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Characterization and Investigation of Antifungal Activity of Endophytic Bacteria Isolated from Lavender (*Lavandula angustifolia*) Plant

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Abstract
In this study, 65 endophytic bacteria were isolated from lavender plants. The morphological, physiological, and biochemical properties and enzyme activities of endophytic bacteria were investigated. In the test of tolerance of isolates to different temperature degrees, isolate LA6 was positive at 4°C, and all other isolates were negative. From the 41°C isolates, isolates LA42 and LA46 were negative, and all other isolates were positive. From endophytic bacteria, isolates LA1, LA5, LA6, LA7, LA8, LA11, LA12, LA13, LA25, LA28, LA41, LA45, LA48, LA50, LA53, and LA61 gave positive results in their tolerances at 10% NaCl concentration. In the carbohydrate test, isolates gave positive results between 71% and 91%. All isolates gave positive results in the phosphatase activity and protease activity of endophytic bacteria. Among other enzyme activities, 86% of the isolates gave positive results in cellulase activity, ACC deaminase activity, and nitrate reduction. 75% of the isolates gave positive results in siderophore production, and effective results were obtained. The % inhibition rates of endophytic isolates against pathogens varied between 3.7% and 78% against *Neoscytalidium dimidiatum*, between 8% and 80% against *Fusarium culmorum*, and between 36.1% and 61.8% against *Fusarium oxysporum*. As a result of this study, promising results are seen in the potential use of endophytic bacteria isolated from lavender as biofertilizer.

Research Article

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1. Introduction

Lavender, which is in the medicinal-aromatic class of Turkish flora, stands out due to its functionality, widespread use in industry, and high demand. Lavender cultivation has gained momentum in recent years. Turkey is one of the richest countries in the world in terms of genetic diversity in medicinal and aromatic plants, through its geographical structure, climatic and agricultural advantages, agricultural potential, and large surface area in recent years, lavender cultivation has become increasingly widespread in our country. In Turkey, lavandin and hybrid lavender cultivation is more common. *L. intermedia* (L. hybrida), which is the triploid (3n) hybrid of *L. angustifolia* and *L. latifolia*, cannot be produced from seed because they are sterile and therefore they are propagated vegetatively (Baydar and Kineci, 2009; Özel, 2023).

The world population is constantly increasing, and the sustainability of agricultural production must also increase in order to meet nutritional demands. In order to ensure sustainable agriculture, it is necessary to adhere to cultural processes and, in addition, to plant protection of cultivated plants against diseases, pests, and weeds (Koul et al., 2008). Diseases that are a problem in agricultural areas cause significant losses in terms of quality and yield, and intensive pesticides are used to reduce these losses. Considering the damages caused to the ecosystem in intensive agriculture, studies aimed at preventing intensive pesticide use and developing and disseminating sustainable production models in agriculture are of great importance. Therefore, alternative control methods have begun to be seen as necessary (Berg and Hallman, 2006).

The method of combating endophyte bacteria plays an important role in regulating plant physiology by promoting plant growth with the plant growth regulators they produce in the presence of various biotic and abiotic stress conditions and by providing plant resistance. Inoculation of plants with endophytic bacteria reduces the problems that occur in plants due to diseases and pests, and thanks to this inoculation, the damage caused by phytopathogens in agricultural production, which causes a great loss of yield, can be prevented (Sturz et al., 2000; Berg and Hallman, 2006). Chemical preparations are the most important factor in disease control, but biological control with biological control agents is one of the most important issues today due to their benefits for human and environmental health. Endophytic bacteria also have an application area that can be effective in this respect. The results of biological control studies conducted with many bacteria in our country show that they have a high potential against various disease agents (Glick, 2015).

In this study, the isolation of endophytic bacteria from the root and root collar regions of lavender plants and from EB candidates in lavender cultivation areas was carried out. The most successful isolates were evaluated by characterization tests and their antagonistic effects against plant pathogenic fungi were determined by *in vitro* studies. It was aimed to minimize the damage caused by these fungal pathogens by determining the % inhibition rates against pathogens that cause damage to lavender plants *in vitro*.

2. Material and Methods

2.1. Endophytic bacteria isolation

Samples were taken from sage (*Lavandula angustifolia*) plants in the Koruklu village of the Akçakele district of the Şanlıurfa province (36° 42′ N; 38° 58′ E, 410 m altitude). Small pieces were taken from the roots and crowns of lavender plants brought to the laboratory; surface disinfection was performed, and they were planted in nutrient agar (NA) medium. The bacteria showing different growth were purified into the medium as representative colonies (Zvyagintsev, 1991). All representative isolates taken from 24-48 hours of fresh culture on NA medium were stored in 30% glycerol at –80 °C.

2.2. Obtaining and storing pathogen ısolates

The *F. culmorum* isolate, designated Fc22, used in the current study was initially obtained

from a diseased wheat sample obtained during a previous research effort (Alkan et al., 2019). The pathogen *N. dimidiatum* (MZ576552.1) and *Fusarium oxysporum* (MW366548.1) were obtained from the Mardin Artuklu University laboratory.

2.3. Investigation of morphological, physiological, and biochemical properties of bacteria

Gram staining; Gram staining of isolates was performed (Demirbağ and Demir, 2005). Catalase: Isolates were grown in nutrient broth for 2 days at 28 °C and 3% H_2O_2 was added and foaming status was observed. If there was foaming, it was evaluated as positive (+); if not, it was evaluated as negative (-) (Holt et al., 1994). Oxidase test: A loopful of freshly developed samples from bacterial isolates was taken and applied on blotting paper; then oxidase (Fluka, N, N-dimethyl-p-phenylenediamine oxalate, α-naphthol) was poured and color change was observed. Blue color formation was concluded as positive (Holt et al., 1994). Carbohydrate Tests: The growth of sterile mineral salts medium separately in glucose, maltose, fructose, xylose, mannitol, and tryptophan media was evaluated at 28 °C for 3, 7, and 14 days (Ji and Wilson, 2002). Tolerance of the isolates to different temperature degrees: The growth of the isolates was examined at 4, 15, 27, 37, and 41 °C (Gardner et al., 1984). Tolerance of the isolates to different concentrations of salt: The isolates were incubated in concentrations of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 % NaCl for seven days at 28 °C (Cappucino and Sherman, 1992). Experiments were carried out with 3 replicates.

2.4. Enzymatic activity

2.4.1. Phosphatase activity

The pH of the prepared medium, prepared with Pikovskaya medium (sucrose 10 g, $Ca(PO_4)2$ 5 g, $(NH_4)2SO_4$ 0.5 g, KCl 0.2 g, $MgSO_4.7H_20$ 0.1 g, $MnSO_4.7H_20$ 0.001 g, Fe $SO_4.7H_20$ 0.001 g, yeast extract 0.5 g, agar 15 g, distilled water 1000 ml), was adjusted to 7±0.2 with 1 M NaOH or 1 M HCl and then poured into Petri dishes after being sterilized. 10 µl of isolates were taken, and they were cultured in drop form. After 2 and 4 days of development at 28 ºC, the formation of a clear zone around the colony was evaluated as positive (+) (Kim et al., 1998). As a control, isolates were grown in media without $Ca(PO_4)_2$ addition.

2.4.2. Protease activity

Sterile 50 ml skim milk was added to the sterilized 4% agar and 50 ml 1/5 TSA-containing medium and poured into Petri dishes. Cultures were streaked onto Petri dishes with a loop and incubated at 24 ºC for 5 days. Light-colored zones around the colony were evaluated as positive (Costa et al., 2006).

2.4.3. Cellulase activity

1 ml of the sterilized B and D solutions was taken and added to the sterilized A+C solution. The prepared medium was poured into sterile Petri dishes. Petri dishes were incubated at 28 ºC for 4 days; at the end of incubation, 0.1 % Congo red solution was dropped onto the colony and kept for 15-20 min, then the Petri dishes were washed with 1 N NaCl solution. The clear zone determined around the colony was reported as positive (Egamberdieva et al., 2005).

2.4.4. Nitrate reduction

Prepared media (peptone 10 g, K_2HPO_4 5 g, agar 2 g, yeast extract 1 g, distilled water 1000 ml, pH= 7.2) were put into 5 ml tubes. Solution A (5 N acetic acid, 50 ml and sulfanilic acid, 400 mg) and solution B (5 N acetic acid 50 ml and 1-naphthylamine, 300 mg) were used as nitrate reagents. The prepared medium was melted at 121 ºC for 3 minutes and put into the tubes as 5 ml each and autoclaved at 121ºC for 15 minutes. Bacteria were taken from fresh bacterial cultures with a sterile loop, and dipped inoculation was performed into the tubes. The tubes were incubated at 26 ºC for 24-48 hours, then 1 drop of Gram iodine was added, followed by 0.5 ml of solution A and 0.5 ml of solution B. A red color in the tubes was considered positive (+) (Lelliot et al., 1966).

2.4.5. ACC deaminase production

The method described by Dworkin and Foster (1958) was used for ACC deaminase production in DF minimal salt medium. Endophytic bacteria were incubated in DF minimal salt medium, and those showing growth in the medium were evaluated as positive.

2.5. Siderophore production

Blue agar medium was used (Schwyn and Neilands, 1987). In those showing color change, the formation of a clear zone was evaluated as positive for siderophore production.

2.6. Antagonistic activity

The effects of endophytic bacterial isolates with detected antagonistic effects against pathogens *N. dimidiatum, F. culmorum* and *F. oxysporum* were determined *in vitro* in Petri dishes. Ten microliters of bacterial suspension were dropped onto four equal points 2.5 centimeters from the center of the PDA medium. After 24 hours, a 1-centimeter-diameter mycelial plate of the pathogen was placed in the center. A medium without bacterial inoculation and with only the pathogen mycelial plate was left as a control. The antagonistic activities of bacteria against pathogens were determined. The antagonistic activity of bacteria in Petri dishes against pathogens was calculated according to the formula below (Özyılmaz, 2007).

$\%RI = (R-r)/R \times 100$

R: Development of pathogenic fungus on the bacteria-free side

r: Development of pathogenic fungus towards bacteria

%RI: Inhibition rate

3. Findings and Discussion

3.1. Investigation of morphological, physiological, and biochemical properties of bacteria

3.1.1. Gram staining

Endophytic bacteria isolated from lavender LA11, LA8, LA23, LA28, LA53, and LA66 were evaluated as Gr (+) and all other isolates were evaluated as Gr (-).

3.1.2. Catalase test

Isolates LA1, LA5, LA8, LA40, LA47, LA54, LA68, and LA65 were negative in catalase test and all other isolates were positive.

3.1.3. Oxidase test

Endophytic bacteria LA18, LA21, LA22, LA27, LA31, LA34, LA38, LA 44, LA 50, LA 56, LA59, and LA66 were positive in the oxidase test and all other isolates were negative (Table 1).

3.1.4. Tolerance of ısolates to different temperatures

In the tolerance test of isolates to different temperature levels, LA6 isolate was positive at 4 °C and all other isolates were negative. Among the 41 °C isolates, LA42 and LA46 isolates were negative, and all other isolates were positive.

3.1.5. Salt tolerance of ısolates at different concentrations

In the 10% salt tolerance of endophytic bacteria, LA1, LA5, LA6, LA7, LA8, LA11, LA12, LA13, LA25, LA28, LA41, LA45, LA48, LA50, LA53, and LA61 isolates gave positive results.

Table 1. Physiological and enzymatic test results of endophytic bacteria.

Isolates	Gram Stain	Oxidase Test	Catalase	Phosphatase	Cellulase	Protease	ACC Deaminase	Nitrate reduction	Siderophore production
LA1	Gr(-)	-	+	+++	+	++	+	+	+
LA2	Gr(-)	-	+	+++	+	++	+	+	+++
LA3	Gr(-)	-	+	+++	+	++	+	+	+
LA4	Gr(-)	-	+	+	+	++	+	+	+
LA5	Gr(-)	-	-	+	+	++	+	-	+
LA6	Gr(-)	-	+	+	+	+++	+	+	+
LA7	Gr(-)	-	+	+	+	++	+	+	+
LA8	Gr(+)	-	-	++	+	+	+	+	+
LA9	Gr(-)	-	+	+	+	++	+	+	+
LA10	Gr(-)	-	+	+	+	++	+	+	+++
LA11	Gr(+)	-	+	+	+	+++	+	-	+++
LA12	Gr(-)	-	-	++	+	++	+	+	+
LA13	Gr(-)	-	+	+	+	++	+	+	++
LA14	Gr(-)	-	+	+	+	++	+	+	++
LA15	Gr(-)	-	+	+	+	++	+	+	-
LA16	Gr(-)	-	+	++	+	++	+	+	-
LA17	Gr(-)	-	+	++	-	++	-	+	-
LA18	Gr(-)	+	+	+	+	++	+	+	-
LA19	Gr(-)	-	+	++	+	++	+	+	-
LA20	Gr(-)	-	+	+	-	++	+	+	-
LA21	Gr(-)	+	+	+	+	++	+	-	++
LA22	Gr(-)	+	+	++	+	+++	+	+	++
LA23	Gr(+)	-	+	++	+	++	+	+	+++
LA26	Gr(-)	-	+	+	+	+++	+	+	+
LA27	Gr(-)	+	+	+	+	++	+	+	-
LA28	Gr(+)	-	+	+	+	++	+	+	++
LA29	Gr(-)	-	+	++	+	++	+	+	++
LA30	Gr(-)	-	+	+	+	++	+	+	+++
LA31	Gr(-)	+	+	+	+	++	+	+	+
LA33	Gr(-)	-	+	+++	+	++	+	+	+
LA34	Gr(-)	+	+	+++	+	++	+	+	+
LA35	Gr(-)	-	+	++	-	++	+	+	+
LA36	Gr(-)	-	+	+	-	++	-	-	+
LA37	Gr(-)	-	+	+	-	++	+	+	-
LA38	Gr(-)	+	+	+	+	++	+	+	-
LA39	Gr(-)	-	+	++	+	++	+	+	-
LA40	Gr(-)	-	-	+	+	++	+	+	-
LA41	Gr(-)	-	+	++	+	+++	+	+	++
LA42	Gr(-)	-	+	+	+	+++	+	+	+
LA43	Gr(-)	-	+	+	+	+++	+	+	+
LA44	Gr(-)	+	+	++	+	+++	+	+	+
LA45	Gr(-)	-	+	+++	+	++	+	+	+++
LA46	Gr(-)	-	+	+++	-	++	-	-	+
LA47	Gr(-)	-	-	++	+	++	+	+	+
LA48	Gr(-)	-	+	+	+	++	+	+	+
LA49	Gr(-)	-	+	+	+	++	+	+	+
LA50	Gr(-)	+	+	+	+	++	+	+	+
LA51	Gr(-)	-	+	+	+	++	+	+	+
LA52	Gr(-)	-	+	++	+	++	-	-	+
LA53	Gr(+)	-	+	+	+	++	+	+	+
LA54	Gr(-)	-	-	+	+	++	+	+	+
LA55	Gr(-)	-	+	+++	+	+	+	+	+
LA56	Gr(-)	+	+	+++	+	+	+	+	-
LA57	Gr(-)	-	+	+++	-	++	-	-	-
LA59	Gr(-)	+	+	+++	+	++	+	+	+
LA60	Gr(-)	-	-	++	+	++	-	-	++
LA61	Gr(+)	+	+	++	+	++	+	+	+
LA63	Gr(-)	-	+	+	-	+++	-	+	-
LA64	Gr(-)	-	+	+	+	+++	+	+	++
LA65	Gr(-)	-	-	++	+	++	-	-	+
LA66	Gr(+)	+	+	+	+	++	+	+	+
LA67	Gr(-)	-	+	+	-	++	-	+	-
LA68	Gr(-)	-	-	+	+	++	+	+	+
LA69	Gr(-)	-	+	+	+	++	+	+	+
LA70	Gr(-)	-	+	+	+	++	+	+	+

Phosphatase zone 0,1-0,5 cm (+); 0,5-1 cm (++); 1 cm > (+++); Protease zone: 0,1-0,9 cm (+); 1-1,9 cm (++); 2-2,9 cm (+++); Siderophore production: 0,1-0,4 cm(+); 0,5-0,8 (++); 0,9-1,2 cm (+++)
+:Positive -:Negative

3.1.6. Carbohydrate Tests

As a result of the m-inositol carbohydrate test of endophytic bacteria, isolates LA6, LA9, LA59, LA30, LA34, LA38, LA47, LA54, and LA17 were negative and all other isolates were positive. As a result of the maltose carbohydrate test of endophytic bacteria, isolates LA5, LA6, LA16, LA20, LA30, LA28, LA38, LA39, LA42, LA55, LA56, LA58, and LA59 were negative, and all other isolates were positive. As a result of the fructose carbohydrate test of endophytic bacteria, isolates LA5, LA6, LA16, LA20, LA30, LA31, LA42, LA46, LA54, and LA59 were negative and all other isolates were positive. As a result of the glucose carbohydrate test of endophytic bacteria, isolates LA5, LA9, LA10, LA20, LA30, LA31, LA35, LA39, LA46, LA47, LA54, LA55, LA56, and LA59 were negative and all other isolates were positive. As a result of the mannitol carbohydrate test of endophytic bacteria, isolates LA5, LA6, LA30, LA46, LA59, and LA65 were negative and all other isolates were positive. As a result of the xylose carbohydrate test of endophytic bacteria, isolates LA5, LA6, LA14, LA30, LA31, LA46, LA47, LA53, and LA54 were negative and all other isolates were positive. In the tryptophan carbohydrate test result of endophytic bacteria, LA2, LA6, LA7, LA8, LA10, LA17, LA30, LA31, LA35, LA36, LA39, LA40, LA53, LA54, LA61, LA64, LA65, LA66, and LA67 isolates gave negative results, and all other isolates gave positive results (Table 2).

3.2. Enzymatic activity

Phosphatase activity: All isolates gave positive results in phosphatase activity of endophytic bacteria (Table 1) (Figure 1a). Protease Activity: All isolates gave positive results in protease activity of endophytic bacteria (Table 4.1) (Figure 1b). Cellulase Activity: In cellulase activity of endophytic bacteria, isolates LA17, LA20, LA35, LA36, LA37, LA46, LA57, LA63, and LA67 were negative, and all other isolates gave positive results (Table 1) (Figure 1e). ACC Deaminase Activity: In ACC deaminase activity of endophytic bacteria, isolates LA17, LA36, LA46, LA52, LA57, LA60, LA63, LA65, and LA67 were negative, and all other isolates gave positive results (Table 1). Nitrate Reduction: In the nitrate reduction activity of endophytic bacteria, LA5, LA11, LA21, LA36, LA46, LA52, LA57, LA60, and LA65 isolates were negative, and all other isolates were positive (Table 1) (Figure 1c). Siderophore Production**:** From endophytic bacteria, LA15, LA16, LA17, LA18, LA19, LA20, LA27, LA37, LA38, LA39, LA40, LA57, LA56, LA62, LA63, and LA67 isolates were negative in siderophore production, and all other isolates were positive in siderophore production. LA2, LA10, LA30, LA23, and LA11 isolates gave the best results in siderophore production (Table 1) (Figure 1d). Idris et al. (2004) reported that ACC deaminase and siderophore are produced among endophytes, and some endophytic bacteria also showed the ability to solubilize phosphate, which is of great importance for the plant during the first colonization and increases P availability in the soil. Mamangkey et al. (2022) reported positive results for important hydrolytic enzyme activities such as amylase, α-amylase, cellulase, chitinase, and protease in most of the endophytic bacteria they isolated from the roots, stems, and leaves of the medicinal plant Chromolaena odorata. They stated that bioactive compounds in medicinal plants confirm that they are a habitat for certain plants. Samani et al. (2019) and our study results showed that the isolates that positively contribute to root and stem development have high or low levels of "1-aminocyclopropane-1-carboxylate deaminase" (ACCd) production, nitrogen fixation, and siderophore production ability in EB isolates can contribute to plant development. Siderophores have been proven to play an important role in antagonistic interactions with bacteria in soil phytopathogens and in promoting growth in plants. In the study, significant hydrolytic enzyme activities in effective isolates were observed to give positive results and support the study (Table 1). Siderophores not only suppress the effect on phytopathogens but also have a stimulating

effect on plants (Boronin, 1998). Siderophore production was observed in endophytic bacteria isolated from lavender, and this is also supported by other studies (Table 1).

Table 2. Carbohydrate test results of isolates

Isolates	M-Inositol	Maltose	Fructose	Glucose	Mannitol	Xylose	Tryptophan
LA1	+	+	+	+	+	+	+
LA2	+	+	+	+	+	+	-
LA3	+	+	+	+	+	+	+
LA4	+	+	+	+	+	+	+
LA5	+	-	-	-	-	-	+
LA6	-	-	-	+	-	-	-
LA7	+	+	+	+	+	+	-
LA8	+	+	+	+	+	+	-
LA9	-	+	+	-	+	+	+
LA10	+	+	+	-	+	+	-
LA11	+	+	+	+	+	+	+
LA12	+	-	+	+	+	+	+
LA13	+	+	+	+	+	+	+
LA14	+	+	+	+	+	-	+
LA15	+	+	+	+	+	+	+
LA16	+	+	-	+	+	+	+
LA17	-	+	+	+	+	+	-
LA18	+	+	+	+	+	+	+
LA19	+	+	+	+	+	+	+
LA20	+	+	-	-	+	+	+
LA21	+	+	+	+	+	+	+
LA22	+	+	+	+	+	+	+
LA23	+	+	+	+	+	+	+
LA26	+	+	+	+	+	+	+
LA27	+	+	+	+	+	+	+
LA28	+	-	+	+	+	+	+
LA29	+	+	+	+	+	+	+
LA30	-	-	-	-	-	-	-
LA31	+	+	-	-	+	-	-
LA33	+	+	+	+	+	+	+
LA34	-	+	+	+	+	+	+
LA35	+	+	+	-	+	+	-
LA36	+	+	+	+	+	+	-
LA37	+	+	+	+	+	+	+
LA38	-	-	+	+	+	+	+
LA39	+	-	+	-	+	+	-
LA40	+	+	+	+	+	+	-
LA41	+	+	+	+	+	+	+
LA42	+	-	-	+	+	+	+
LA43	+	+	+	+	+	+	+
LA44	+	+	+	+	+	+	+
LA45	+	+	+	+	+	+	+
LA46	+	+	-	-	-	-	+
LA47	-	+	+	-	+	-	+
LA48	+	+	+	+	+	+	+
LA49	+	+	+	+	+	+	+
LA50	+	+	+	+	+	+	+
LA51	+	+	+	+	+	+	+
LA52	+	+	+	+	+	+	+
LA53	+	+	+	+	+	-	-
LA54	-	+	-	-	+	-	-
LA55	+	-	+	-	+	+	+
LA56	+	-	+	-	+	+	+
LA57	+	+	+	+	+	+	+
LA59	-	-	-	-	-	+	+
LA60	+	+	+	+	+	+	+
LA61	+	+	+	+	+	+	-
LA63	+	+	+	+	+	+	+
LA64	+	+	+	+	+	+	-
LA65	+	+	+	+	-	+	-
LA66	+	+	+	+	+	+	-
LA67	+	+	+	+	+	+	-
LA68	+	+	+	+	+	+	+
LA69	+	+	+	+	+	+	+
LA70	+	+	+	+	+	+	+

+:Positive -:Negative

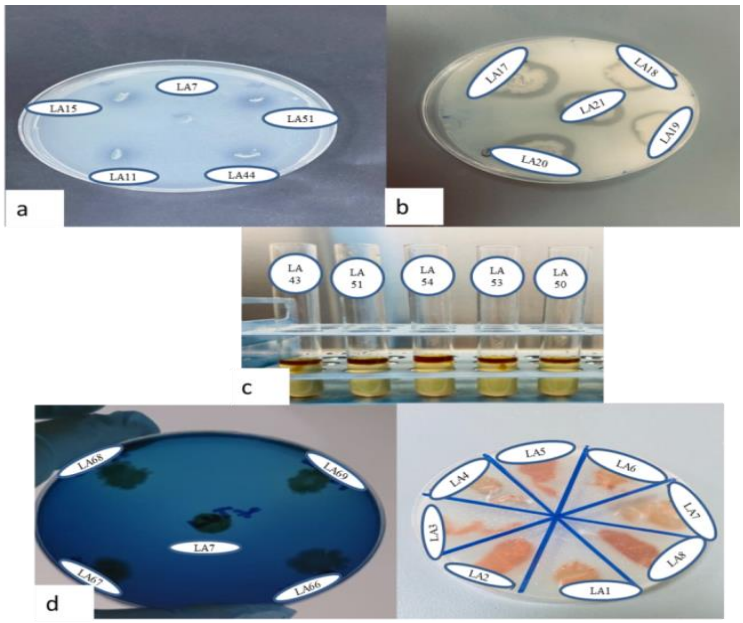

Figure 1. a) Phosphatase test of isolates; b) Protease activity of isolates; c) Nitrate activity of isolates; d) Siderophore production of isolates; e) Cellulase activity of isolates

3.3.Antagonistic activity

3.3.1.Antagonistic activities of endophytic bacteria against *N. dimidiatum*

The antagonistic activities of the developed fungi with bacteria were measured after incubation. The antagonistic activities of endophytic bacteria against *N. dimidiatum* varied between 80% and 3.7% (Table 3) (Figure 2).

Table 3. Inhibition rates of endophytic bacteria against *N. dimidiatum*

Bacteria	%RI**	Bacteria	%RI*	Bacteria	%RI*	Bacteria	%RI*
LA1	59e	LA19	33j	LA40	63d	LA59	59e
LA2	52f	LA20	52f	LA41	44h	LA60	56e
LA3	52f	LA21	33j	LA42	59e	LA61	67c
LA4	48g	LA22	26k	LA43	56e	LA63	70c
LA5	48g	LA23	3,7o	LA44	44h	LA64	74b
LA6	15m	LA26	48g	LA45	37i	LA65	41h
LA7	3,7o	LA27	41h	LA46	52f	LA66	52f
LA8	56e	LA28	59e	LA47	52f	LA67	44h
LA9	37i	LA29	44h	LA48	78a	LA68	56e
LA10	30j	LA30	78a	LA49	41h	LA69	52f
LA11	44h	LA31	63d	LA50	52f	LA70	78a
LA12	30j	LA33	26k	LA51	56e		
LA13	44h	LA34	26k	LA52	52f		
LA14	56e	LA35	48g	LA53	59e		
LA15	22l	LA36	56e	LA54	78a		
LA16	26k	LA37	67c	LA55	56e		
LA17	7,7n	LA38	74b	LA56	48g		
LA18	33j	LA39	63d	LA57	74b		
			F Value	973,06***			

*Differences between means with the same letter in the same column are not significant.
%RI: Inhibition rate
*** Significant at $P \leq 0.001$ level

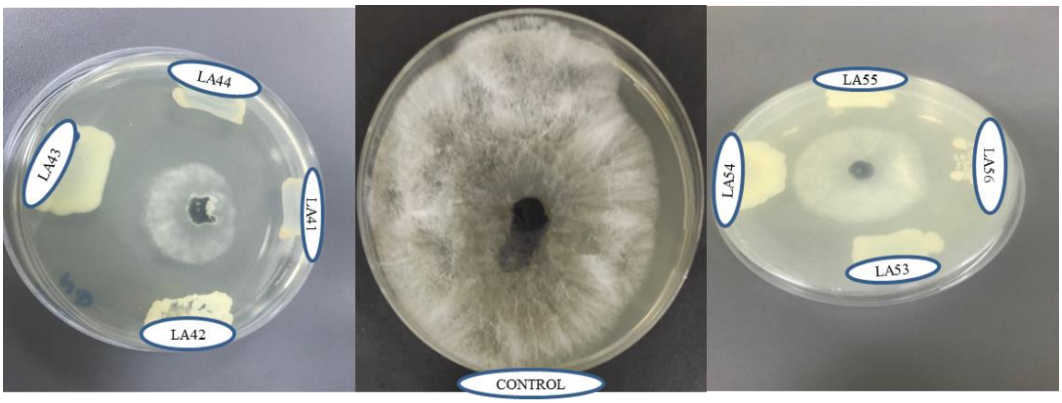

Figure 2. Antagonistic activities of LA41, LA42, LA43, LA44, LA53, LA54, LA55, and LA56 endophytic bacteria against *N. dimidiatum*.

Egamberdieva et al. (2016) and Berg et al. (2014) reported in their studies that endophytes produce various secondary metabolites, benefit their host plants, promote plant growth, and have an effect against diseases. In this case, they stated that endophytes increase plant performance and protect the plant against pests and diseases transmitted in the soil or from the soil, and induce abiotic stress tolerance in plants. Therefore, they reported that endophytes have great potential for use as biopesticides. Our tests of the antagonistic activity of endophytic bacteria against *F. culmorum* and *N. dimidiatum* also support these studies.

3.3.2.Antifungal activities of endophytic bacteria against *F. culmorum*

The antagonistic activities of the developed fungi with endophytic bacteria were measured after incubation. The antagonistic activities of endophytic bacteria against *F. culmorum* varied between 80% and 8% (Table 4) (Figure 3).

Table 4. % inhibition rates of endophytic bacteria against *Fusarium culmorum*

Bakteri	%RI*	Bakteri	%RI *	Bakteri	%RI *	Bakteri	%RI *
LA1	40ij	LA19	48gh	LA40	48gh	LA59	56ef
LA2	8n	LA20	60de	LA41	40ij	LA60	52fg
LA3	36jk	LA21	52fg	LA42	40ij	LA61	64cd
LA4	48gh	LA22	52fg	LA43	40ij	LA63	72b
LA5	48,gh	LA23	52fg	LA44	20m	LA64	72b
LA6	80a	LA26	40ij	LA45	40ij	LA65	40ij
LA7	52fg	LA27	40ij	LA46	44hi	LA66	44hi
LA8	68bc	LA28	28l	LA47	40ij	LA67	40ij
LA9	80a	LA29	36jk	LA48	60de	LA68	36jk
LA10	64cd	LA30	44hı	LA49	36jk	LA69	68bc
LA11	44hı	LA31	56ef	LA50	52fg	LA70	68bc
LA12	60de	LA33	36jk	LA51	52fg		
LA13	80a	LA34	36jk	LA52	57d-f		
LA14	69bc	LA35	44hi	LA53	56ef		
LA15	64cd	LA36	44hi	LA54	52fg		
LA16	36jk	LA37	56ef	LA55	40ij		
LA17	32kl	LA38	33j-l	LA56	44hi		
LA18	28l	LA39	32kl	LA57	80a		
			F Value	133,93***			

*Differences between means with the same letter in the same column are not significant.
%RI: Inhibition rate
*** Significant at $P \leq 0.001$ level

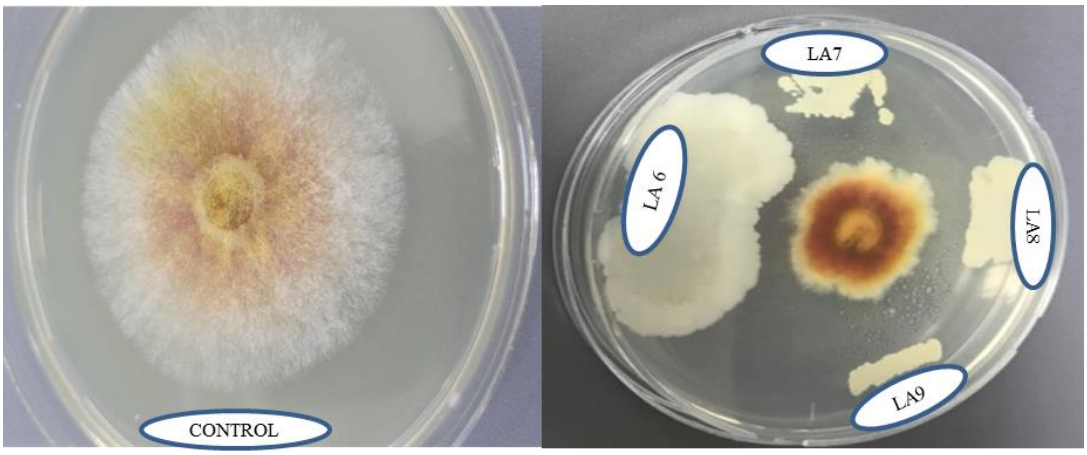

Figure 3. Antifungal activities of LA5, LA6, LA7, LA8, LA49, LA50, LA51 and LA52 endophytic bacteria against *Fusarium culmorum*

In this study, it is thought that there are metabolites with different chemical structures produced by antagonist *Bacillus* isolates that affect the permeability of the fungal membrane inhibit the development of fungal mycelium, and inhibit spore formation.

3.3.3. Antifungal activities of endophytic bacteria against *F. oxysporum*

The antagonistic activities of the developed fungi with endophytic bacteria were measured after incubation. The % inhibition rates of endophytic bacteria against *F. oxysporum* varied between 61.29 % and 36.1 % (Table 5) (Figure 4).

Table 5. % inhibition rates of endophytic bacteria against *F. oxysporum*

Bakteri	%RI*	Bakteri	%RI *	Bakteri	%RI *	Bakteri	%RI *
LA1	40.11n-p	LA19	45.52jk	LA40	48.6gh	LA59	42.99m
LA2	36.80q	LA20	40.11n-p	LA41	36.53q	LA60	39.80n-p
LA3	39.09op	LA21	45.79ı-k	LA42	36.27q	LA61	44.71kl
LA4	36.90q	LA22	57.72b	LA43	50.70ef	LA63	50.70ef
LA5	50.70ef	LA23	42.60m	LA44	36.61q	LA64	50.00fg
LA6	58.48b	LA26	47.19hi	LA45	50.70ef	LA65	41.00n
LA7	58.48b	LA27	43.69lm	LA46	54.21c	LA66	43.30lm
LA8	52.49d	LA28	37.17q	LA47	50.70c	LA67	40.50no
LA9	54.21c	LA29	47.19hi	LA48	54.21c	LA68	38.71p
LA10	47.19hi	LA30	50.00fg	LA49	54.21c	LA69	45.79i-k
LA11	51.79de	LA31	54.21c	LA50	43.72lm	LA70	46.49ij
LA12	49.62fg	LA33	36.10q	LA51	50.70ef		
LA13	57.4b	LA34	54.14c	LA52	47.19hi		
LA14	54.21c	LA35	40.11n-p	LA53	61.29a		
LA15	51.79de	LA36	43.69lm	LA54	40.11n-p		
LA16	39.45op	LA37	54.21c	LA55	43.49lm		
LA17	61.29a	LA38	47.19hı	LA56	40.11n-p		
LA18	43.69lm	LA39	50.7ef	LA57	50.70ef		
				F value	780.198***		

*Differences between means with the same letter in the same column are not significant.
%RI: Inhibition rate
*** Significant at P≤ 0.001 level

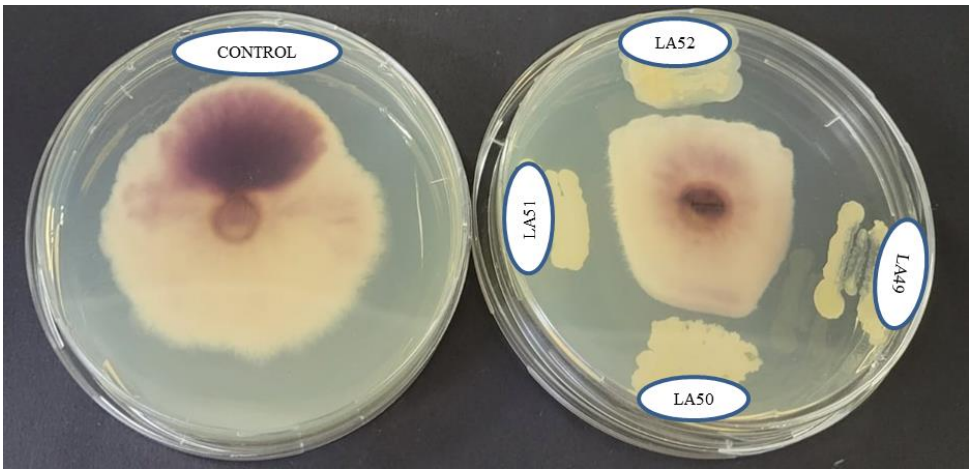

Figure 4. Antifungal activities of LA49, LA50, LA51, and LA54 endophytic bacteria against *Fusarium oxysporum* compared to control

4. Conclusion

In this study, the isolation, characterization, and identification of potential endophytic bacteria from lavender plants were performed. The most successful isolates were determined by evaluating the characterization tests, and their antagonistic effects against plant pathogenic fungi were determined by *in vitro* studies. The aim of this study was to minimize the damage caused by *Neoscytalidium dimidiatum*, *Fusarium culmorum* and *Fusarium oxysporum* pathogens in lavender and to promote plant growth. According to the results of the study, endophytic bacteria gave promising results against some fungal pathogens such as *N. dimidiatum*, *F. culmorum* and *F. oxysporum* that cause diseases in lavender plants. These applications, which affect both plant growth and disease, will later be offered for commercial use in sustainable organic lavender cultivation. After molecular identification of highly effective isolates and field trials, their antagonistic activities against phytopathogenic fungi can be recommended for use as biofungicides.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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