Journal of Biological Research 1 (4), 2024: pp. 1-14.

UDC: 613.166.9 *Original article*

THE ROLE OF BENEFICIAL SOIL MICROORGANISMS IN MITIGATING DETRIMENTAL EFFECTS OF SALINITY STRESS IN *ALLIUM FISTULOSUM*

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ABSTRACT

In the last few decades, sea levels have risen mainly because of global warming. This has caused flooding and increased salinity in low-laying coastal agricultural lands. As a result of salinity, crop production is seriously reduced. The present study evaluated the effects of an arbuscular mycorrhizal fungus, *Rhizophagus irregularis* and a rhizospheric bacterium, *Pseudomonas flourescens,* alone and in dual inoculation on the survival, growth, mycorrhizal colonization, nutrient uptake, glomalin production, and soil aggregation of scallion plants under saline conditions. In saline soils, seedling survival, growth, total biomass, nutrient uptake, glomalin production, and soil aggregation were significantly increased when inoculated with *R. irregularis* and *P. flourescens*. Dual inoculation with *R. irregularis* and *P. flourescens* were superior than single inoculation. *Pseudomonas flourescens* stimulated mycorrhizal colonization in saline soils. The present results indicate that arbuscular mycorrhizal fungi and beneficial rhizospheric bacteria offer potential for mitigating salinity stress in *A. fistulosum*.

Keywords: *Global warming; Salinity tolerance; Pseudomonas fluorescents; Rhizophagus irregularis; scallion.*

1 INTRODUCTION

Global warming has caused sea levels to rise mainly due to additional water from melting ice sheets and glaciers and the expansion of seawater as it warms. Because of the rise of sea water levels, arable lands in low-lying coastal regions are facing a serious problem of salinity [1, 2]. Agricultural plants that are facing salinity problems under field conditions are lethal to plant survival and crop production. It has been reported that long-term effects of increased temperatures over the last 20 years has caused sea water to rise, increased soil salinity due to leaching of salt in the soil, and salinity has increased from 1 to 33% in coastal low-lying areas [3-7]. This will seriously affect food security and food availability worldwide [8].

Plant roots play a vital role by exploring the soil environment and taking up nutrient and water. Salinity can affect root function by altering cell water permeability and influencing the growth and architecture of the root system [9]. Salinity results in dehydration of the plant, interfering with nitrogen and other nutrient uptake, affecting stomatal and hydraulic conductance, reducing photosynthetic efficiency, leading to decline in crop yield or even cause death of the plants [10-13]. Under saline conditions, plants suffer from Na^+ and Cl^+ toxicity and accumulation of Na^+ can cause K^+ deficiency resulting damages of cellular organelles, disrupt osmotic potentials, and impact photosynthetic efficiency [14-16]. Plants must consistently maintain a low Na^+ to K^+ ratio to tolerate salinity stress (Evelin et al. 2019). Na^+ and Cl^- ions are toxic to plants and as the concentration of Cl^- increases plants suffer from toxic effects of Cl^- which affect nutrient uptake [17, 18].

In recent years, there is a growing interest to use beneficial soil microorganisms to improve agricultural productivity under adverse soil conditions. Arbuscular mycorrhizal fungi are considered to be of particular importance for the sustainable management of agricultural ecosystems and mediating crop productivity [19-22]. Arbuscular mycorrhizal fungi are a specialized group of soil fungi that form symbiotic associations with higher [23]. In this association both the partners benefit from each other. The mycorrhizal fungi help host plants enhancing water and nutrient uptake from the soil far beyond the reach of root system [23-25], increasing resistance against diseases [16], and improving water-use efficiency [22, 26, 27]. In return, the plant provides the fungi with carbohydrates and sugars formed during photosynthesis for fungal growth and metabolism. Arbuscular mycorrhizal fungi are also known to provide plants greater tolerance to biotic and abiotic stresses by changing host-plant physiology, biochemistry along with secondary metabolites [28-30].

In addition to arbuscular mycorrhizal fungi, plant growth-promoting bacteria have recently attracted increasing attention because of their effect on promoting the growth in agricultural crops [31-34]. These beneficial bacteria enhance plant growth by producing growth hormones such as indole-acetic acid, giberellic acid, and cytokinins [35], fixing nitrogen from the atmosphere [36], and protecting plants by producing antimicrobial compounds [37]. Their application to field crops enhances the growth and act as biological fertilizers [38]. Recent years, different plant growth-promoting bacteria have been studied including nitrogen fixing bacteria and phosphate solubilizing bacteria for their effect on plant growth and nutrient uptake [39-41].

Plants have developed their own mechanisms such as morphological, biological, physiological, and biochemical changes to deal with various biotic and abiotic stresses during the evolutionary process. They have developed mutualistic and symbiotic relationships with different soil microorganisms to deal with these stresses [42, 43]. Mycorrhizal plants have greater tolerance to deal with biotic and abiotic stresses compared to non-mycorrhizal plants [30, 44]. Similarly, beneficial phosphate solubilizing bacteria particularly *Pseudomonas flourescens* can co-exist with arbuscular mycorrhizal fungi and can help plants to deal with various abiotic stresses

[40, 41, 43, 44].

Scallion (*Allium fistulosum*) is one of the earliest cultivated crops and are grown world-wide: its leaves can be eaten either raw or cooked. Like many other crops, salinity can reduce the yield and quality of *A. fistulosum*. The effect of arbuscular mycorrhizal fungi and rhizospheric bacteria on salinity tolerance on *A. fistulosum* is unknown. The objective of this study was to determine the salinity tolerance of *A. fistulosum* inoculated with an arbuscular mycorrhizal fungus, *Rhizopagus irregularis* and a rhizospheric bacterium, *Pseudomonas flourescens* alone and in combinations.

2 MATERIALS AND METHODS

2.1 Organisms.

Seeds of *A. fistulosum* were obtained from Armstrong Garden Center, Glendora, California, U.S.A. The arbuscular mycorrhizal fungus, *R. irregularis* (PL 1794RI) and a rhizospheric bacterium, *P. flourescens* (PL 009PF) were obtained from the culture collection bank of Pasteur Laboratory, Glendora, California, U.S.A. The inoculum of *R. irregularis* was maintained in the fragmented roots of carrots whereas *P. flourescens* was maintained in tryptic soya broth nutrient medium. The identity of these organisms was verified through DNA metabarcoding analysis of the rDNA ITS2 region.

2.2 Seed germination.

Garden soils were autoclaved at 121^0C for 15 minutes at 15 lb pressure. When cooled, soils were placed on germination trays and covered with lids. Seeds of *A. fistulosum* were soaked in water overnight, washed with sterile distilled water and then sown in germination trays containing moist sterile soil. The germination trays were then covered with a lid to prevent evaporation. The trays were kept in a growth chamber (25^0C ± 2^0C) and lightly sprayed with sterile distilled water daily to keep soil moist. Seeds started sprouting 4 days after sowing.

2.3 Effect of R. irregularis and P. flourescens on salinity tolerance of A. fistulosum.

Autoclaved soil was treated with a 3.5% sodium chloride solution and filled with 5-inch plastic pots. Electrical conductivity of the soil was 2.39 dSm^{-1} and pH was 8.3. The seedlings were inoculated with *P. flourescens* and *R. irregularis* alone and in combination [44]. The following 8 treatments resulted: non-inoculated control with and without NaCl, *R. irregularis* with and without NaCl, *P. flourescens* with and without NaCl, a dual inoculation of *R. irregularis* plus *P. flourescens* with and without NaCl. Seedlings were kept in the growth chamber at 25^0C ± 2^0C under LED growth light (Model X001NTBWA5) for 10 hours daily illumination. Special attention was taken while watering to prevent leaching of NaCl from the pots into holding trays. The pots were randomized in the growth chamber every 2 days. Seedling mortality was recorded for each treatment. Since garden soils were used, pots were not fertilized.

The plants were harvested and evaluated 8 weeks after planting. At harvest, seedlings from each treatment were carefully removed from the pots without damaging the root system. Roots were washed with water and shoot and root lengths were measured. Several randomly selected roots from each treatment were stored in test tubes with water for later quantification of mycorrhizal colonization, while the remaining root mass was dried along with shoots for quantifying total biomass and nutrient contents. For calculating mycorrhizal colonization, roots from the test tubes were cleared in 10% KOH, autoclaved for 10 minutes, acidified with 1% hydrochloric acid, stained with cotton blue, and percent mycorrhizal colonization were recorded [45, 46]. Nutrient contents (phosphorus and potassium) of the seedlings from each treatment were measured after oven drying of seedlings. The seedlings were pre-digested with a mixture of nitric acid and hydrogen peroxide overnight, followed by microwave heating for 15 minutes [47]. Total nitrogen was determined using Kjeldahl method [48].

From each treatment, the amount of total glomalin-related soil protein (T-GRSP) and easily extractable glomalin-related soil protein (EE-GRSP) were determined [49]. One gm of rhizospheric soil from different treatments was air dried, incubated with 8 ml of 20 mM sodium citrate solution (pH 7.0), autoclaved at 121^0C for 30 min and then centrifuges at 1000 rpm for 15 min to extract EE-GRSP. The T-GRSP was extracted with 8 ml of 50 mM sodium citrate solution (pH 8.0) by autoclaving at 121^0C for 30 min. The procedure was replicated 5 times and all suspensions were collected. The T-GRSP and EE-GRSP concentrations were determined spectrophotometrically by the Bradford dye-binding assay using bovine serum albumin as the standard [50].

2.4 Statistical analysis.

Data were subjected to analysis of variance [51]. Individual means were compared using Scheffe's test for multiple comparisons using SAS software [52]. Means followed by the same letters (a,b,c and so on) in bars in the graphs and tables for a particular treatment are not significantly ($P = 0.05$) different from each other by Scheffe's test for multiple comparison.

3 RESULTS

3.1 Effect of P. flourescens and R. irregularis on seedlings mortality, growth, mycorrhizal colonization, and nutrient contents of A. fistulosum seedlings under saline conditions.

Non-inoculated control seedlings when grown under saline soil, 55.6% seedlings failed to survive (Figure 1). Mortality of seedlings were 43.0% for *P. flourescens* and *22.0%* for *R. irregularis* when grown in saline soil (Figure 1). Lowest mortality (9%) was recorded when seedlings were co-inoculated with *P. flourescens* and *R. irregularis* in saline soil (Figure 1). Seedlings grown without NaCl had no mortality (Figure 1).

3.2 Shoot length and root length.

Shoot and root length of *A. fistulosum* were significantly higher when seedlings were inoculated with *R. irregularis* alone and in combination with *P. flourescens* in saline soils (Figure 2). Lowest shoot lengths were observed in non-inoculated control seedlings compared to other treatments (Figure 2). In all treatments, seedlings grown in saline soils had lower shoot and root length compared to seedlings grown in soil without NaCl (Figure 2).

3.3 Biomass production.

When *A. fistulosum* seedlings were co-inoculated with

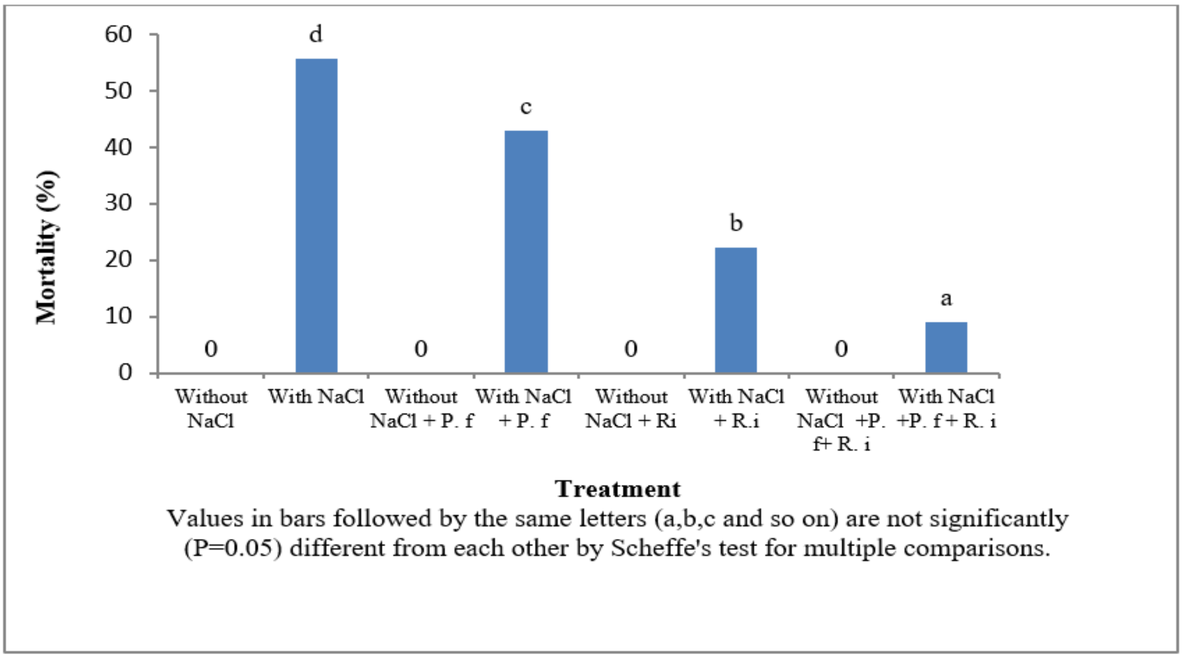


Figure 1 – Effect of *P. flourescens* and *R. irregularis* on mortality in *A. fistulosum* seedlings grown in saline and non-saline soils.

both *P. flourescens* and *R. irregularis,* significant higher biomass was obtained in both saline and non-saline soils (Figure 3). Lowest biomass was recorded in non-inoculated control seedlings grown in saline soils (Figure 3). Salinity significantly reduced the production of biomass of *A. fistulosum* seedlings in all inoculated and non-inoculated seedlings compared to seedlings grown without NaCl (Figure 3).

3.4 Mycorrhizal colonization:

Seedlings inoculated with *R. irregularis* and in combination with *P. flourescens* had a lower arbuscular mycorrhizal colonization in saline soils compared to seedlings grown in non-saline soils. Mycorrhizal colonization was stimulated when *R. irregularis* was co-inoculated with *P. flourescens* (Figure 4). No mycorrhizal colonization was observed in non-inoculated control and seedlings inoculated with *P. flourescens* (Figure 4).

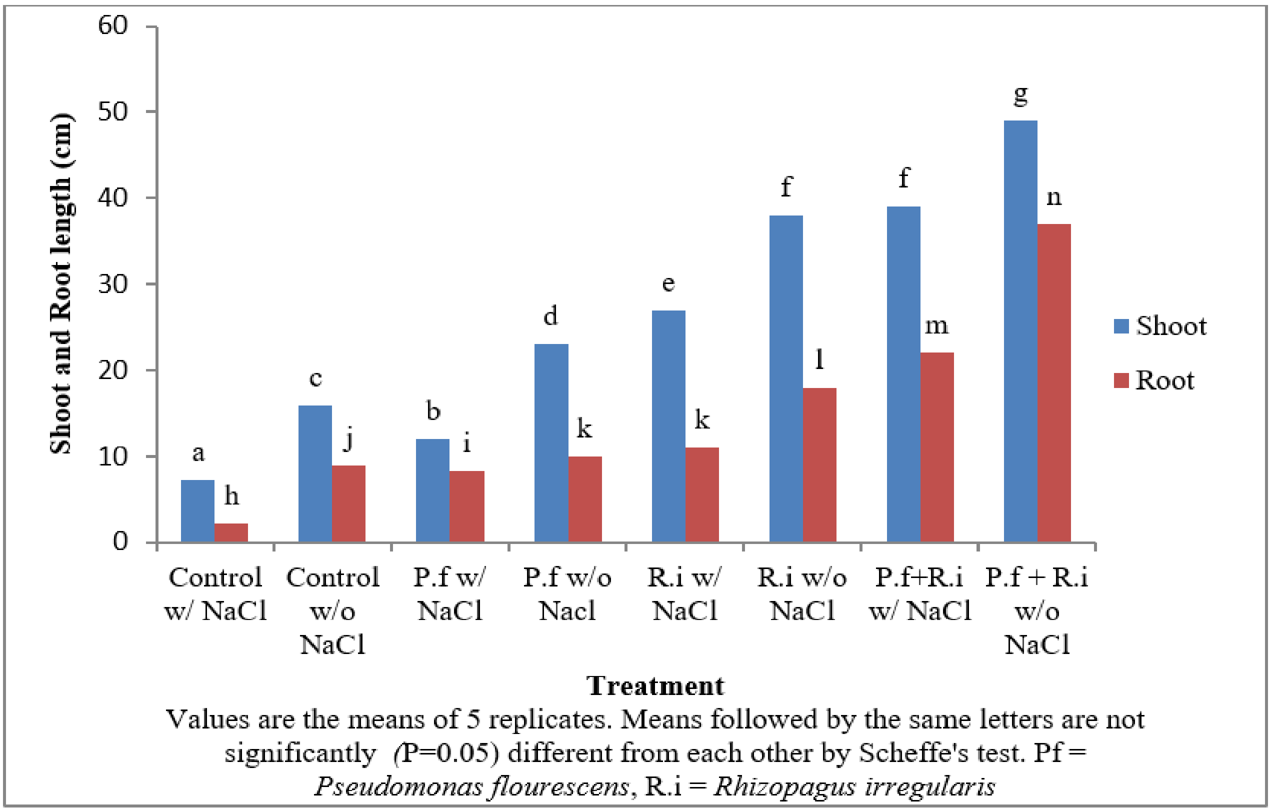
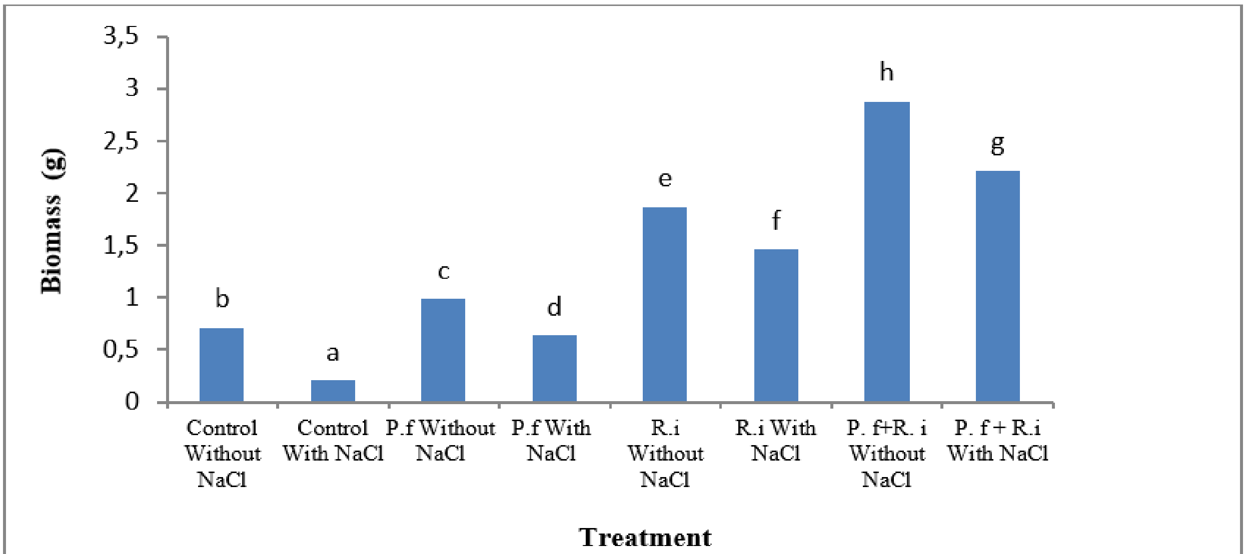
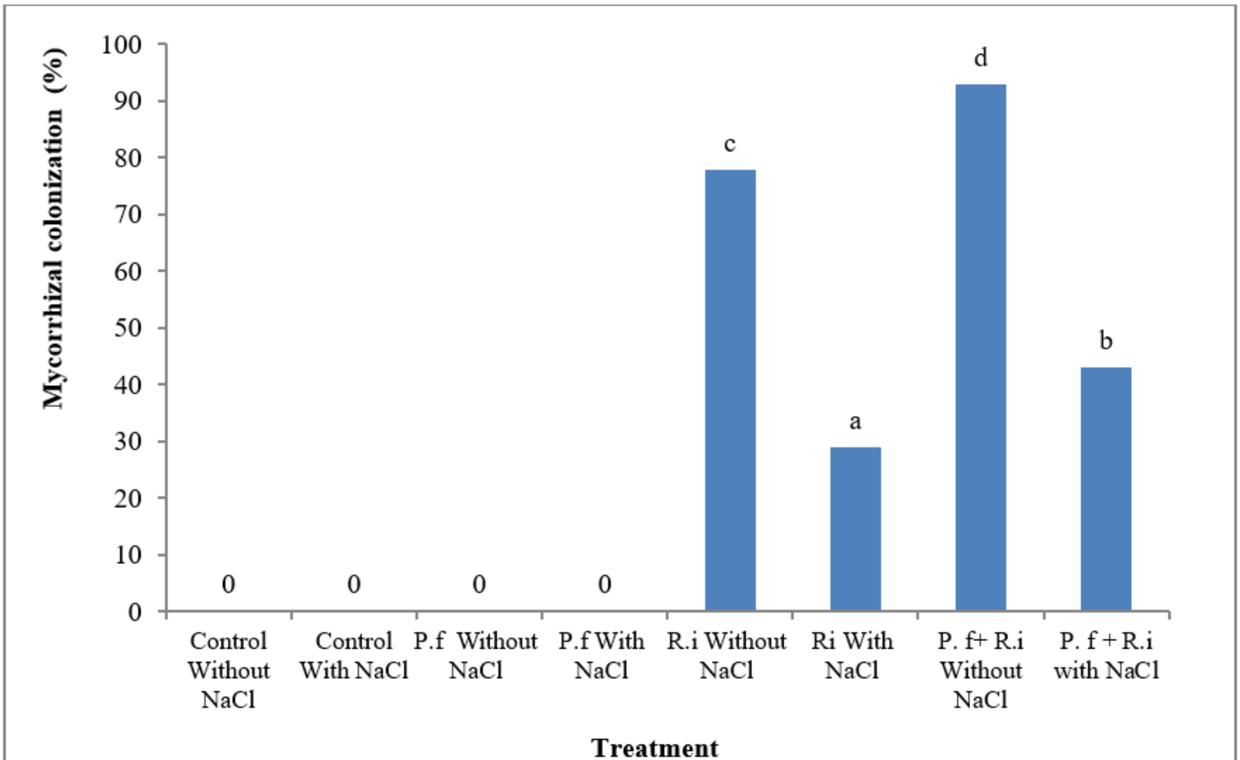


Figure 2 – Effect of *P. flourescens* and *R. irregularis* on shoot and root length in *A. fistulosum* seedlings grown in saline and non-saline soils.



Values in bars followed by the sames letters are not significantly (P=0.05) different from each other by Scheffe's test. P.f = *Pseudomonas flourescens*, R.i = *Rhizopagus irregularis*

Figure 3 – Effect of *P. flourescens* and *R. irregularis* on biomass production in *A. fistulosum* seedlings grown in saline and non-saline soils.



Letters in bars followed by the same letters (a,b,c, and d) are not significantly (P=0.05) different from each other by Scheffe's test. P.f = *Pseudomons flourescens*, R.i = *Rhizopagus irregularis*

Figure 4 – Effect of *P. flourescens* and *R. irregularis* on mycorrhizal colonization in *A. fistulosum* seedlings grown in saline and non-saline soils.

3.5 Nutrient contents

The amount of nitrogen, phosphorus, and potassium was significantly higher when *A. fistulosum* seedlings were inoculated with *P. flourescens* and *R. irregularis* alone or in combinations saline soils (Table 1). The highest amount of nitrogen, phosphorus and potassium was observed when seedlings were co-inoculated with both *P. flourescens* and *R. irregularis* in non-saline soils (Table 1). Non-inoculated control seedlings had lowest amount of nitrogen, phosphorus, and potassium content when grown in saline soil (Table 1).

Table 1 – The effect of *P. flourescens* and *R. irregularis* on nutrient uptake in *A. fistulosum* seedlings grown in saline soil.

Treatment	Nitrogen (g/kg)	Phosphorus (g/kg)	Potassium (g/kg)
Control – with NaCl	0.064_a	0.071_a	0.121_a
Control – without NaCl	0.313_b	0.154_b	0.581_b
P. flourescens (*P.f*) – with NaCl	0.389_b	0.149_b	0.498_c
P. flourescens (*P.f*) – without NaCl	0.467_c	0.311_c	1.131_d
R. irregularis (*R.i*) – with NaCl	0.967_d	0.812_d	1.413_e
R. irregularis (*R.i*) – without NaCl	3.872_f	2.443_f	2.872_g
P.f + *R.i* – with NaCl	1.667_e	1.117_e	1.931_f
P.f + *R.i* – without NaCl	4.793_g	3.371_g	3.673_h

Values are the means of three replicates. Means followed by the same letters (a,b,c and so on) in columns for a particular element are not significantly (P=0.05) different from each other by Scheffe's test for multiple comparison.

3.6 Total glomalin-related soil protein (T-GRSP-mg per g), easily extractable glomalin-related soil protein (EE-GRSP - mg/g), and soil aggregate stability

Total T-GRSP and EE-GRSP were highest in the rhizosphere of seedlings when co-inoculated with *P. flourescens* and *R. irregularis* grown in non-saline soil. Inoculated seedlings significantly improved the glomalin production when grown in saline soils. No glomalin was reported in non-inoculated control and seedlings inoculated with *P. flourescens* in the rhizosphere of *A. fistulosum* in both saline and non-saline soils (Table 2).

The soil aggregate stability was significantly improved when seedlings were inoculated with *P. flourescens* and *R. irregularis* alone or in combinations in saline soils compared to non-inoculated seedlings. The highest amount of soil aggregate stability was observed when seedlings were co-inoculated with both *P. flourescens* and *R. irregularis* in non-saline soils. Non-inoculated control seedlings had lowest amount of soil aggregate stability when grown in saline soil (Table 2).

4 DISCUSSION

Rising sea level is one of the major environmental problems which reduces agricultural productivity worldwide [4, 53]. As sea water enters the low-lying coastal arable lands, crop productivity is seriously affected. The harmful effect of salinity causes Na^+ and Cl^- ions to accumulate in the lands and reduce the soil water potential to agricultural crops. Excess of Na^+ and Cl^- accumulate in the cytoplasm cause both osmotic and ion stress in plants. However, plants adapt biochemically and physiologically to alleviate the harmful effects of salinity through ion homeostasis, compartmentalization, osmotic regulation, solute biosynthesis, antioxidant enzyme activation, antioxidant compound synthesis, polyamine synthesis, hormone modulation, and nitric oxide generation [54-56]. Beneficial soil microorganisms offer great potential for alleviating detrimental effects of salinity in agricultural practices. Among beneficial microorganisms' arbuscular mycorrhizal fungi and rhizospheric bacteria are potential candidates for mitigating salinity stress. Arbuscular mycorrhizal fungi are an important beneficial soil-inhabiting fungus in natural ecosystems which form symbiotic associations with most land plants. They form fungal networks connecting plant roots and soil and can influence plant growth, nutrient uptake, combat against root pathogens, and form plant-microbe-soil interactions [57, 58]. Several studies have shown that arbuscular mycorrhizal fungi can alleviate saline stresses [59-67] and this is mainly due to the combination of nutritional, physiological, biochemical changes, and microbial associations with plants [63, 68].

In our study, growth of *A. fistulosum* seedlings were significantly stunted and showed higher rates of mortality in saline soils when grown without any microbial treatment. The efficiency of the arbuscular mycorrhizal fungi and rhizospheric bacteria is determined in terms of plant growth,

Table 2 – Total glomalin-related soil protein (T-GRSP-mg/g), easily extractable glomalin-related soil protein (EE-GRSP - mg/g), and soil aggregate stability (%) in the rhizosphere of *A. fistulosum* under different treatments.

Treatments	T-GRSP	EE-GRSP	Soil Aggregate stability (%)
Control – with NaCl	0.000_a	0.000_a	0.097_a
Control – without NaCl	0.000_a	0.000_a	0.887_b
P. flourescens (*P.f*) – with NaCl	0.000_a	0.000_a	0.391_c
P. flourescens (*P.f*) – without NaCl	0.000_a	0.000_a	1.109_d
R. irregularis (*R.i*) – with NaCl	1.897_b	1.993_b	2.114_e
R. irregularis (*R.i*) – without NaCl	4.914_c	4.381_c	4.872_e
P.f + *R.i* – with NaCl	3.916_b	3.141_b	3.204_c
P.f + *R.i* – without NaCl	5.793_d	4.992_d	7.511_h

Values are the means of five replicates. Means followed by the same letters (a,b,c and so on) in columns for a particular glomalin are not significantly (P=0.05) different from each other by Scheffe's test for multiple comparison.

biomass production, and nutrient content under saline condition. It was found that *A. fistulosum* seedlings inoculated with mycorrhizal fungi always outperformed non-mycorrhizal seedlings when subjected to saline stress. Mycorrhizal fungal hyphae are thinner than plant roots and can facilitate absorption of water-filled pores, which otherwise are inaccessible to roots [61]. Both mycorrhizal fungi and rhizospheric bacteria boosted overall plant growth and nutrient uptake, which is consistent with the results of other studies showing mycorrhizal fungi can alleviate the negative effects of salt and improve plant growth [69, 70, 35, 71, 72, 22]. This could be attributed to the fact that improvement in saline soils in *A. fistulosum* leaves had higher carbon assimilation rate, photosynthesis, and the antioxidant capacities [73]. Mycorrhizal fungi produce hyphae that can extend far beyond the reach of plant roots and transport the elemental nutrients to intracellular arbuscles to the colonized roots. Rhizospheric bacteria on the other hand, produce various plant growth hormones such as indole-acetic acid, gibberellic acid and cytokines, which can enhance overall healthier plant growth. Superior plant growth and nutrient uptake (nitrogen, phosphorus and potassium) by *A. fistulosum* seedlings were evident in this study when seedlings were inoculated with *P. flourescens* and *R. irregularis* alone and in combinations.

Salinity decreases plant growth by lowering water content of the soil and adding excessive salts moving in the transpiration stream to leaves and causing leaf damage [4, 18]. Salinity inhibits photosynthetic ability that leads to decrease in crop production. Salt stress causes reduction of chlorophyll content due to suppression of specific enzymes that are responsible for synthesis of photosynthetic pigments [74]. In our study, *A. fistulosum* seedlings showed higher rate of mortality when grown in saline soil without any microbial inoculation. Both *R. irregularis* and P. *flourescens* significantly increased seedling survival, shoot and root length, total biomass, and nutrient uptake compared to non-inoculated seedlings in saline soils. Mycorrhizal colonization of *R. irregularis* was significantly reduced when grown in saline soils, however, mycorrhizal colonization was significantly increased when co-inoculated *P. flourescens* in both saline and non-saline soils. Mycorrhizal fungal hyphae can regulate roots to manage salt stress, maintain ionic homeostasis and osmotic equilibrium, and modulate plant hormone profile to minimize salinity effects on growth and development [64, 74-77]. In our study, both *P. flourescens* and *R. irregularis* reported to help *A. fistulosum* seedlings by managing toxic effect of salinity and helping nutrient uptake at the same time.

Recent studies have shown that arbuscular mycorrhizal fungi produce glomalin and increase soil aggregation under stress conditions [44]. Glomalin is a special class of glycoprotein, released by spores and hyphae of arbuscular mycorrhizal fungi [78]. This protein plays an important role in detoxifying toxins, accumulating soil organic carbon and soil aggregates, and regulating plant growth [78-84]. In our study, dual inoculation with *P. flourescens* and *R. irregularis* significantly increased glomalin production and soil aggregation in both saline and non-saline soils compared to single inoculation with *R. irregularis* alone in similar soils. It is interesting to note that *P. flourescens* alone did not produce any glomalin or increase soil aggregation in both saline and non-saline soils, however, glomalin production and soil aggregation were significantly increased in the presence of *R. irregularis* in saline soils. The synergistic effect of *P. flourescens* and *R. irregularis* in glomalin production and soil aggregation is unknown and needs further study. For non-inoculated control and seedlings inoculated with *P. flourescens*, no glomalin production was recorded in both saline and non-saline soils since there were no spores or hyphae of *R. irregularis* in the rhizosphere. This indicates that glomalin is produced only in the presence of arbuscular mycorrhizal fungi. Similarly, soil aggregation was lowest in both saline and non-saline control soils since there were no microorganisms present to aid in soil aggregation.

Rising sea level has adversely affected fertility status, depleted soil nutrients, increased salinity contents, and changed physio-chemical properties of arable soils in low-laying lands. Mycorrhizal fungi and rhizospheric bacteria induce tolerance against salinity stress by enhancing root proliferation, total biomass production, and improving the water use efficiency to minimize the oxidative stresses and improve osmoregulation. Under salinity stress these microorganisms produce bioactive metabolites which help in their endurance and provide synergistic effect to plant growth and crop production. A combination of arbuscular mycorrhizal fungus and plant growth promoting bacteria offer an alternative approach that may provide a significant impact on physiological and biochemical changes of *A. fistulosum*. This approach can lead to an increase in photosynthesis, defense against oxidative damage, and overall superior growth under saline conditions. Further studies are needed under field conditions to see if these microorganisms offer similar beneficial effects in saline soils affected by rising sea level.

CONCLUSION

Due to global warming, sea water levels are rising and flooding low-lying arable lands. Agricultural plants that are facing salinity problems are lethal to plant survival and crop production. Under saline conditions, plants suffer from Na^+ and Cl^- toxicity that causes damage to cellular organelles, disrupts osmotic potentials, and impact photosynthetic efficiency. Beneficial soil microorganisms, particularly arbuscular mycorrhizal fungi and plant growth promoting bacteria, offer potential for mitigating adverse effects of Na^+ and Cl^- toxicity in the soil. These microorganisms could be an environmentally friendly approach for reducing toxic effects of salinity.

COMPETING INTEREST

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work presented in this paper.

ACKNOWLEDGEMENTS

We would like to thank the staff members of Pasteur Laboratory's Microbiology Department for their technical support.

FUNDING

This research was funded by Pasteur Laboratory's Environmental Stress Project.

AUTHORS CONTRIBUTION

The corresponding author (P.C.) carried out the experiment, collected the empirical data, and wrote the paper. The co-author (C.Z.) performed chemical analysis of the samples and analyzed data. Both the authors have read and agreed to the published version of the manuscript.

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УДК: 613.166.9

РОЛЬ ПОЛЕЗНЫХ ПОЧВЕННЫХ МИКРООРГАНИЗМОВ В СМЯГЧЕНИИ ПАГУБНЫХ ПОСЛЕДСТВИЙ СТРЕССА ЗАСОЛЕНИЯ У *ALLIUM FISTULOSUM*

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АБСТРАКТ

За последние несколько десятилетий уровень моря поднялся в основном из-за глобального потепления. Это вызвало наводнения и повышенную соленость низколежащих прибрежных сельскохозяйственных земель. В результате засоления производство сельскохозяйственных культур серьезно сократилось. Настоящее исследование оценило влияние гриба арбускулярной микоризы *Rhizophagus irregularis* и ризосферной бактерии *Pseudomonas fluescens*, по отдельности и в двойной инокуляции, на выживаемость, рост, микоризную колонизацию, усвоение питательных веществ, выработку гломалина и агрегацию почвы растений зеленого лука в условиях засоления. В засоленности почвы выживаемость сеянцев, рост, общая биомасса, усвоение питательных веществ, выработка гломалина и агрегация почвы значительно увеличились при инокуляции *R. irregularis* и *P. fluescens*. Двойная инокуляция *R. irregularis* и *P. fluescens* оказалась лучше, чем одиночная инокуляция. *Pseudomonas fluescens* стимулировала микоризную колонизацию в засоленных почвах. Полученные результаты показывают, что арбускулярные микоризные грибы и полезные ризосферные бактерии обладают потенциалом для смягчения стресса от засоления у *A. fistulosum*.

Ключевые слова: *глобальное потепление, устойчивость к засолению, Pseudomonas fluorescens, Rhizophagus irregularis, зеленый лук.*

ӘОЖ: 613.166.9

ТҰЗДЫЛЫҚТЫҢ *ALLIUM FISTULOSUM*-ҒА ЗИЯНДЫ ӘСЕРІН ЖҰМСАРТУДАҒЫ ПАЙДАЛЫ ТОПЫРАҚ МИКРООРГАНИЗМДЕРІНІҢ РӨЛІ

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АҢДАТПА

Соңғы бірнеше онжылдықта теңіз деңгейі негізінен жаһандық жылынуға байланысты көтерілді. Бұл су тасқынына және теңіз жағалауындағы ауылшаруашылық алқаптарында тұздылықтың жоғарылауына әкелді. Тұзданудың салдарынан егін шаруашылығы күрт төмендеді. Бұл зерттеуде *Rhizophagus irregularis* арбускулярлы микоризалы саңырауқұлақтың және ризосфералық *Pseudomonas fluescens* бактериясының жеке және қосарланған егу кезінде тіршілік етуіне, өсуіне, микоризаның колонизациясына, қоректік заттардың алынуына, сортаңдану жағдайында өсімдіктердің сортаңдануына әсері бағаланды. Топырақтың тұздылығында *R. irregularis* және *P. fluescens* егу кезінде өскіндердің тіршілігі, өсуі, жалпы биомассасы, қоректік заттардың сіңуі, гломалиннің түзілуі және топырақтың агрегациясы айтарлықтай артты. *R. irregularis* және *P. fluescens* екі рет егу бір реттік егуден жоғары болды. *Pseudomonas fluescens* тұзды топырақта микоризалардың колонизациясын ынталандырды. Нәтижелер арбускулярлы микоризальды саңырауқұлақтар мен пайдалы ризосфералық бактериялардың *A. fistulosum*-дағы тұздылық стресін азайтуға мүмкіндігі бар екенін көрсетеді.

Түйін сөздер: *жаһандық жылыну, тұздылыққа төзімділік, Pseudomonas fluorescens, Rhizophagus irregularis, жасыл пияз.*