Identification and bio-control activity of *Streptomyces* strain (*Koyanogensis*) against *Magnaporthe grisea*

Taswar Ahsan\(^{a}\) \(\text{a}\), He Liu\(^{b}\), Yu hang Shan\(^{b}\), Tao Zhou\(^{b}\), Maqsood Ahmed\(^{c}\), Bingxue Li\(^{a}\) and Yuanhua Wu\(^{b}\)

\(^{a}\)Department of Resources and Environmental Microbiology, College of Land and Environment, Shenyang Agricultural University, Shenyang, PR China; \(^{b}\)Department of Plant Pathology, College of Plant Protection, Shenyang Agricultural University, Shenyang, PR China; \(^{c}\)Department of Agriculture (Plant Protection) Pest Warning and Quality Control of Pesticides, Gujrat, Pakistan

**ABSTRACT**

Rice blast is a major threat to the rice crop in rice-growing areas around the globe. However, synthetic fungicides are injurious for the ecosystem and the existing bio-control agents facing the resistance from the pathogens. In this study, an isolated novel *Streptomyces* strain (TA-47), from the rice field was identified by culturing on different media, physiological tests, biochemical tests, chemo-taxonomy and molecular biological approaches. *In-vitro* and *in-vivo* bio-control activity of the isolated strain was evaluated. Growth on the media, spore production, utilization of sole carbon and nitrogen sources, presence of diaminopimelic acid (DAP) in the cell wall of the strain and fatty acid production were observed.16S rRNA (gene sequence) and a neighbour-joining hood tree indicated that the strain TA-47 is *Streptomyces koyanogensis*. *In-vitro* inhibition zone of 29 mm against the *M. grisea* showed the antagonistic potential of the novel strain TA-47. On the other hand, in the *in-vivo* studies, strain TA-47, showed the strong bio-control effect, as disease severity decreased to 19.66 ± 1.6%, while in the non-treated sample the disease severity was recorded as 44.66 ± 5.249%. Moreover, after the treatment of the strain, effects on the growth, such as increased height and root length by 72.22 and 16.54 cm, respectively, were also recorded. In conclusion, rhizosphere *Streptomyces* TA-47, was a novel *Streptomyces koyanogensis* strain. The study found that the strain had strong bio-control and growth-promoting abilities.

**Introduction**

*Magnaporthe grisea* causes rice blast, which is the most devastating disease in virtually all rice-growing countries [1]. Rice is economically significant since it feeds 60% of the world’s population. Blast infections may be effectively controlled by cultivating resistant types with chemical control [2]. Blast disease has been treated by using a variety of fungicides. Synthetic fungicides, on the other hand, pollute the environment, produce residual issues, lead to pesticide resistance, reduce soil quality and harm natural ecosystems [3]. The development of fungicide-resistant organisms, necessitates immediate agricultural disease control measures [4].

Natural materials that are environmentally benign and have minimal toxicity to living creatures are gaining popularity as a significant resource for the creation of fungicides. *Streptomyces* are naturally occurring soil bacteria that have been widely employed as biological control agents [5]. *Streptomyces* species are capable of producing a wide range of bioactive chemicals with antibacterial, antifungal, antiviral, anticancer and anti-oxidant activities [5]. In recent years, rice blast disease has been controlled by the two products of *Streptomyces* (Kasugamycin and blasticidin-S) [3,5,6]. The occurrence of rice blast has been controlled by pyrroles (pyrroles [1,2-a] pyrazine-1,4-dione, hexahydro) Oligomycin A and rapamycin [7]. Chemical fungicides could be replaced by bio-control antagonists in the form of *Streptomyces* spp. Since fungal pathogens can develop resistance against the existing bio-control agents, we need to explore novel antagonistic agents to combat the fungus phytopathogen. In this study, a *Streptomyces* strain was isolated from soil and identified and evaluated against rice blast pathogen (*M. grisea*).
Materials and methods

Microorganism

*Streptomyces* strain TA-47 isolated from the rice soil from a rice growing area in Gujrat, Pakistan (32°37′N, 74°7′44″E). The strain was cultivated on nutrient media and maintained at −4°C. Fungus pathogen *M. grisea* was obtained from the Department of Agriculture (Plant Protection) Warning and Quality Control of Pesticides, Gujrat, Pakistan. Fungus pathogen was cultivated on potato dextrose agar (PDA) and maintained at −4°C for further work.

Taxonomy of strain TA-47

Potent strain was grown on different medium. Seven-, fourteen- and twenty-one-day-old cultures of the isolated TA-47 were grown in several agar media, including the four ISP media (ISP 2–5) recommended by Shirling and Gottlieb [8], the Bennett agar medium, the Nutrient agar medium and the S-agar medium (SEM). Tests were conducted on the formation of melanin in peptone-yeast extract-iron (ISP6) and trypsin (ISP7) medium agars. SEM was used to analyse the morphological features of spores and aerial mycelia of strain TA-47 cultivated on the medium at 28°C for 120 h. The method of Holding and Collee [9] was used to assess physiological and biochemical properties.

After three days of incubation at 28°C in shake-flasks with ISP 2 broth, sufficient biomass for chemotaxonomic investigations was obtained. In the entire cell hydrolysates, thin layer chromatography (TLC) was used to determine the isomeric form of diaminopimelic acid (DAP), glycine and sugars [10]. As a part of a two-dimensional TLC analysis, phospholipids were detected utilizing spray reagents and comigration with standards [11,12]. A conventional Microbial Identification System (MIDI) was used to extract fatty acids, methylate them, and then, analyse them using gas chromatography (GC) [13].

PCR amplification of the 16S rRNA gene of strain TA-47 was performed using the universal primers: 27(5′AGTTTGTCMTGCTCATG-3′) and 1492 R (5′GGTACCTTACGACTT-3′) (verity TM 96-well PCR, Applied Biosystems, Singapore). The PCR products were sent to Sangon Biotech (Shanghai, China) Co., Ltd for sequence determination. Phylogenetic analysis was conducted by using Mega version 6 [14], Gene sequences were submitted to the NCBI and waiting for accession number.

Fermentation process to produce antifungal compound

A two-stage fermentation process was carried out: seed growth and the generation of a potent antifungal compound Gausses medium was used to cultivate strain TA-47 for 5 d at 28°C after spore formation in the liquid fermentation medium [15]. After 48 h of incubation at 28°C and 160 rpm, two spore cakes (5 mm) from Strain 128 were used to seed 40 mL of medium into a 250 mL flask. Seed culture (5%, v/v) was inoculated aseptically into a 250 mL flask containing 40 mL of fermentation media. The medium comprised: 47 g soluble starch, 3 g yeast extract, 22 g peanut meal, 2.7 g (NH4)2SO4, 2.7 g NaCl and 2.7 g CaCO3 dissolved in 1 L distilled water and pH were adjusted to 6.8–7.2 and incubated at 28°C in a rotary shaker (HZQ-F16 Harbin Dong Lian Electronic Technology Production. Co., Ltd., Harbin, China) at the speed of 160 rpm for 96 h. This fermented culture was then centrifuged, and the supernatant was kept at 4°C for future research. The diameter of the inhibitory zones was measured to evaluate antifungal activity.

In-vitro antifungal assay against *M. grisea*

For initial screening, a spore cake was used against the pathogen. The spores of the pathogen were mixed in PDA and 5 mm spore cake of antagonistic strain TA-47 was challenged with it. Oxford cup method was used to study the activity of fermentation broth (200µL) for each trail.

Bio-control activity of strain TA-47 in a greenhouse

In greenhouse settings, the antagonistic *Streptomyces* spp. was tested for its ability to suppress rice blast in vivo. The rice variety 1121 White Basmati Rice (*Oryza sativa* L.) was chosen as the host plant because it is particularly vulnerable to rice blast disease. All the experiment performed in the greenhouse under same and control conditions. All the plants were grown on sterilized paddy soil. Four treatments with ten plants each were carried out. (1) Ck (Check) control, without any treatment. (2) Inoculated with strain TA-47 and *M. grisea*. The treatment was given as 2000 µL of the fermentation broth per 10 plants and 2000 µL of spore suspension of *M. grisea* per 10 plants. (3) Inoculated with strain TA-47 given as 2000 µL of the fermentation broth per 10 plants). (4) Inoculated with 2000 µL of spore suspension of *M. grisea* per 10 plants. Treatments were applied to the plants by spraying method.
**Statistical analysis**

Minitab software version 17 was used to analyse the data. Values are the means with standard deviation (±SD). Mean values were compared by least significant difference (LSD) to determine the significant differences at a level of $p \leq .05$.

**Results**

**Taxonomy of the isolated strain TA-47**

Soil isolated strain has been identified by different methods. Strain TA47 grew well on different ISP media, and especially on ISP2, it grew well with whitish-grey aerial and substrate mycelium, while on ISP3 the growth was good with whitish-grey aerial and blackish-grey substrate. However, the growth of the strain on ISP4 was normal without aerial and substrate mycelium appearance, and the growth of the strain was poor on ISP5 with grey appearance of aerial and substrate mycelium. Similarly, the strain grew well on nutrient agar media with whitish-grey substrate and aerial mycelium. A good growth appeared on Bennet agar media too, with whitish-grey substrate and grey aerial mycelium, while moderate growth on Sabouraud agar medium without clear observation of aerial and substrate mycelium as seen in Table 1. Sole nitrogen sources, such as L-asparagine and L-proline, were utilized by strain TA-47, while L-cysteine and L-tyrosine were not utilized. As sole carbon sources, D-sorbitol was not utilized by strain TA-47, while D-fructose, maltose and galactose were utilized by TA-47. In sole energy sources, sodium citrate was consumed, while sodium acetate was not consumed by strain TA-47. Melanin and diffusible were produced on ISP6 medium while both were not produced on ISP7 (Table 2). GC-MS profile of fatty acid included several types of saturated and saturated iso- and anteiso-branched chains and straight-chain fatty acids. The $C_{17,0}$ 2-OH Cis 30% was the major cis form long-chain fatty acid (Table 3).

TLC results showed the presence of ribose, galactose, mannos and DAP in the cell wall of the strain TA-47. Strain TA-47 produced different types of enzymes such as catalase, urease and esterase. Metabolites results showed the production of metabolites as the nitrogen was reduced, consumed by the strain TA-47. The Voges-Proskauer test indicated that there was no production of metabolites. Coagulation and methyl red showed negative results, while peptonization showed positive results (Table 4). Scan electron microscopic analysis indicated the presence of spores and morphologically, a cylindrical shape of

**Table 1. Growth characteristics of Streptomyces strain TA-47, on different nutrient medium.**

| Growth medium         | Growth | Arial mycelium | Substrate mycelium |
|-----------------------|--------|----------------|--------------------|
| ISP2                  | Good   | Whith grey     | Whith grey         |
| ISP3                  | Good   | Whith grey     | Blackish grey      |
| ISP4                  | Normal | Not identified | Not identified     |
| ISP5                  | Poor   | Grey           | Grey               |
| Nutrient agar media   | Very good | Whith grey     | Whith grey         |
| Sabouraud agar media  | Moderate | Not identified | Not identified     |
| Bennet agar media     | Good   | Grey           | Whith grey         |

**Table 2. Physiological characteristics of Streptomyces strain TA-47.**

| Nitrogen utilization  | Carbon utilization | Utilization of sole energy compound | Pigment production |
|-----------------------|--------------------|-------------------------------------|--------------------|
| L-asparagine          | +                  | D-fructose                          | Sodium citrate     | Melanin on ISP6 |
| L-cysteine            | –                  | Maltose                             | Sodium acetate     | Melanin on ISP7 |
| L-proline             | +                  | Galactose                           | –                  | Diffusible ISP6 |
| L-tyrosine            | –                  | D-sorbitol                          | –                  | Diffusible ISP7 |

**Table 3. Cellular fatty acid contents %, chemical characteristics of Streptomyces strain TA-47.**

| Fatty acids | Content% | Fatty acids | Content% |
|-------------|----------|-------------|----------|
| C_{12,0} 2-OH | 1.36     | C_{17,0} 2-OH | 5.67     |
| C_{10,0} 2-OH | 0.91     | Iso C_{16,0} 2-OH | 0.76     |
| C_{11,0} 2-OH | 0.23     | Antiso C_{16,0} 2-OH | 1.54     |
| C_{12,0} 2-OH | 0.14     | C_{17,0} 2-OH Cis | 30.0     |
| Iso C_{13,0} 2-OH | 12.07 | C_{17,0} 2-OH Trans | 20.34     |
| Antiso C_{13,0} 2-OH | 0.54 | C_{16,0} 2-OH | 22.96     |
| C_{14,0} 2-OH        | –        | C_{16,0} 2-OH | 22.96     |
| Iso C_{15,0} 2-OH    | 3.11     | C_{16,0} 2-OH | 22.96     |
TA-47 (Figure 1). These results showed that strain TA-47 was a *Streptomyces* spp. In molecular biological identification, 16S rRNA sequences used to construct the phylogenetic tree. The nucleotide sequences were analysed by BLAST by using Mega software version 6. The nearest close match was 90% with the *Streptomyces koyangensis* genes (T): VK-A60. The evolutionary tree indicated that strain TA-47 belongs to the *S. koyangensis* (Figure 2).

In-vitro antifungal activity of *Streptomyces TA-47* against *M. grisea*

In oxford cup method, fermented broth showed a strong antifungal activity against *M. grisea*, with an inhibition zone of 32.72 ± 1.054. In the same way, in the direct method of microbial inhibition, the zone was 22.28 ± 5.714 mm (Figure 3). In-vitro antifungal potential showed a strong antagonistic potential against *M. grisea*. The results are presented in Figure 4(a,b).

Bio-control assessment in greenhouse conditions

Greenhouse experiments showed the strong antifungal effects of strain TA-47 against *M. grisea*. Rice plant treated with *Streptomyces* strain TA-47, had positive effects. There was no blast lesion produced on the plant and no dry leaves were observed. Besides the disease control, strain TA-47 had even positive effects on the growth of the rice. Results showed that the height of rice plants was 72.22 ± 0.9195 cm, the root length 16.54 ± 1.311 cm, the weight of dry roots 3.396 ± 0.142 g and the number of tillers produced was 7.0 ± 0.408. Compared to the control (without inoculation of strain TA-47 and *M. grisea*), the height of rice plants was 54.41 ± 4.379 cm, the root length 9.52 ± 0.3630 cm, the weight of dry roots 2.03 ± 0.042 g and the number of tillers 3.66 ± 0.471.

### Table 4. Biochemical characteristics of *Streptomyces* strain TA-47.

| Cell wall composition | Metabolite production | Enzymes production |
|-----------------------|-----------------------|---------------------|
| Ribose                | +                     | + Methyl red test   | −                   |
| Galactose             | +                     | Nitrate reduction   | − Catalase          | +                   |
| Mannose               | +                     | Coagulation         | − Urease            | +                   |
| DAP acid              | +                     | VP test             | − Esterase          | +                   |

Figure 1. SEM observation of spore chain and morphological mycelium of *Streptomyces* strain TA-47 on ISP2 medium.

Figure 2. Phylogenetic tree of *Streptomyces* strain TA-47.
In mixed treatment (inoculated with strain TA-47 and *M. grisea*), strain TA-47 had strong antifungal effects. A small lesion of blast disease was produced in the treatment with *M. grisea*, however strain TA-47 controlled the expansion of the blast infection. As the results showed, lesion was 0.76 ± 0.08, the number of dry leaves was 1.33 ± 0.23 and disease severity was 19.66 ± 1.6%. Rice plants also had positive effect from strain TA-47 in the company of *M. grisea*: the height of rice plants was 65.68 ± 0.240 cm, the root length 12.72 ± 0.496 cm, the weight of dry roots 2.31 ± 0.095 g and the number of tillers 5.33 ± 0.235. While the results of inoculation of *M. grisea* only had negative effects, such as presence of infection and increased disease severity. Growth factor also showed negative effects. As the disease lesion was 1.18 ± 0.089, the number of dry leaves was 2.33 ± 0.23, and disease severity was 44.66 ± 5.249%, as the height of rice plants was 46.786 ± 4.379 cm, the root length 5.609 ± 0.3634 cm, the weight of dry roots 0.96 ± 0.024 g and the number of tillers 2.33 ± 0.471.

Figure 5 represents the biological control impact of strain TA-47 in greenhouse on the rice plant. In Figure 5(A), plants were treated with strain TA-47 and *M. grisea*. The blue arrows point to the infection. The results indicated that there was an infection produced by *M. grisea*, inhibited by strain TA-47. There was no infection produced on rice plants treated with fermentation broth of strain TA-47 only (Figure 5(B)). In plants treated with *M. grisea* only (Figure 5(C)) there were lesions and even drying leaves due to infection. In Ck control plants (Figure 5(D)), there was no treatment given and no infection occurred under greenhouse condition.

Figure 6 presents the effects of strain TA-47 on rice growth under greenhouse conditions. There was poor growth of the plant. The plant size, the root length and the number of tillers were less. Lesions and symptoms of infection appeared. Strain TA-47 showed positive impact on the rice plant, though the infection occurred as by the mix treatment. The height of plant, the root length and the number of tillers increased. No disease occurred and growth was normal under
greenhouse conditions. Strain TA-47 had a positive impact on the growth of the rice plants. The height of the plants, the root length and the number of tillers revealed positive impact of strain TA-47.

**Discussion**

This work was intended to identify *Streptomyces* strains from the rice field in order to explore their potential
in vitro and under greenhouse conditions to suppress the rice blast fungus *M. grisea*. The soil is a rich source of *Streptomyces* strains [5], and these microbes are reported as potential antagonists against fungus pathogens [3,16]. Growth on different medium, presence of spore, colour of aerial and substrate mycelium, utilization of sole nitrogen and carbon sources, melamin production, production of enzymes and metabolites. These findings correspond to our results for *Streptomyces koyangensis* strain TA-47 [17].

The presence of DAP in the cell wall and the presence of several types of saturated and iso- and anteiso-branched chains and straight-chain fatty indicated that this strain belongs to the *Streptomyces* genus, as previously described [18]. Molecular analysis indicated that strain TA-47 is closely related to *Streptomyces*. Applications of 16S rDNA or rRNA are reliable approaches to identify the bacterial strains [19].

Disease management of rice blast has become a major concern, as the rice is a major staple crop throughout the world. In this study, *S. koyangensis* potently inhibited the *M. grisea* and controlled the rice blast. Besides the antagonistic potential, strain TA-47 even induced rice growth. Several *Streptomyces* strains were reported to inhibit the fungus pathogen in *in-vitro* conditions. Recently, Ahsan et al. [20] found that *Streptomyces* sp. strongly inhibited the growth of *Rhizoctonia solani* AG-3, by inhibiting basidiospores, mycelia and seclerotia in *in-vitro* conditions. Ahsan et al. controlled the *F. oxysporum* in *in-vitro* conditions.

Strain TA-47 showed bio-control effects in the greenhouse, as the treated plants did not develop disease symptoms. Pathogen-inoculated samples of rice gained a strong resistance from strain TA-47. *Streptomyces* strain TA-47 had a significant contribution in disease control under greenhouse conditions. *Streptomyces albus* successfully inhibits *Macrophomina phaseolina* under greenhouse conditions [21].

Bacteria additionally worked as growth promoters in the plants. In this study, strain TA-47 helped the plant growth as a bio-control agent. Rice plants treated with this strain, showed increase in height, root size and number of tillers. As previously reported [22,23], actinobacteria have the potential to promote growth in plants.

**Conclusions**

Strain TA-47 is a novel strain *S. koyangensis*. *S. koyangensis* TA-47 had a strong antifungal potential against *M. grisea in vitro*. *In-vivo* studies under greenhouse conditions, revealed that *S. koyangensis* had potential bio-control abilities, to inhibit *M. grisea* and control the exploitation of the blast disease. Additionally, *S. koyangensis* TA-47 acted as a growth promoter. In conclusion, *S. koyangensis* TA-47 could be a potential biological control agent for the rice blast disease management.

**Disclosure statement**

The authors declare no conflict of interest.

**Data availability statement**

The data sets analysed in this study are available from the corresponding author upon reasonable request.

**Funding**

This work was funded by the National Key R&D Program of China (2017YFD0201104); National Key R&D Program of China (2017YFE0104900).

**ORCID**

Taswar Ahsan  [http://orcid.org/0000-0001-8777-257X](http://orcid.org/0000-0001-8777-257X)
References

[1] Asibi AE, Chai Q, Coulter JA. Rice blast: a disease with implications for global food security. Agronomy. 2019;9(8):451.

[2] Shahriar SA, Intiaz AA, Hussain MB, et al. Rice blast disease. Ann Res Rev Biol. 2020;35:50–64.

[3] Law JWF, Ser HL, Khan TM, et al. The potential of streptomycetes as biocontrol agents against the rice blast fungus, Magnaporthe oryzae (Pyricularia oryzae). Front Microbiol. 2017;8:3.

[4] Kunova A, Palazzolo L, Forlani F, et al. Structural investigation and molecular modeling studies of Strobilurin-Based fungicides active against the rice blast pathogen Pyricularia oryzae. Int J Mol Sci. 2021;22(7):3731.

[5] Newitt JT, Prudence SM, Hutchings MI, et al. Biocontrol of cereal crop diseases using streptomycetes. Pathogens. 2019;8(2):78.

[6] Copping LG, Duke SO. Natural products that have been used commercially as crop protection agents. Pest Manag Sci. 2007;63(6):524–554.

[7] Yang P, Li MG, Zhao JY, et al. Oligomycins a and C, major secondary metabolites isolated from the newly isolated strain Streptomyces diastaticus. Folia Microbiol (Praha). 2010;55(1):10–16.

[8] Shirling ET, Gottlieb D. Methods for characterization of streptomycetes species1. Int J Syst Evol Microbiol. 1966;16(3):313–340.

[9] Holding A, Collee J. Chapter I routine biochemical tests. Methods in microbiology. Amsterdam, Netherlands: Elsevier; 1971. p. 1–32.

[10] Staneck JL, Roberts GD. Simplified approach to identification of aerobic actinomycetes by thin-layer chromatography. Appl Microbiol. 1974;28(2):226–231.

[11] Collins M, Jones D. Lipids in the classification and identification of coryneform bacteria containing peptidoglycans based on 1, 4-diaminobutyric acid. J Appl Bacteriol. 1980;48(3):459–470.

[12] Minnikin D, Collins M, Goodfellow M. Fatty acid and polar lipid composition in the classification of cellulosomonas, oerskovia and related taxa. J Appl Bacteriol. 1979;47(1):87–95.

[13] Sasser M. Identification of bacteria by gas chromatography of cellular fatty acids. MIDI technical note 101. Newark (DE): MIDI Inc.; 1990.

[14] Ahsan T, Chen J, Wu Y, et al. Screening, identification, optimization of fermentation conditions, and extraction of secondary metabolites for the biocontrol of Rhizoctonia solani AG-3. Biotechnol Biotechnol Equipment. 2017;31(1):91–98.

[15] Gao X, He Q, Jiang Y, et al. Optimization of nutrient and fermentation parameters for antifungal activity by Streptomyces lavendulae xjy and its biocontrol efficacies against fulvia fulva and botryosphaeria dothidea. J Phytopathol. 2016;164(3):155–165.

[16] Dasgupta S, Meisner C, Wheeler D, et al. Pesticide poisoning of farm workers-implications of blood test results from Vietnam. Int J Hyg Environ Health. 2007;210(2):121–132.

[17] Gao F, Wu Y, Wang M. Identification and antifungal activity of an actinomycete strain against alternaria spp. Span J Agric Res. 2014;12(4):1158–1165.

[18] Smaoui S, Mathieu F, Fguira B, et al. Taxonomy and antimicrobial activities of a new streptomyces sp. TN17 isolated in the soil from an oasis in Tunis. Arch Biol Sci (Beogr). 2011;63(4):1047–1056.

[19] Zheng J, Zhu J, Chen B, et al. Application of 16s rDNA sequencing in the analysis of pathogenic bacteria in sputum of severe bacterial pneumonia. Adv Microbiol. 2021;11(02):109–116.

[20] Ahsan T, Chen J, Zhao X, et al. Action mechanism of Streptomyces diastatochromogenes KX852460 against Rhizoctonia solani AG-3 involving basidiospores suppression and oxidative damage. Iran J Sci Technol Trans Sci. 2019;43(5):2141–2147.

[21] Gopalakrishnan S, Sharma R, Srinivas V, et al. Identification and characterization of a Streptomyces albus strain and its secondary metabolite organophosphate against charcoal rot of sorghum. Plants. 2020;9(12):1727.

[22] Monteiro P, Borba MP, Van Der Sand ST. Evaluation of the antifungal activity of streptomyces sp. on Bipolaris sorokiniana and the growth promotion of wheat plants. J Agric Sci. 2017;9(12):229.

[23] El-Tarabily KA, AlKhajeh AS, Ayyash MM, et al. Growth promotion of salicornia bigelovii by Micromonospora chalcea UAE1, an endophytic 1-aminocyclopropane-1-carboxylic acid deaminase-producing actinobacterial isolate. Front Microbiol. 2019;10:1694.