Effects of *Bacillus amyloliquefaciens* on Volatile Components and Nutrient Element Contents of *Mentha piperita* L. Grown under Salt Stress

Songül Tuğba Üner, and Aslıhan Cesur Turgut *

Bacillus amyloliquefaciens (*Ba*) was applied to *Mentha piperita* L. (peppermint) seedlings grown at various salt levels (0, 50, 75, and 100 mM) for 42 days (six weeks). The study was conducted in a total of eight groups, with 24 seedlings per group. At the end of the study, the seedlings were analyzed for plant nutrient elements and volatile compound contents. The negative effect of salt was observed in almost all parameters. When all groups were evaluated for plant nutrient elements, *Ba* had a positive effect on Zn, Mn, Cu, and Na values compared to the control, but it did not show any effect on B, Fe, K, P, Mg, and Ca. In volatile compounds, limonene was detected as the major component in all groups. As a result of the evaluation based on limonene, the highest rate was found in the control, and the lowest rate was found in 100 mM NaCl. The salt-dependent inhibition between the groups with the highest and lowest limonene was 73%. While the negative effects of salt were observed in almost all parameters, the promoter effects of *Ba* were not as pronounced.

DOI: 10.15376/biores.19.2.2826-2841

Keywords: Peppermint; Mentha piperita L.; Bacillus amyloliquefaciens; Salt stress; Volatile components; SPME; Nutrient elements

*Contact information: Burdur Mehmet Akif Ersoy University, Burdur Food Agriculture and Livestock Vocational School, 15030, Burdur, Türkiye; *Corresponding author: acesur@mehmetakif.edu.tr*

INTRODUCTION

Climate change affects agriculture in many ways. Salinity, droughts, floods, and rainfall distribution changes greatly impact agriculture and land use (Nong *et al.* 2021). Crop yields, maturity periods, livestock feed shortages, animal health issues, and crop quality and quantity decrease due to climate change (Singh 2019). It may also lower crop yields and boost new crop growth (Setu *et al.* 2019). Climate change affects soil health, erosion, water availability, pests, diseases, and weeds, lowering agricultural productivity (Abdel-Maksoud 2018). It can also disrupt irrigation water, which is vital for food crop production (Joyo and Ram 2018). In some areas, climate change will intensify salt stress on agricultural soils (Etesami and Beattie 2018). Climate change causes crop and seed failure due to unpredictable weather (Syahputra and Sucahyono 2022). It dehydrates and salinates fertile soils, limiting food production (Teshaeva and Sadriddinova 2021). Climate change may aggravate drought, heat, salinity, and flooding (Andjelkovic 2018). Kumar and Gautam (2014) revealed that even a little increase in global warming-induced evapotranspiration demand can deplete fragile desert ecosystems' water resources.

Plant growth-promoting bacteria (PGPB) have been widely explored to reduce salt stress in numerous plant types. PGPB improves plant tolerance to abiotic stresses, including salt (Santos *et al.* 2018). Endophytic PGPB preserves plant performance better than rhizospheric PGPB under salt stress, perhaps due to their closer relationship with the host (Heydarian *et al.* 2016).

Several studies have shown that PGPB induces the synthesis of osmolytes, which assists the resistance of plants to salt stress, promoting plant development, and salt tolerance (Hmaeid *et al.* 2019). For example, PGPB bio-inoculation also reduces salt stress by regulating plant antioxidant defense (Ma *et al.* 2022). PGPB may also improve plant performance in salt-affected soil (Al-Garni *et al.* 2019). To improve plant salt stress resistance, PGPB is a sustainable and cost-effective option (Ayuso-Calles *et al.* 2021).

Plant growth-promoting bacterium inoculation improves plant growth and stress tolerance. Salt stress has been studied in relation to *Bacillus amyloliquefaciens* (*Ba*), a PGPB species. Plant-associated *Ba* promotes plant growth and produces secondary compounds that reduce soil-borne plant diseases (Chen *et al*. 2007). *Ba* strains may colonize plant organs and endure intense plant response reactions, encouraging plant growth (Fan *et al*. 2017). This bacterium promotes plant development and removes organophosphorus herbicides (Ngalimat *et al*. 2021). *Ba* degrades plant polysaccharides and can withstand high temperatures, pressures, and acidic or alkaline conditions (Hong *et al*. 2019). *Ba* strains can help plants grow faster, fight off infections, and be healthier by changing the structure of the microbial community in the rhizosphere which makes the plants more resistant throughout their bodies (Liu *et al*. 2021). Inoculating corn seeds with *Ba* improves plant development and grain yield (Silva *et al*. 2023). The bacterium improves plant health by increasing disease and insect resistance (Li *et al*. 2015). *Ba* strains are frequently employed in agriculture to boost crop output, plant growth, and disease control (Zhao *et al*. 2015). They inhibit a wide range of plant pathogenic fungi, indicating their potential as agricultural biocontrol agents (Zhang *et al*. 2016). *Ba* also makes plants better able to handle *Fusarium oxysporum*, water, and nutrient stress (Prisa 2021). In salinized soils, *Ba* increases photosynthetic activity and oxidative stress tolerance (Rossi *et al.* 2021). *Bacillus amyloliquefaciens* affects salt-stressed plants through unknown methods. However, it known that salt stress impacts plant ion homeostasis and Na^+ transport-related gene expression (Sun *et al.* 2021). PGPB, especially *Ba*, may affect ion homeostasis and gene expression in salt-stressed plants, improving salt tolerance. PGPB, including *Ba*, communicate and benefit when they form a consortium, especially under various stress circumstances (Santoyo *et al.* 2021).

In this study, the effects of *Bacillus amyloliquefaciens* (*Ba*) a halotolerant species, were examined on the volatile compounds and plant nutrients of *Mentha piperita* L. seedlings grown under salt stress.

EXPERIMENTAL

Materials

Mentha piperita L. (peppermint) seedlings, *Bacillus amyloliquefaciens* (Cilus Plus), NaCl (Merck KGA, Germany), torf (Klasmann), and perlite (Klasmann) were commercially purchased. Four-week-old seedlings were purchased from Kırcami Fide Agricultural Company in Antalya/Türkiye. Cilus Plus is a microbial preparation containing a high concentration (2×10^{10} CFU/g) of *Bacillus amyloliquefaciens* strain IT45 isolated through Lallemand Research.

Experimental Design

Planting and application details

Seedlings were divided into eight equal groups, and the experiment was set up with 24 seedlings per group. There are three repetitions for each group and eight seedlings in each repetition.

Table 1. Experimental Groups

Groups	
1.	Control (non-bacterial and non-saline conditions)
2.	*Ba + non-saline conditions
3.	50 mM NaCl
4.	*Ba* + 50 mM NaCl
5.	75 mM NaCl
6.	*Ba* + 75 mM NaCl
7.	100 mM NaCl
8.	*Ba* + 100 mM NaCl
*Ba: *Bacillus amyloliquefaciens*	

In the first stage of the study, 4-week-old peppermint seedlings of similar sizes (10 to 12 cm) were planted in the seedling trays containing a mixture of 50% perlite and 50% sterile peat, and 24 samples were included for each group. All seedlings (24 seedlings) belonging to the same group were placed in the 24-cell tray (8*3), but each seedling was watered separately. For statistical studies, each of these three rows was considered a repetition, and statistics were applied that way. Seedling trays were left to grow and develop for 6 weeks (42 days) at 19 ± 1 °C in a climate chamber with a 16-h light (12000 lux) and 8-h dark photoperiod (Sabzalian *et al* 2014; Üner and Cesur Turgut 2023). The experiment started with the planting of four-week-old seedlings. On the day of planting, the seedlings were watered only with distilled water, and then NaCl solutions (in distilled water) were applied six times at six-day intervals. Measurements were made 42 days after planting (70-day-old seedlings).

Salt and bacteria applications

Tort and Türkyılmaz (2003) report that NaCl is usually mentioned when soil salinity and salt stress are discussed. For this reason, only NaCl was used to create salinity stress. Salt levels for peppermint seedlings were determined at control (non-bacterial and non-saline), 50 mM, 75 mM, and 100 mM NaCl based on the literature and after preliminary studies (Tüzüner 1990; Tort and Türkyılmaz 2003; Baydar and Çoban 2017). Bacteria applications are grouped in four different ways (*Ba* + non-saline, *Ba* + 50 mM, *Ba* + 75 mM, and *Ba* + 100 mM NaCl). Salt applications were applied to the seedlings planted in the peat-perlite mixture at a rate of 30 mL/seedling.

Microbial fertilizer solution was prepared at the rate recommended on the package (1.6 g/10 L), taking into account the total peat-perlite volume. The prepared solution was applied to each eye (30 mL/seedling) twice, the day after planting and 28 days (4 weeks) later, in accordance with the instructions.

Obtaining data

The study continued for six weeks (42 days after planting). At the end of 42 days, the following analysis of volatile components and plant nutrient elements was made in accordance with the literature.

Volatile component analyses were carried out in solid phase microextraction/gas chromatography (SPME/GC) at Burdur Mehmet Akif Ersoy University scientific and technology application and research center. Aerial parts of *Mentha piperita* L. were used for SPME (sample weight 1.0 g) analysis. The starting temperature in oven was kept at 60 °C. After waiting at 60 °C for 2 min, it was increased to 220 °C with an increase of 2 °C/min. It was held at this temperature for 20 min (Baydar *et al.* 2013; Taherpour *et al*. 2017). The detector and injector temperatures were set at 250 and 240 °C. Analyses were performed on the Agilent 5975 C Agilent 7890A device (Agilent Technologies, Santa Clara, CA, USA) with a CP WAX 52 CB column.

Plant nutrient elemental analysis was performed at Burdur Mehmet Akif Ersoy University scientific and technology application and research center. Dried aerial parts of *Mentha piperita* L. were used for ICP-OES analysis. By grouping the samples (1.0 g per sample), washed by tap water first and deionized water secondly, and dried at 70 °C for 48 hours. The dried samples were then pulverized using a blender. For P, K, Ca, Fe, Zn, Cu, Mn, B, Na, and Mg analysis, the samples were microwaved (Milestone Stard D, Sorisole Bergamo, Italy), and the readings were taken with the Perkin Elmer Optima-8000 (Waltham, MA, USA), which was taken using the ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry) device (Saltan and Seçilmiş Canbay 2015).

Statistical evaluation of results

The statistical significance of the differences between the averages in the data obtained was analyzed with the Duncan ($P < 0.05$) multiple comparison test in SPSS (IBM-SPSS Inc., Armonk, NY, USA) version 25.0, and the values are given as mean ± SD (standard deviation) (Efe *et al*. 2000).

RESULTS AND DISCUSSION

Nutrient Elements

When applying bacteria *Ba* to peppermint seedlings under salt stress, the effects on the intake of Zn (zinc), B (boron), Mn (manganese), Fe (iron), Cu (copper), Na (sodium), K (potassium), P (phosphorus), Mg (magnesium), and Ca (calcium) elements were examined. The results of this examination (Table 2) are discussed below.

When the results were evaluated, Zn values increased depending on salt levels. The highest value was found in *Ba* + 100 mM NaCl compared to the control (74.2% increase), and the lowest value was detected in the control. It was observed that at almost all salt levels (except 75 mM), bacteria-applied groups contained higher Zn content than non-bacterial groups. There are many studies in literature showing that salt stress increases Zn values, and this is compatible with the authors' results (Maas *et al.* 1972; Chavan and Karadge 1980; Martinez *et al*. 1987; Alpaslan *et al*. 1998). Additionally, there are studies showing that *Bacillus* species, as one of the PGPB species, increase zinc uptake and support the current study's results (Turan *et al*. 2007). Singh *et al*. found that *Bacillus amyloliquefaciens* increased zinc uptake in wheat despite salt stress. It is thought that mechanisms such as bacteria's phosphate solubilization abilities, ion exchange capacities, and antioxidant production are effective in increasing Zn uptake (Singh *et al.* 2021).

When B results were examined, unlike Zn, the highest value was observed in the control, while the lowest value was detected in *Ba* + 100 mM NaCl (more than 50% decrease). With increasing salinity, a regular decrease in B amounts was observed in both bacteria-applied and non-applied groups. The decrease in stomatal conductance under salinity stress limits the movement of water and nutrients, including boron, within the plant, thereby reducing boron uptake (Carvajal *et al*. 2023). Additionally, high concentrations of sodium and chloride ions in the soil solution under salinity stress can have detrimental effects on plant growth and yield, potentially leading to nutrient imbalances, including boron deficiency (Tavakkoli *et al*. 2010). Studies in the literature that show salinity reduces B intake are in agreement with the results obtained (Holloway and Alston 1992). However, the presence of bacteria did not have a positive effect on B intake in the groups. There are studies on the positive effects of *Bacillus* species on boron intake (Masood *et al*. 2019), but they do not match the current results.

Manganese levels increased compared to the control in almost all groups (except *Ba* + non-saline). The Mn uptake increased in parallel with salt concentration. The highest values were detected at 75 and 100 mM NaCl, and the increase was ~110% compared to the control. The increase in Mn uptake with increasing salt levels in the current study is consistent with the literature (Maas *et al*. 1972; Chavan and Karadge 1980; Martinez *et al*. 1987; Alpaslan *et al*. 1998). There are reports indicating that PGPB can promote Mn uptake (Xue *et al*. 2011). In this study, it was observed that *Ba* had a salt stress-reducer effect only at 50 mM NaCl, but this level did not increase Mn uptake compared to the control or at other salt levels.

Iron uptake was highest in the control group with 68.7 mg, while the lowest uptake was in 50 mM NaCl with 42.6 mg (38% decrease). In non-bacterial groups, Fe intake decreased with increasing salt levels. Studies in the literature that show salinity limits Fe uptake in plants support these results (Rabhi *et al.* 2007). However, while Fe intake decreased in the presence of salinity compared to the control, it was observed that Fe intake increased with increasing salinity when salt levels were compared. Numerous factors are believed to be able to affect the increased absorption of Fe in higher salinity conditions. Some studies have demonstrated that plants may enhance the absorption of certain nutrients, such as iron, in response to salinity stress. Research has also shown that the application of iron nanoparticles can boost iron content in plants under salinity stress, suggesting a potential mechanism for increased iron absorption in saline conditions. Under saline-alkaline stress, plants may exhibit higher iron accumulation, potentially as a mechanism to cope with the stress condition (Askary *et al*. 2017; Zhou *et al*. 2017). *Bacillus amyloliquefaciens* alleviated salt stress only at 50 mM NaCl, just like Mn uptake, but could not increase it to the control level. There are studies showing that volatile organic compounds released by Ba increase Fe uptake (Wang *et al*. 2017). However, in this study, the positive effect of Ba on Fe uptake in the presence of salt was not clearly observed.

Copper levels increased in parallel to the increase in salt levels in almost all groups, except 100 mM. It was determined that Ba decreased Cu uptake only in Ba + 75 mM NaCl compared to 75 mM NaCl but increased it in 100 mM. As a result, an irregular increase or decrease was observed. Differences in other salt levels were statistically insignificant. Literature supports current results that Cu intake increases due to salt intake and concentration increases (Achakzai *et al*. 2010).

As expected, sodium intake increased significantly in parallel with the increase in salt (NaCl) levels. With this increase, the Na value, which was 0.7 g in the control, increased approximately 10 times to 6.8 g at the lowest concentration of 50 mM. These values continued to increase depending on the salt level. In *Ba* + 100 mM NaCl, it increased to the highest value of 17.4 g (~25 times). *B. amyloliquefaciens* application reduced Na uptake ~50% at 75 mM but increased ~12% at 100 mM. These results are intriguing. Multiple studies have demonstrated that the application of Ba can restrict the uptake of Na in saline conditions (Ashraf *et al*. 2004; Chen *et al*. 2016). Table 2 highlights the significant difference in Na uptake at higher rates compared to the control. It was determined that bacterial application caused a decrease in Na uptake at almost all salt concentrations (except 100 mM). In particular, there was a significant decrease of approximately 50% at 75 mM (between the bacteria-applied and non-bacterial groups). This reduction in Na uptake helps to alleviate Na toxicity and improve salt tolerance in the plant.

In terms of potassium intake, there was a decrease in the groups without bacterial application compared to the control, which was likely due to the effects of salt. However, there was no statistically significant difference observed in the bacterial groups. This is consistent with the results of Ruiz *et al.* (1997) and Tolay (2021), who also found a decrease in potassium intake under salt stress.

No significant differences were observed in phosphorus, magnesium, and calcium levels due to either salinity or bacterial application. This is in line with previous studies, such as Poss *et al*. (1985), who also found no effect of salinity on the uptake of these minerals.

In the literature, the inhibition of salt stress on growth parameters is generally mentioned. Salt (NaCl) stress affects plants in two ways: specific and osmotic effects (Al-Karaki 2001; Ghoulam *et al*. 2002). According to the first mechanism, it is stated that the greatest harms on physiological events are related to germination (Levit 1980). As a second mechanism, it is mentioned that salt inhibits post-germination morphogenetic developments due to its toxic effect on plant tissues in ion form (Chrominski *et al*. 1986; Üner and Cesur Turgut 2023). In addition, salt has many indirect effects. It can prevent germination by stopping mitosis (Cesur and Tabur 2011); it can prevent development and growth by preventing protein synthesis and nucleic acid synthesis; it can affect the permeability of the cell membrane (Yakıt and Tuna 2006); and it can affect the metabolic rate of the cell due to the antagonistic effect of Cl- or Na+ ions taken into the cells. It prevents the uptake of other ions, such as K^+ and Ca^{++}, which are necessary for their functions (Özcan 2000).

Table 2. Effect of *B. amyloliquefaciens* on Some Nutrient Elements in *Mentha piperita* L. Seedlings Grown Under Salt Stress

Groups	Zn (mg)	B (mg)	Mn (mg)	Fe (mg)	Cu (mg)	Na (g)	K (g)	P (g)	Mg (g)	Ca (g)
Control (non-saline and non-bacterial)	24.9 ±2.9^{a*}	65.9 ± 5.5^{f}	20.7 ± 1.9^{ab}	68.7 ± 9.1^{b}	3.8 ± 0.9^{a}	0.7 ± 0.5^{a}	25.0 ± 1.5^{b}	1.4 ± 0.0^{a}	2.3 ± 0.1^{a}	14.9 ± 0.8^{a}
***Ba* (non-saline)	27.6 ±5.1^{a}	52.5 ± 2.9^{e}	17.8 ± 4.9^{a}	58.3 ± 13.1^{ab}	3.1 ± 0.8^{a}	0.1 ± 0.0^{a}	19.7 ± 3.9^{ab}	1.4 ± 0.3^{a}	2.1 ± 0.8^{a}	13.4 ± 0.3^{a}

50 mM NaCl	27.8 ± 7.3^{a}	46.9 ± 3.8^{d}	31.1 ± 6.2^{abc}	42.6 ± 7.2^{a}	4.0 ± 0.8^{ab}	6.8 ± 0.9^{b}	18.4 ± 0.8^{a}	1.4 ± 0.1^{a}	2.6 ± 0.5^{a}	11.3 ± 0.1^{a}
***Ba* + 50 mM NaCl**	38.3 ± 4.9^{b}	44.0 ± 1.7^{cd}	37.0 ± 7.1^{bc}	67.9 ± 10.0^{b}	4.2 ± 0.2^{ab}	4.9 ± 0.9^{b}	20.7 ± 1.7^{ab}	1.5 ± 0.1^{a}	2.7 ± 0.4^{a}	14.3 ± 0.2^{a}
75 mM NaCl	39.5 ± 4.8^{b}	38.9 ± 1.4^{bc}	42.3 ± 19.4^{c}	46.7 ± 12.2^{ab}	5.5 ± 0.9^{b}	12.9 ± 0.1^{c}	22.9 ± 0.1^{ab}	1.8 ± 0.0^{a}	2.8 ± 0.1^{a}	14.4 ± 0.2^{a}
***Ba* + 75 mM NaCl**	38.4 ± 3.0^{b}	36.9 ± 2.5^{ab}	33.9 ± 2.5^{abc}	44.1 ± 11.0^{a}	3.4 ± 0.7^{a}	6.3 ± 0.1^{b}	20.9 ± 1.0^{ab}	1.3 ± 0.1^{a}	2.2 ± 0.1^{a}	13.1 ± 0.1^{a}
100 mM NaCl	34.7 ± 1.6^{ab}	35.3 ± 1.67^{ab}	42.8 ± 8.4^{c}	54.2 ± 3.1^{ab}	4.3 ± 0.6^{ab}	15.5 ± 2.6^{cd}	22.4 ± 3.8^{ab}	1.5 ± 0.3^{a}	2.9 ± 0.5^{a}	13.9 ± 0.2^{a}
***Ba* + 100 mM NaCl**	43.4 ± 8.3^{b}	31.8 ± 2.9^{a}	40.9 ± 15.0^{c}	58.1 ± 19.5^{ab}	5.4 ± 1.5^{b}	17.4 ± 0.4^{d}	20.1 ± 6.1^{ab}	1.7 ± 0.9^{a}	2.5 ± 0.5^{a}	11.3 ± 0.3^{a}

*Shows values with insignificant difference ($p < 0.05$) for each column shown with same letters (± standard deviation)
** *Ba*: *Bacillus amyloliquefaciens*

Plant growth-promoting rhizobacteria (PGPR) are soil bacteria that can contribute to plant growth and increase tolerance to stresses. As a result of the application of PGPRs in agriculture, benefits have been achieved in seed germination, crop yield, and disease resistance, and direct or indirect effects have been observed (Kloepper 1993; Van Loon 2007; Kuan *et al*. 2016). Plant hormones are made, ethylene levels are lowered, and plant nutrients (*via* the release of phosphate and micronutrients from insoluble sources and the fixation of non-symbiotic nitrogen) (Van Loon 2007) and microbial volatile organic compounds (mVOCs) (Ryu *et al*. 2004; Wenke *et al*. 2012; Santoro *et al*. 2015) are raised. There are studies showing that salt tolerance can be increased by adding beneficial microorganisms (PGPB, such as *Bacillus amyloliquefaciens*) to plant environments under salt stress conditions (Kim *et al*. 2013). In addition, such applications, which increase the ability to scavenge reactive oxygen species (ROS) in plants exposed to salt stress, increase antioxidant activities (Farag *et al*. 2013; Kim *et al*. 2013).

In the study of *Bacillus amyloliquefaciens*' intake of plant nutrients, it was determined that it increased the intake of Na, Zn, Mn, and Cu compared to the control, that it could not exceed the control values in B and Fe, and that there was no statistical difference between them and the control in P, Mg, and Ca (Table 2). The Ca^{2+} ion is one of the basic elements required for growth and development. K^{+} and Ca^{2+} uptake are affected by salt stress. Na^{+} replaces Ca^{2+} in the cell membrane, increasing the Na^{+}/Ca^{2+} ion ratio in the apoplast part of the membrane. In this case, both the physiological and functional structure of the membrane are disrupted, and the Ca^{2+} balance in the cell is affected. High Na^{+} concentrations in the inner membrane structures of the cell cause internal Ca^{2+} stores to be emptied and free Ca^{2+} to increase in the cell. It is also thought that too much NaCl can depolymerize microtubules and stop the formation of spindle fibers during cell division (Rengel 1992; Yokoi *et al.* 2002; Çulha and Çakır 2011). However, similar to our findings, there are also studies showing that high Na levels do not cause an increase in Ca and Mg, or even decrease them (Poss *et al*. 1985; Cook and Veseth 1991). It was found that increased K^{+} uptake due to *Bacillus licheniformis* helped tomatoes grow better in soils that were stressed by salt. However, there seem to be no increases in potassium in this study (Muthuraja and Muthukumar 2022). Inhibition of salt-dependent growth and development in plants may be due to the excess of Na^{+} ions in the environment and the plant being deprived of an essential nutrient by preferentially taking in Na^+ instead of potassium ions (K^+), as well as the inhibition of some enzyme systems (Okon 2019).

Volatile Components

The complete list of volatile components analyzed by SPME/GC for all groups is also provided. The proportions of volatile components in *Mentha piperita* L. seedlings of *B. amyloliquefaciens* under salt stress were evaluated. In the prepared Table 3, only volatile components present at 5% or more are stated.

When the volatile component numbers and major components were compared, limonene was detected as the major component in the control group (non-saline and non-bacterial), and there were 38 chemical components in total. Similarly, there are studies in the literature that identify limonene as the major component in *M. piperita* L. (Buleandra *et al*. 2016), which is compatible with current results. The effects of the bacteria on limonene, the major component in peppermint seedlings grown under salt stress, are also presented graphically.

There are studies in the literature showing that the components detected between the hydro-distillation and SPME methods may be different (Taherpour *et al*. 2017). For this reason, major components (menthol, menthone, *etc.*) that are generally detected as a result of hydro-distillation (Verma *et al*. 2010) were not found in this study. This difference is thought to be due to the method difference used.

In *Ba* (non-saline), 36 volatile components were detected, and the major component was limonene. Forty-nine volatile compounds were detected in 50 mM NaCl, 46 volatile compounds were detected in *Ba* + 50 mM NaCl, and the major component in both was carvotanaceton. Thirty-three volatile components were detected at 75 mM NaCl, and the major component was 2,4-decadienal. Thirty-nine volatile components were detected in *Ba* + 75 mM NaCl, 19 volatile components were detected in 100 mM NaCl, and the major component was carvotanaceton in both. Finally, 40 volatile components were detected in *Ba* + 100 mM NaCl and the major component was limonene.

Salt stress was found to reduce limonene and *cis*-dihydrocarvone values, but it was observed that application of bacteria did not increase the component percentages and only alleviated the effect of stress on limonene at 100 mM. It was determined that salt or bacterial application did not cause a regular increase or decrease in dihydrocarvone, carvotanaceton (2-cyclohexen-1-one, 2-methyl-5-(1-methylethenyl)), and eucalyptol (1,8-cineole) values. The values were fluctuating. Cyclohexene, 1-methyl-4-(1-methylethenyl), α-pinene, β-pinene, 2,4-decadienal, *trans*-caryophyllene, and carvol were the components detected in a single group. For this reason, no decrease or increase in these components could be observed. There are many studies that report salt stress changes the volatile component ratios in the plant and even causes the synthesis of components that are not present the control group (Khorasaninejad *et al.* 2010; Roodbari *et al.* 2013; Baydar and Çoban 2017). This literature is consistent with the results obtained.

Table 3. Effect of *B. amyloliquefaciens* on Volatile Components in *Mentha piperita* L. Seedlings Grown Under Salt Stress

Volatile Components * / Groups (NaCl)	Limonene (%)	Dihydrocarvone (%)	*cis*-Dihydrocarvone (%)	Carvotanaceton (%)	Eucalyptol (1,8-cineol) (%)	α-Pinene (%)	β-pinene (%)	2,4-Decadienal (%)	*trans*-Caryophyllene (%)	Carvol (%)
Control (non-saline and non-bacterial)	49.3	13.3	-	-	7.8	-	5	-	-	-
*******Ba*** (non-saline)**	36	12.1	-	21.8	8.7	5	-	-	-	-
50 mM NaCl	26.2	10.9	-	34.1	11.1	-	-	-	-	-
***Ba* + 50 mM NaCl**	20.9	17.3	-	24	7	-	-	-	-	-
75 mM NaCl	29.1	6	-	-	8.6	-	-	32.6	-	-
***Ba* + 75 mM NaCl**	25.2	-	19.2	28.2	-	-	-	-	-	-
100 mM NaCl	13.3	18.3	-	57.6	5	-	-	-	-	-
***Ba* + 100 mM NaCl**	22.5	-	7.8	15.1	6.1	-	-	-	5	13.8

*****Only components present at 5% or more are given in this table. Volatile component lists for all groups are shared at the end of the document

When the contents of the volatile components are summarized, in the control group, limonene was determined as the major component, and in the other groups, carvotanaceton and 2,4-decadienal were major components along with limonene. It was determined that salt stress reduced limonene and *cis*-dihydrocarvone values, but bacterial application did not increase the percentages of the components. The components given in Table 3, except for limonene, dihydrocarvone, eucalyptol (1,8 cineole), and β-pinene, which had the highest values in the control, were determined by stress/bacteria application. It was observed that *B. amyloliquefaciens* did not positively affect the accumulation of volatile compounds and secondary metabolites, contrary to the literature (Zhao *et al.* 2016) in the peppermint seedlings.

CONCLUSIONS

In this study, the effects of salt stress on plant nutrients and volatile compounds in *Mentha piperita* L. seedlings grown at various salt levels and periodically applied with *Bacillus amyloliquefaciens* were examined.

1. The inhibition effect of salt stress manifested itself in many parameters, as expected.

2. It was found that *B. amyloliquefaciens* did not increase the rates of volatile components or help *Mentha piperita* L. take in all nutrient elements, which was different from that had been observed before in other studies.
3. It is thought that the reason for this lack of effectiveness of *B. amyloliquefaciens* may be due to the insufficient six-week growth period of the seedlings or the insufficient number (twice) or rate of bacterial applications. Subsequent studies with longer-term and different doses of bacterial application may reveal more striking results.
4. This study was conducted to guide farmers and producers commercially who want to obtain information about the volatile component contents of *M. piperita*, grown from more qualified seedlings.

ACKNOWLEDGMENTS

This study is derived from master's thesis of Songül Tuğba Üner and is financially supported by "Burdur Mehmet Akif Ersoy University Scientific Research Projects Coordination" with the project number 0794-YL-21.

REFERENCES CITED

Abdel-Maksoud, B. M. (2018). "Estimation of air temperature and rainfall trends in Egypt," *Asian Journal of Advanced Research and Reports* 1(4), 1-22. DOI: 10.9734/ajarr/2018/v1i413090

Achakzai, A. K. K., Kayani, S. A., and Hanif, A. (2010). "Effect of salinity on uptake of micronutrients in sunflower at early vegetative stage," *Pakistan Journal of Botany* 42(1), 129-139.

Al-Garni, S. M., Khan, M. A. I., and Bahieldin, A. (2019). "Plant growth-promoting bacteria and silicon fertilizer enhance plant growth and salinity tolerance *Incoriandrum sativum*," *Journal of Plant Interactions* 14(1), 386-396. DOI: 10.1080/17429145.2019.1641635

Al-Karaki, G. N. (2001). "Germination, sodium, and potassium concentrations of barley seeds as influenced by salinity," *Journal of Plant Nutrition* 24(3), 511-522. DOI: 10.1016/j.ijbiomac.2018.11.155

Alpaslan, M., Güneş, A., Taban, S., Erdal, İ., and Tarakcıoğlu, C. (1998). "Variations in calcium, phosphorus, iron, copper, zinc and manganese contents of wheat and rice varieties under salt stress," *Turkish Journal of Agriculture and Forestry* 22*,* 227-233.

Andjelkovic, V. (2018). "Introductory chapter: Climate changes and abiotic stress in plants," in: *Plant, Abiotic Stress and Responses to Climate Change (Edt: Violeta Andjelkovic)*, IntechOpen Books, London, UK, pp. 1-8. DOI: 10.5772/intechopen.76102

Ashraf, M., Hasnain, S., Berge, O., and Mahmood, T. (2004). "Inoculating wheat seedlings with exopolysaccharide-producing bacteria restricts sodium uptake and stimulates plant growth under salt stress," *Biology and Fertility of Soils* 40, 157-162. DOI: 10.1007/s00374-004-0766-y

Askary, M. A. E., Talebi, S. M., Amini, F., and Bangan, A. D. B. (2017). "Effects of iron nanoparticles on *Mentha piperita* L. under salinity stress," *Biologija* 63(1). DOI: 10.6001/biologija.v63i1.3476

Ayuso-Calles, M., Flores-Félix, J. D., and Rivas, R. (2021). "Overview of the role of rhizobacteria in plant salt stress tolerance," *Agronomy* 11(9), article 1759. DOI: 10.3390/agronomy11091759

Baydar, H., Kuleasan, H., Kara, N., Secilmis-Canbay, H., and Kineci, S. (2013). "The effects of pasteurization, ultraviolet radiation and chemical preservatives on microbial spoilage and scent composition of rose water," *Journal of Essential Oil-Bearing Plants* 16(2), 151-160. DOI: 10.1080/0972060X.2013.794043

Baydar, N. G., and Çoban, Ö. (2017). "The effects of salt stress on growth, essential oil content and components of mint (*Mentha piperita* L.)," *Turkish Journal of Agriculture-Food Science and Technology* 5(7), 757-762. DOI: 10.24925/turjaf.v5i7.757-762.1178

Buleandra, M., Oprea, E., Popa, D. E., David, I. G., Moldovan, Z., Mihai, I., and Badea, I. A. (2016). "Comparative chemical analysis of *Mentha piperita* and *M. spicata* and a fast assessment of commercial peppermint teas," *Natural Product Communications* 11(4), 551-555. DOI: 10.1177/1934578X1601100433

Carvajal, M., Nicolas-Espinosa, J., Yepes, L., Martinez-Bernal, F., and Fernandez-Pozurama, M. (2023). "Deciphering the broccoli plants response to salinity and boron stress on with a focus on membranes and aquaporins," *Authorea Preprints* (2023), 1-16. DOI: 10.22541/au.167949022.22940247/v1

Cesur, A., and Tabur, S. (2011). "Chromotoxic effects of exogenous hydrogen peroxide (H_2O_2) in barley seeds exposed to salt stress," *Acta Physiologiae Plantarum* 33, 705-709. DOI: 10.1007/s11738-010-0594-7

Chavan, P. D., and Karadge, B. A. (1980). "Influence of salinity on mineral nutrition of peanut (*Arachis hyogea* L.)," *Plant and Soil* 54, 5-13. DOI: 10.1007/BF02181995

Chen, X. H., Koumoutsi, A., Scholz, R., Eisenreich, A., Schneider, K., Heinemeyer, I., Morgenstern, B., Voss, B., Hess, W. R., Reva, O., Junge, H., Voigt, B., Jungblut, P. R., Vater, J., Süssmuth, R., Liesegang, H., Strittmatter, A., Gottschalk, G., and Borriss, R. (2007). "Comparative analysis of the complete genome sequence of the plant growth–promoting bacterium *Bacillus amyloliquefaciens* fzb42," *Nature Biotechnology* 25(9), 1007-1014. DOI: 10.1038/nbt1325

Chen, L., Liu, Y., Wu, G., Veronican Njeri, K., Shen, Q., Zhang, N., and Zhang, R. (2016). "Induced maize salt tolerance by rhizosphere inoculation of *Bacillus amyloliquefaciens* SQR9," *Physiologia Plantarum* 158(1), 34-44. DOI: 10.1111/ppl.12441

Chrominski, A., Weber, D. J., Smith, B. N., and Khan, A. M. (1986). "NaCl-salinity-dependent conversion of ACC to ethylene in the halophyte, *Allenrolfea Occidentalis*," *Naturwissenschaften* 73, 274-275. DOI: 10.1007/BF00367785

Cook, R. J. and Veseth, R. J. (1991). "Wheat health management," *The American Phytopathological Society*, 3340 Pilot Knob Road, St. Paul, Minnesota 55121, USA.

Çulha, Ş., and Çakırlar, H. (2011). "The effect of salinity on plants and salt tolerance mechanisms," *Afyon Kocatepe University Journal of Science and Engineering* 11(2), 11-34.

Efe, E., Bek, Y., and M. Sahin. (2000). "Statistical methods with solutions using SPSS," in: *Course Book of the Rectorate of Kahramanmaras Sutcu Imam University*, Textbooks Publication No: 9, Kahramanmaraş Sütçü Imam University Publications, Kahramanmaras, Turkey.

Etesami, H., and Beattie, G. A. (2018). "Mining halophytes for plant growth-promoting halotolerant bacteria to enhance the salinity tolerance of non-halophytic crops," *Frontiers in Microbiology* 9, article 148. DOI: 10.3389/fmicb.2018.00148

Fan, B., Blom, J., Klenk, H. P., and Borriss, R. (2017). "*Bacillus amyloliquefaciens*, *Bacillus velezensis*, and *Bacillus siamensis* form an "operational group *B. amyloliquefaciens*" within the *B. subtilis* species complex," *Frontiers in Microbiology* 8(2017). DOI: 10.3389/fmicb.2017.00022

Farag, M. A., Zhang, H., and Ryu, C. M. (2013). "Dynamic chemical communication between plants and bacteria through airborne signals: Induced resistance by bacterial volatiles," *Journal of Chemical Ecology* 39, 1007-1018. DOI: 10.1007/s10886-013-0317-9

Ghoulam, C., Foursy, A., and Fares, K. (2002). "Effects of salt stress on growth, inorganic ions and proline accumulation in relation to osmotic adjustment in five sugar beet cultivars," *Environmental and Experimental Botany* 47(1), 39-50. DOI: 10.1016/S0098-8472(01)00109-5

Heydarian, Z., Yu, M., Gruber, M. Y., Glick, B. R., Zhou, R., and Hegedus, D. D. (2016). "Inoculation of soil with plant growth promoting bacteria producing 1-aminocyclopropane-1-carboxylate deaminase or expression of the corresponding acds gene in transgenic plants increases salinity tolerance in *Camelina sativa*," *Frontiers in Microbiology* 7, article 1966. DOI: 10.3389/fmicb.2016.01966

Hmaeid, N., Wali, M., Mahmoud, O. M., Pueyo, J. J., Ghnaya, T., and Abdelly, C. (2019). "Efficient rhizobacteria promote growth and alleviate nacl-induced stress in the plant species *Sulla carnosa*," *Applied Soil Ecology* 133, 104-113. DOI: 10.1016/j.apsoil.2018.09.011

Holloway, R. E., and Alston, A. M. (1992). "The effects of salt and boron on growth of wheat," *Australian Journal of Agricultural Research* 43(5), 987-1001. DOI: 10.1071/AR9920987

Hong, Y., Cheng, Y., Li, Y., Li, X., Zhou, Z., Shi, D., Li, Z., and Xiao, Y. (2019). "Preliminary study on the effect of *Bacillus amyloliquefaciens* TL on cecal bacterial community structure of broiler chickens," *BioMed Research International* 2019, 1-11. DOI: 10.1155/2019/5431354

Joyo, M. A., and Ram, N. (2018). "Simulating and resilience in cotton productivity due to climate change of Sindh, Pakistan," *Archives of Agriculture Sciences Journal* 1(1), 142-153. DOI: 10.21608/aasj.2018.23578

Khorasaninejad, S., Mousavi, A., Soltanloo, H., Hemmati, K., and Khalighi, A. (2010). "The effect of salinity stress on growth parameters, essential oil yield and constituent of peppermint (*Mentha piperita* L.)," *World Applied Sciences Journal* 11(11), 1403-1407.

Kim, Y. W., Kim, M. J., Chung, B. Y., Bang, D. Y., Lim, S. K., Choi, S. M., and Lee, B. M. (2013). "Safety evaluation and risk assessment of d-limonene," *Journal of Toxicology and Environmental Health, Part B* 16(1), 17-38. DOI: 10.1071/AR9920987

Kloepper, J. W., Tuzun, S., Liu, L., and Wei, G. (1993). "Plant growth-promoting rhizobacteria as inducers of systemic disease resistance," in: *Pest Management: Biologically Based Technologies*, American Chemical Society Books, Washington D.C., USA, pp 156-165.

Kuan, K. B., Othman, R., Abdul Rahım, K., and Shamsuddın, Z. H. (2016). "Plant growth-promoting rhizobacteria inoculation to enhance vegetative growth, nitrogen fixation and nitrogen remobilization of maize under greenhouse conditions," *Plos One* 11(3), article ID e0152478. DOI: 10.1371/journal.pone.0152478

Kumar, R., and Gautam, H. R. (2014). "Climate change and its impact on agricultural productivity in India," *Journal of Climatology & Weather Forecasting* 2(1), article ID 1000109. DOI: 10.4172/2332-2594.1000109

Levit, F. (1980). "Treatment of hyperhidrosis by tap water iontophoresis," *Cutis* 26(2), 192-194.

Li, H., Soares, M. A., Torres, M. S., Bergen, M. S., and White, J. F. (2015). "Endophytic bacterium, *Bacillus amyloliquefaciens*, enhances ornamental hosta resistance to diseases and insect pests," *Journal of Plant Interactions* 10(1), 224-229. DOI: 10.1080/17429145.2015.1056261

Ma, X., Xu, Z., Lang, D., Zhou, L., Zhang, W., and Zhang, X. (2022). "Comprehensive physiological, transcriptomic, and metabolomic analyses reveal the synergistic mechanism of *Bacillus pumilus* g5 combined with silicon alleviate oxidative stress in drought-stressed *Glycyrrhiza uralensis* fisch," *Frontiers in Plant Science* 13, article ID 1033915. DOI: 10.3389/fpls.2022.1033915

Maas, E. V., Ogata, G., and Garber, M. J. (1972). "Influence of salinity on Fe, Mn and Zn uptake by plants," *Agronomy Journal* 64, 793-795. DOI: 10.2134/agronj1972.00021962006400060026x

Martinez, V., Cerda, A., and Fernandez, G. A. (1987). "Salt tolerance of four tomato hybrids," *Plant and Soil* 97, 233-242.

Masood, S., Zhao, X. Q., and Shen, R. F. (2019). "*Bacillus pumilus* increases boron uptake and inhibits rapeseed growth under boron supply irrespective of phosphorus fertilization," *AoB Plants* 11(4), article ID plz036. DOI: 10.1093/aobpla/plz036

Muthuraja, R., and Muthukumar, T. (2022). "Co-inoculation of halotolerant potassium solubilizing *Bacillus licheniformis* and *Aspergillus violaceofuscus* improves tomato growth and potassium uptake," *Chemosphere* 294 (2022), article ID 133718. DOI: 10.1016/j.chemosphere.2022.133718

Ngalimat, M. S., Yahaya, R. S. R., Baharudin, M. M. A., Yaminudin, S. M., Karim, M., Ahmad, S. A., and Sabri, S. (2021). "A review on the biotechnological applications of the operational group *Bacillus amyloliquefaciens*," *Microorganisms* 9(3), 614. DOI: 10.3390/microorganisms9030614

Nong, D. H., Ngo, A. T., Nguyen, H. P., Nguyen, T. T., Nguyen, L. T., and Saksena, S. (2021). "Changes in coastal agricultural land use in response to climate change: An assessment using satellite remote sensing and household survey data in Tien Hai district, Thai Binh Province, Vietnam," *Land* 10(6), article 627. DOI: 10.3390/land10060627

Okon, O. G. (2019). "Effect of salinity on physiological processes in plants," in: *Microorganisms in Saline Environments: Strategies and Functions*, *Soil Biology*, Vol. 56, Giri, B., and Varma, A. (eds), Springer, Cham, Switzerland, pp. 237-262. DOI: 10.1007/978-3-030-18975-4_10

Özcan, H. (2000). "Growth and variations in proline, sodium, chloride, phosphorus and potassium concentrations of chickpea (*Cicer arietinum* L. cvs.) varieties under salinity stress," *Turkish Journal of Agriculture and Forestry* 24(6), 649-654.

Poss, J. A., Pond, E., Menge, J. A., and Jarrell, W. M. (1985). "Effect of salinity on mycorrhizal onion and tomato in soil with and without additional phosphate," *Plant and Soil* 88, 307-319. DOI: 10.1007/BF02197488

Prisa, D. (2021). "Antifungal and plant growth promoting activity with *Bacillus amyloliquefaciens* in aeonium subs.," *Magna Scientia Advanced Biology and Pharmacy* 1(2), 042-050. DOI: 10.30574/msabp.2021.1.2.0008

Rabhi, M., Barhoumi, Z., Ksouri, R., Abdelly, C., and Gharsalli, M. (2007). "Interactive effects of salinity and iron deficiency in *Medicago ciliaris*," *Comptes Rendus Biologies* 330(11), 779-788. DOI: 10.1016/j.crvi.2007.08.007

Rengel, Z. (1992). "Disturbance of cell Ca^{2+} homeostasis as a primary trigger of Al toxicity syndrome," *Plant, Cell and Environment* 15(8), 931-938. DOI: 10.1111/j.1365-3040.1992.tb01025.x

Roodbari, N., Roodbari, S., Ganjali, A., Nejad, F. S., and Ansarifar, M. (2013). "The effect of salinity stress on growth parameters and essential oil percentage of peppermint (*Mentha piperita* L.)," *International Journal of Advanced Biological and Biomedical Research* 1(9), 1009-1015. article 20133349471.

Rossi, M., Borromeo, I., Capo, C., Glick, B. R., Gallo, M. D., Pietrini, F., and Forni, C. (2021). "PGPB improve photosynthetic activity and tolerance to oxidative stress in *Brassica napus* grown on salinized soils," *Applied Sciences* 11(23), article 11442. DOI: 10.3390/app112311442

Ruiz, D., Martínez, V., and Cerdá, A. (1997). "Citrus response to salinity: Growth and nutrient uptake," *Tree Physiology* 17(3), 141-150. DOI: 10.1093/treephys/17.3.141

Ryu, C. M., Farag, M. A., Hu, C. H., Reddy, M. S., Kloepper, J. W., and Paré, P. W. (2004). "Bacterial volatiles induce systemic resistance in Arabidopsis," *Plant Physiology* 134(3), 1017-1026. DOI: 10.1104/pp.103.026583

Sabzalian, M. R., Heydarizadeh, P., Zahedi, M., Boroomand, A., Agharokh, M., Sahba, M. R., and Schoefs, B. (2014). "High performance of vegetables, flowers, and medicinal plants in a red-blue LED incubator for indoor plant production," *Agronomy for Sustainable Development* 34, 879-886. DOI: 10.1007/s13593-014-0209-6

Saltan, F. Z., and Seçilmiş Canbay, H. (2015). "Determination of heavy metals and nutrient elements in some plants medicinal used in Eskişehir," *Suleyman Demirel University Journal of Natural and Applied Science* 19(1), 83-90. DOI: 10.19113/sdufbed.63091

Santoro, M., Cappellari, L. d. R., Giordano, W., and Banchio, E. (2015). "Plant growth-promoting effects of native *Pseudomonas* strains on *Mentha piperita* (peppermint): An *in vitro* study," *Plant Biology* 17(6), 1218-1226. DOI: 10.1111/plb.12351

Santos, A. d. A., Silveira, J. A. G. d., Bonifácio, A., Rodrigues, A. C., and Figueiredo, M. d. V. B. (2018). "Antioxidant response of cowpea co-inoculated with plant growth-promoting bacteria under salt stress," *Brazilian Journal of Microbiology* 49(3), 513-521. DOI: 10.1016/j.bjm.2017.12.003

Santoyo, G., Guzmán-Guzmán, P., Parra-Cota, F. I., Santos-Villalobos, S. d. l., Orozco-Mosqueda, M. d. C., and Glick, B. R. (2021). "Plant growth stimulation by microbial consortia," *Agronomy* 11(2), article Number 219. DOI: 10.3390/agronomy11020219

Setu, M. W. A., Hosen, M. E., Mazumder, M. S. U., Nur-E-Alam, S. M., and Hasan, A. (2019). "Effects of farmers knowledge and climate change on yields of crop in the saline prone area of Bangladesh," *Asian Journal of Agricultural Extension, Economics & Sociology* 33(13), article 165. DOI: 10.9734/ajaees/2019/v33i130165

Silva, A. V., Gonçalves, J. d. M., Costa, N., Scalli, B. M., Oliveira, T. C. d., and Sartori,

T. C. F. d. T. (2023). "Agronomic characteristics and yield of corn after inoculation with *Bacillus amyloliquefaciens*," *Revista Agrogeoambiental* 15(2023), 1-10. DOI: 10.18406/2316-1817v15nunico20231730

Singh, S. N. (2019). "Climate change and agriculture in Ethiopia: A case study of Mettu Woreda," *SocioEconomic Challenges* 3(3), 61-79. DOI: 10.21272/sec.3(3).61-79.2019

Singh, U. B., Malviya, D., Singh, S., Singh, P., Ghatak, A., Imran, M., Rai, J. P., Singh, R. K., Manna, M. C., Sharma, A. K., and Saxena, A. K. (2021). "Salt-tolerant compatible microbial inoculants modulate physio-biochemical responses enhance plant growth, Zn biofortification and yield of wheat grown in saline-sodic soil," *International Journal of Environmental Research and Public Health* 18(18), article 9936. DOI: 10.3390/ijerph18189936

Sun, J., Li, S., Guo, H., and Hou, Z. (2021). "Ion homeostasis and Na^+ transport-related gene expression in two cotton (*Gossypium hirsutum* L.) varieties under saline, alkaline and saline-alkaline stresses," *Plos One* 16(8), article ID e0256000. DOI: 10.1371/journal.pone.0256000

Syahputra, B. P., and Sucahyono, D. (2022). "Validation of rainfall reanalysis data to explore changes in Oldeman agricultural climate patterns due to variability of surface temperature anomalies with time series analysis techniques (case study of Dumai city for 30 years period)," *Proceedings of International Conference on Multidisciplinary Research* 4(1), 221-228. DOI: 10.32672/pic-mr.v4i1.3773

Tavakkoli, E., Rengasamy, P., and McDonald, G. (2010). "High concentrations of Na^+ and Cl^- ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress," *Journal of Experimental Botany* 61(15), 4449-4459. DOI: 10.1093/jxb/erq251

Taherpour, A. A., Khaef, S., Yari, A., Nikeafshar, S., Fathi, M., and ve Ghambari, S. (2017). "Chemical composition analysis of the essential oil of *Mentha piperita* L. from Kermanshah, Iran by hydrodistillation and HS/SPME methods," *Journal of Analytical Science and Technology* 8, article 11. DOI:10.1186/s40543-017-0122-0

Teshaeva, D., and Sadriddinova, M. (2021). "The influence of salinity on the ecophysiology of durum wheat," in: *Theoretical and Empirical Scientific Research: Concept and Trends Volume 1*, Collection of Scientific Papers, Oxford, UK, pp. 133-136. DOI: 10.36074/logos-28.05.2021.v1.41

Tolay, I. (2021). "The impact of different zinc (Zn) levels on growth and nutrient uptake of basil (*Ocimum basilicum* L.) grown under salinity stress," *PLOS One* 16(2), article ID e0246493. DOI: 10.1371/journal.pone.0246493

Tort, N., and Türkyılmaz, B. (2003). "Physiological effects of NaCl on two barley (*Hordeum vulgare* L.) cultivars," *Turkish Journal of Field Crops* 8(2), 68-75.

Turan, M., Ataoglu, N., and Sahin, F. (2007). "Effects of *Bacillus* FS-3 on growth of tomato (*Lycopersicon esculentum* L.) plants and availability of phosphorus in soil," *Plant Soil and Environment* 53(2), 58-64.

Tüzüner, A. (1990). "Soil and water analysis laboratories handbook," in: *Ministry of Agriculture and Rural Affairs*, General Directorate of Rural Services Publication, Ankara, Türkiye, pp. 11-12.

Üner, S. T., and Cesur Turgut, A. (2023). "The effects of *Bacillus amyloliquefaciens* on *Mentha piperita* grown under salt stress," *Turkish Journal of Health Science and Life* 6(2), 48-52. DOI: 10.56150/tjhsl.1263608 van Loon, L. C. (2007). "Plant responses to plant growth-promoting rhizobacteria," in: *New Perspectives and Approaches in Plant Growth-Promoting Rhizobacteria Research*, Springer, Dordrecht, pp. 243-254. DOI: 10.1007/978-1-4020-6776-1_2

Verma, R. S., Rahman, L., Verma, R. K., Chauhan, A., Yadav, A. K., and Singh, A. (2010). "Essential oil composition of menthol mint (*Mentha arvensis*) and peppermint (*Mentha piperita*) cultivars at different stages of plant growth from Kumaon region of Western Himalaya," *Open Access Journal of Medicinal and Aromatic Plants* 1(1), 13-18.

Wang, J., Zhou, C., Xiao, X., Xie, Y., Zhu, L., and Ma, Z. (2017). "Enhanced iron and selenium uptake in plants by volatile emissions of *Bacillus amyloliquefaciens* (BF06)," *Applied Sciences* 7(1), Article Number 85. DOI: 10.3390/app7010085

Wenke, K., Weise, T., Warnke, R., Valverde, C., Wanke, D., Kai, M., and Piechulla, B. (2012). "Bacterial volatiles mediating information between bacteria and plants," in: *Biocommunication of Plants*, Springer, Berlin, Heidelberg, pp. 327-347. DOI: 10.1007/978-3-642-23524-517

Xue, S., Lei, J., Zhou, X., Ma, Y., Zhou, X., and He, Z. (2011). "Biological characteristics of a manganese resistant microorganism," in: *2011 International Symposium on Water Resource and Environmental Protection* 4(2011), pp. 3013-3016, Publisher: IEEE. DOI: 10.1109/ISWREP.2011.5893512

Yakıt, S., and Tuna, A. L. (2006). "The effects of Ca, K and Mg on the stress parameters of the maize (*Zea mays* L.) plant under salinity stress," *Akdeniz University Journal of the Faculty of Agriculture* 19(1), 59-67.

Yokoi, S., Bressan, R. A., and Hasegawa, P. M. (2002). "Salt stress tolerance of plants," *Japan International Research Center for Agricultural Sciences Working Report* 23(1), 25-33.

Zhang, S., Jiang, W., Li, J., Meng, L., Cao, X., Hu, J., Liu, Y., Chen, J., and Chang-qing, S. (2016). "Whole genome shotgun sequence of *Bacillus amyloliquefaciens* tf28, a biocontrol entophytic bacterium," *Standards in Genomic Sciences* 11(73), 1-10. DOI: 10.1186/s40793-016-0182-6

Zhao, X., Jong, A. d., Zhou, Z., and Kuipers, O. P. (2015). "Complete genome sequence of *Bacillus amyloliquefaciens* strain bh072, isolated from honey," *Genome Announcements*, *American Society for Microbiology* 3(2). DOI: 10.1128/genomea.00098-15

Zhao, Q., Wu, Y. N., Fan, Q., Han, Q. Q., Paré, P. W., Xu, R., Wang, Y. Q., Wang, S. M., and Zhang, J. L. (2016). "Improved growth and metabolite accumulation in *Codonopsis pilosula* (Franch.) Nannf. by inoculation of *Bacillus amyloliquefaciens* GB03," *Journal of Agricultural and Food Chemistry* 64(43), 8103-8108. DOI: 10.1021/acs.jafc.6b03390

Zhou, C., Zhu, L., Xie, Y., and Wang, J. (2017). "*Bacillus licheniformis* SA03 confers increased saline–alkaline tolerance in Chrysanthemum plants by induction of abscisic acid accumulation," *Frontiers in Plant Science* 8(2017), 1-17, article ID 272824, DOI: 10.3389/fpls.2017.01143

Article submitted: December 26, 2023; Peer review completed: March 9, 2024; Revised version received and accepted: March 14, 2024; Published: March 19, 2024.
DOI: 10.15376/biores.19.2.2826-2841