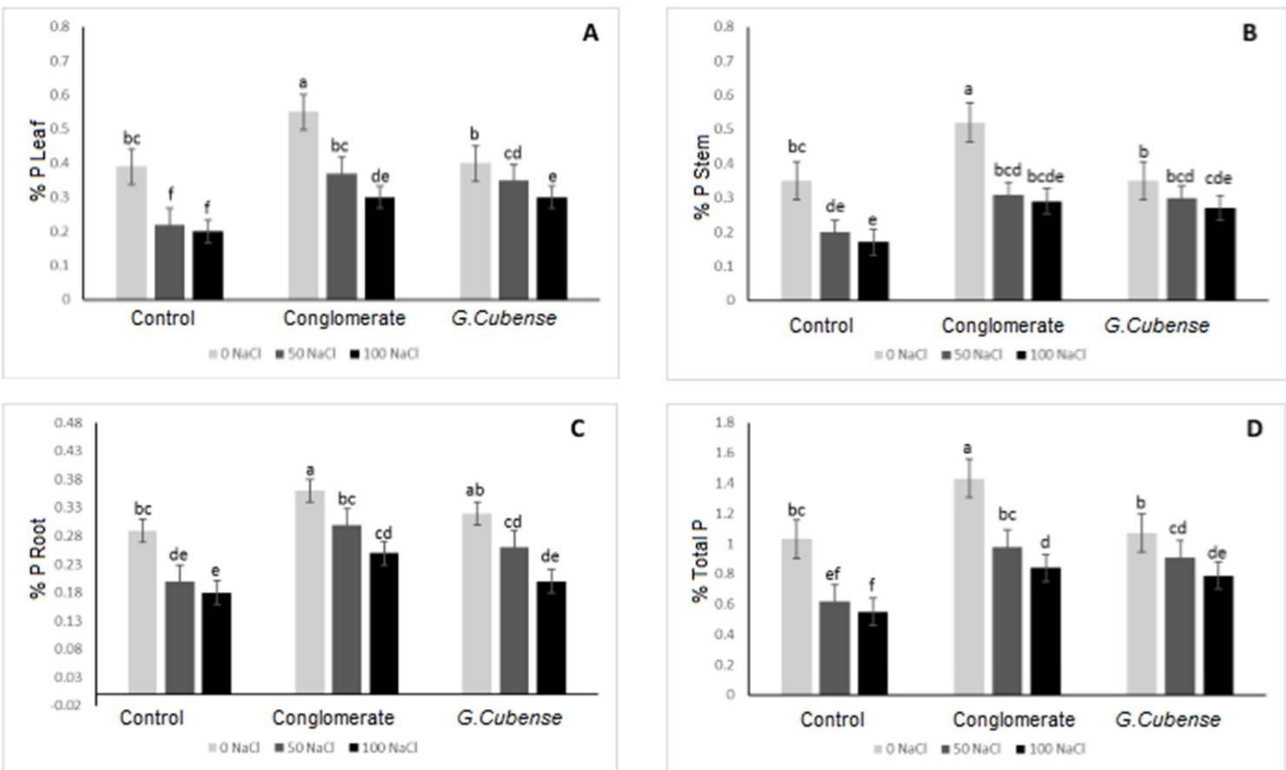
The contents of this nutrient in plants subjected to salt stress had a behavior similar to that described above for nitrogen. Figure 3 shows the values of the contents of this element, by organs and total, in inoculated and non-inoculated tomato plants, at different levels of salinization.

Thus, although the phosphorus contents in the leaves, stem, roots and total of the plants inoculated with the cluster were significantly higher, when the NaCl treatments were applied, the contents of the element decreased in a similar way, both in the plants inoculated with the cluster and in those inoculated with *G. cubense* and those not inoculated.

The increase in P uptake by mycorrhizal plants is a reality that has been widely documented. Certain modifications in the rhizosphere can increase the transfer of P to plant roots and the efficiency with which crops use this element (13). Some authors found results indicating that AM symbiosis could be a good tool to improve physiological traits and biomass production by increasing P uptake under salinity stress conditions during the early stages of plant development (14). Specific toxic effects of sodium have been associated with the accumulation of high NaCl concentrations in leaves, Plaut and Grieve found that increased P results in decreased Na, which may be indirectly related to Ca and Mg uptake (15).

Other authors suggest that AMF induce increased phosphorus levels in plants under salt stress and reduce the negative effects of Na by maintaining the integrity of the vacuolar membrane, which prevents these ions from intervening in metabolic pathways and facilitates compartmentalization within the vacuoles and selective ion uptake (16).

On the other hand, it is known that soil salinity significantly reduces the absorption of mineral nutrients, especially phosphorus, since phosphate ions precipitate with the cations present in saline soils, making them unavailable to plants (17). Therefore, the improvement in phosphorus nutrition observed in mycorrhizal plants, both by the conglomerate and by the *G. cubense* strain, is beneficial for plant growth and can help mitigate salt stress by overcoming the phosphorus retention capacity of the soil.



Bars with common letters do not differ from each other according to Duncan=0.05. The error bars represent the standard error of the mean per treatment

Figure 3. Effect of mycorrhization on the P content in leaves (**A**), stems (**B**), roots (**C**) and total (**D**) of tomato plants subjected to saline stress

Potassium

As shown in Figure 4, the behavior of potassium content in plants in the different variants evaluated was also similar to that already analyzed for N and P, so that inoculation with the conglomerate of strains allowed obtaining higher values of the nutrient in all organs, as well as for the plant as a whole. Likewise, K contents decreased in all inoculation variants with increasing salinization level.

When water in the soil is limited, under salinity conditions, plants suffer a loss of turgor and begin to wilt, typical symptoms of K deficiency (18). As a solute in the vacuoles, K plays an important role in the control of water relations by helping to keep the water level in the tissues high, even under unequal osmotic conditions. Thus, the increased accumulation of K in the tissues of mycorrhized plants may constitute an important contribution to the maintenance of the osmotic potential of the cells and tissues of plants subjected to salt stress (19).

In mycorrhizal plants, effective K uptake helps to reduce ion leakage, compartmentalization of toxic ions in vacuoles, and selective ion uptake, thereby reducing the adverse effects of salinity (5).

The best nutritional status observed in mycorrhizal plants may be related to numerous factors influenced by AMF that contribute to the maintenance of homeostasis, protection of cell membrane integrity, and improved water and nutrient acquisition under stress conditions (20).

CONCLUSIONS

It can be concluded, after the above observations, that the reduction in Na uptake into the plant, together with the increase in N, P and K uptake observed in mycorrhizal plants, especially in those inoculated with strains adapted to environments with high salt content, can be an important relief mechanism for plants growing in saline soils.

Plants inoculated with strains from the conglomerate had a better nutritional status, both under normal conditions and under salt stress, with a notable decrease in sodium content in plants colonized by these strains under salinity stress conditions.

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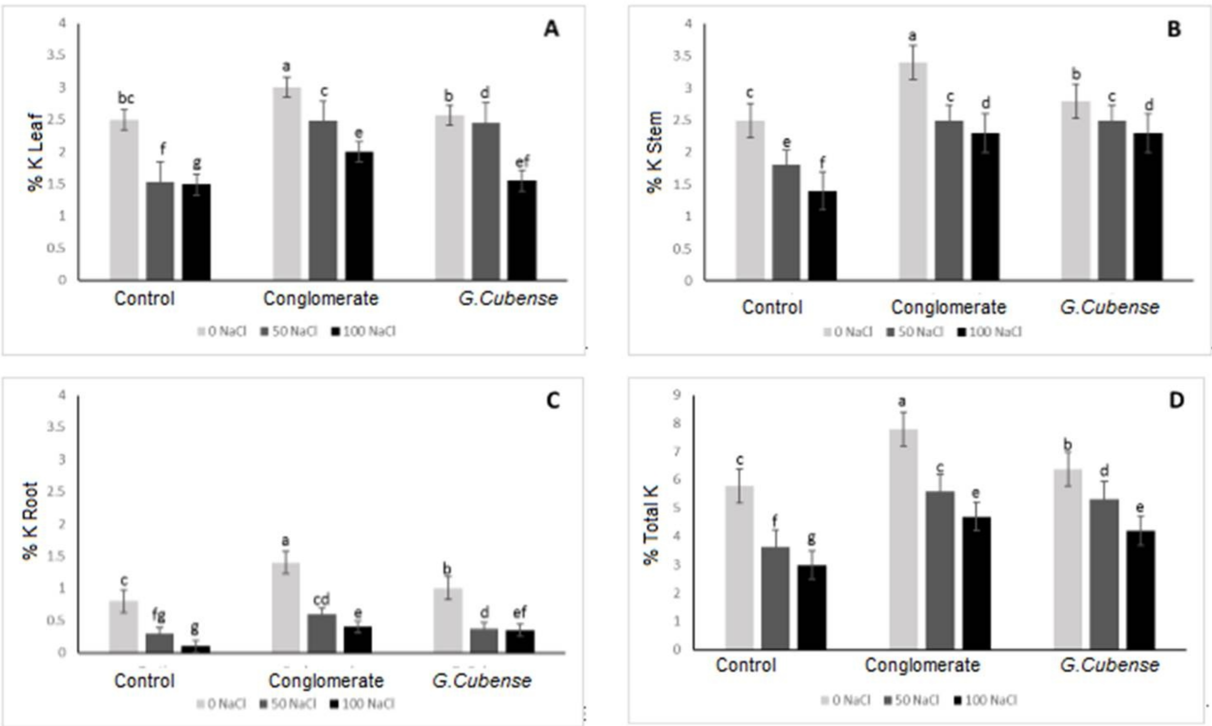

Bars with common letters do not differ from each other according to Duncan=0.05. The error bars represent the standard error of the mean per treatment

Figure 4. Effect of mycorrhization on the K content in leaves (**A**), stems (**B**), roots (**C**) and total (**D**) of tomato plants subjected to saline stress

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