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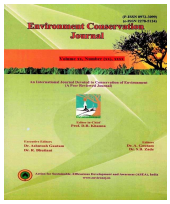

Biological control of *Fusarium*-wilt *and* quality improvement of *Sesamum indicum* cv. ST-1 using fluorescent *Pseudomonas*

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ABSTRACT

Seven plant growth-promoting bacterial strains (LES1-LES7) were isolated from rhizosphere of *Lycoperscion esculentum* Mill. (Tomato) and further screened based on colony morphology, carbon source utilization and biochemically characterized as fluorescent *Pseudomonads*. Among the isolates prominent strain identified as *Pseudomonas aeruginosa* LES4 produced maximum siderophores *in vitro* besides indole acetic acid, hydrocyanic acid, solubilized insoluble inorganic phosphate and secreted β-1, 3-glucanase urease and chitin solubilizing enzymes chitinase. It also exhibited a strong antagonism against *Fusarium oxysporum* f.sp. *sesami* when co-cultured on nutrient agar medium and inhibiting the growth of the pathogen by 69% after 5 days incubation at 28 ± 1°C. Sesame (*Sesamum indicum* L. cv. ST-1). When surface sterilized seeds bacterized with *P. aeruginosa* LES4 showed enhancement in seedling sprouting early vegetative growth, and increased seed yield components viz. biomass accumulation, and all other yield and quality improving components. Strain LES4 significantly reduced the wilt disease of sesame in *F. oxysporum* f.sp. *sesami*-infested soil. Moreover, *Tn*5 induced streptomycin resistant trans-conjugants of spontaneous tetracycline-resistant LES4 (designated LES4$^{tetra+strep+}$) used to exhibit efficient rhizosphere colonization of sesame. Such properties of fluorescent *P. aeruginosa* LES4 prove it as a beneficial and potential microbial agent against wilt causing sesame.

Introduction

Sesame (*Sesamum indicum* L.) is one of the most ancient oil seed crop cultivated in all over the world. Wherever, sesame is grown, it is likely to attack by a number of serious phyto-pathogenic fungi (El-Shazly *et al*. 1999; Jyothi *et al*. 2011). Fungal pathogens cause wilt by invading and gradually blocking the conducting tissues. *Fusarium oxysporum* is a notorious phyto-fungal pathogen may be soil or seeds/seedling borne which completely block water conducting xylem vessels and photosynthate supply leads to wilting of plants (Bateman *et al*. 1996). Sesame is susceptible and liable to attack by various phytopathogens on different developmental stages and resulted in serious damage or great crop loss. *F. oxysporum* f.sp. *sesami* (Zaprometoff) Castellani is one of the serious pathogen of sesame wilt and leads to reduced sesame production. Armstrong and Armstrong (1950), reported for the first time from America. Use of broad-spectrum biocides, soil fumigation and cultivation resistant cultivars are the common methods to control this pathogen. However, use of fungicides and soil fumigation are not environmentally (Kumar *et al.* 2011). Recently, Gricher *et al*. (2001a, b) observed negative effects of these phytochemicals on sesame and accumulation harmful chemicals have been reported in seeds, oil and oil cake of Sesame

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(Shinde *et al.* 2021) leads to reduction in sesame export and consumptions. Due to which, sometime export consignments in international market are cancelled and leads to loss of revenues (Duhoon *et al*. 2004). Thus the use of fungicide, synthetic fertilizers and pesticide not only distract soil fertility, ecology, microbiome but leads pollutes water resources and consequently drastically affect human health directly and indirectly (Ayala and Rao 2002; Kumar *et al*., 2009).

Biocontrol of plant pathogens is one of the ecological safe methods being used in recent years. Among the bacterial antagonists, pseudomonads have shown a promising potential biocontrol rhizobacteria against soil as well as seed borne phytopathogens with plant growth-promoting (PGP) activities under controlled and field conditions (Kloepper *et al*. 1989; Gupta *et al*. 2002, Kumar *et al*. 2005). Pseudomonads are able to colonize plant roots and dominant rhizospheric microbiome over the native soil-microflora as compared with other inoculated strains (Kumar *et al*., 2009; Lim *et al*. 2002). The disease management involves antagonism through iron deficiency due to chelation by siderophores, which may lead to elimination of fungal pathogens in the rhizosphere). The present study was designed to evaluate the efficiency of seed bacterization with fluorescent *P. aeruginosa* LES4 on seed germination, root colonization, plant biomass accumulation, crop yield, oil contents and its requisite population in rhizosphere to suppress the sesame wilt caused by *F. oxysporum* f.sp. *sesami*.

Material and Methods

Bacterial inoculum

The fluorescent Pseudomonad strains were isolated from the rhizosphere ofvigorously growingplant of*Lycopersicon esculantum* L. (Tomato) growing in waste land seems to be deficient in nutrients. The strains were isolated by serial dilution method on nutrient agar medium (NAM), and the petri-plates were incubated at 30 ± 2°C for 48-78 h. The fluorescent water soluble pigment producing bacterial colonies were selected and further streaked onto a NAM addition of 100 µg ml^{-1} tetracycline and streptomycin to evaluate the antibiotic-resistant strain. All the isolates were cultured and maintained on NAM slants at 4°C for further studies. Morphological, physiological and biochemical characterization of isolates was carried out with Microbial Type Culture Collection (MTCC) standard strain as described by Holt *et al*. (1994). *F. oxysporum* f. sp. *sesami* was isolated from seeds, roots and infected plant parts of sesame on potato-dextrose agar f(PDA) and identified following Barnett and Hunter (1972) and maintained on PDA slants for further uses.

Direct and indirect plant growth promoting (PGP) properties of all the promising strains were determined by using log phase cultures (24 h old). Siderophores production was estimated on Chrom Azurol agar medium (CAS) qualitatively following the method of Schwyn and Neilands (1987). The strains were separately inoculated on CAS agar medium, and the Petri-plates were incubating at 30 ± 2°C for 78 h. Hydrocyanic acid (HCN) production was evaluated (modified) as described by Miller and Higgins (1970), and indole acetic acid (IAA) production was determined correspondingly to the method of Gupta *et al*. (1999).Phosphate solubilization abilities of strains were appropriately determined by inoculating a loopful culture of isolates on Pikovskya's agar plates (Pikovskaya's 1948).

Chitinase activity

The chitin minimal medium (CMM) was used test for production of extra cellular chitinase activities. Bacterial cultures were infused on CMM plates and incubated at 28 ± 1^0C up to 5-6 days. Formation clear halo zone around the bacterial spots indicated secretion of chitinase enzyme (Dunne *et al*. 1997). Similarly, ß-1-3 glucanase enzymatic activity determined by supplementing the laminarin (0.2%) in growth medium as a sole source of carbon and observed by appearance of turbid growth.

Antagonistic activities

Antagonistic activities of bacterial strains were evaluated against wilt causing pathogen *F. oxysporum*f.sp. *sesami*on NAM using a dual culture method of the as described by Skidmore and Dickinson (1976). Five days old mycelial agar blocks of 5 mm diameter were placed on 90 mm diameter NAM plate, and the log phase culture were infused 2 centimeters apart from the fungal pathogen and incubated at 30 ± 2°C along with control (Without bacterial strain). Antagonistic

activities were evaluated by calculate the growth inhibition of fungal colonies by bacterial strains, and represented in percent by following formula:

Growth inhibition = Control -Treatment/Control X100

The experiment was performed in three replicates. The mycelia of *F. oxysporum*f.sp. *sesami* were periodically recovered from zone of inhibition for deformities and microscopic examination as described by Gupta *et al*. (2001).

Preparation of fungal inoculum

Potato Dextrose Broth (PDB) was used to prepared the pathogen inoculum by culturing the fungus for 15 days at 27± 1°C. Actively growing pathogen colony was gather on sterilized filter paper to remove the extra water, and the inoculum was prepared by pulverized 100 gram of fungal mycelia in 1000 mlDW by using 10 mlinoculum to provide 1 g for each *flower*-pot for pathogeninfested soil.

Seeds treatment and pot trial assay

Sesamum indicum L. cv. ST-1 certified seeds were obtained from Center for Transgenic Plant Development, Department of Biotechnology, Jamia Hamdard Deemed to be University, Hamdard Nagar, New Delhi, India. Surface sterilized seeds were bacterized by the modified method given by Weller and Cook (1983). Surfaced sterilization was done with the help of 90% alcohol followed by 0.1% (w/v) $HgCl_2$ for 2-3 minutes and then 7-8 time washed with sterilized distilled water (SDW) and dried under aseptic conditions in Laminar Air Flow (LAF). The actively growing log phase culture of LES4 was centrifuged at 8000 revolutions per minutes for 12min at 4°C by ultra-centrifuge. After centrifuge LES4 pellets were washed with SDW and obtained a cell density of 1 × 10^8 CFU ml^{-1} in SDW. Above mixture used for seed coating with the help of 1% carboxymethylcellulose (CMC) slurry and air-dried overnight under LAF. The sesame seeds coated with CMC slurry (without *P. aeruginosa* LES4) treated as the control.

Bacterized and control seeds (without bacterization only coated with CMC) were sown separately in earthen pots of 15 cm diameter containing about 1 kg sterilized (steam) soil with composition of 0.097% total organic carbon, 14.4 % silt, 12.3% clay, 75.2% sand, pH 6.9 and 38% WHC and arranged all treatments as: Treatment 1: *F. oxysporum* f.sp. *sesami*inoculated soilplus non-bacterized seeds; Treatment 2: *P. aeruginosa* LES4 coated seeds plus soil; Treatment 3: *F. oxysporum* f.sp. *sesami* plus *P. aeruginosa* LES4 coated seeds; Treatment 4: *F. oxysporum* f.sp. *sesami* plus standard MTCC1934 strain Treatment 5: Seeds shown without bacterized seeds and *F. oxysporum* f.sp. *sesami* treated ascontrol**.** All the growth and development parameters including plant shoot fresh and dry weight, number of capsules per plants, number of seeds per capsules, seeds weight, oil contents and seedling infected with *Fusarium*-wilt were observed up to 90 DAS. All the treatments were arranged in completely random design (CBD) in triplicate number.

Root colonization

Antibiotic resistant marker strain was used to study rhizosphere colonization of *S. indicum*. Tetracycline and streptomycin resistant strain of Pseudomonads inoculated on Tryptic Soy Agar medium, supplemented with 100 mg l^{-1} of tetracycline designated as *P. aeruginosa* LES4^{tetra+}. The very same strain was acquainted resistance for another antibiotic streptomycin and designated *P. aeruginosa* LES4$^{tetra+strept+}$ with the help of *Tn*5 delivery suicidal vector in donor *Escherichia coli* strain WA803 (pGS9) (Selvaraj and Iyer, 1983; Kumar *et al*. (2003). Quantitative examination of rhizospheric colonization and changes in microbiome of sesame was studied. Seedlings emerged with bacterized seeds (with *P. aeruginosa* LES4$^{tetra+strept+}$)was sampled after 30 to 90 DAS and population dynamics was analyzed. Freshly collected sesame roots pieces of one centimeter about 1 g weight were vortexes in measured volume of SDW to liberate the root-adhering microbes into water. Optimum amount of the dilution was plated on Tryptic Soy Agar medium containing both antibiotic i.e. tetracycline and streptomycin (100 mg l^{-1}) to study the colonization and rhizospheric population dynamics. Further, analysis of bacterial population was done after 24 h incubation at 30 ± 2°C, and colony forming units per gram of sesame root segment were enumerated.

Pathogen infestation and *Fusarium*-wilt

Assessment of diseases incidence of *Fusarium* infestation and wilt was done in five, one-centimeter-long root pieces of sesame, surface-sterilized with the help of 3% NaClO for 2-3 min, and incubated on to potato dextrose agar plates

supplemented with antibiotics penicillin (100,000 units litre^{-1}) and streptomycin (0.2 gram litre^{-1}) at 30°C for 5-6 days, the occurrence of *F. oxysporum* f.sp. *sesami* was observed in root samples (Siddiqui *et al*. 2000). To identify *Fusarium* wilt, sesame plants showing wilt symptoms were leniently uprooted, individually kept in sterilized poly-bags for further study in research lab. *Fusarium* wilt symptoms on root were observed by cut and peel back a section of the epidermis and cortical tissues just above the soil, observing with a 10x field lens and conidia under microscope. The isolate was collected, identified and maintained on PDA plate and corroboration of isolate was done as following the Koch,s postulation and microscopic analysis in laboratory.

Estimation of oil content

Seed oil content was extracted and estimated with the help of n-hexane in research laboratory using cold percolation technique by rapid gravimetric determination of oil content by modified methods (Kartha and Sethi, 1957) and represented in percentage.

Results and Discussion

Isolation of rhizobacteria

A large number of rhizospheric fluorescent pseudomonads were isolated and further screened for direct and indirect plant growth promoting (PGP) activities. Among the isolates seven isolates were found potent for PGP activities. Among the isolated strains, LES4 was found as most encouraging strain, in view of fact that it solubilized inorganic phosphate, produced plant growth hormone and phytostimulating hydrogen cyanide, along with inhibition of *F. oxysporum* f.sp. *sesami* in dual culture. In biochemical screening LES4 was producing urease, oxidase, and catalase. However, found negative for mannose utilization and starch solubilization forming smooth-round colonies and bacterial cells were found motile, Gram-negative, rod, and not forming spores on NAM plates after 24 h of incubation at 28 ± 1 ºC. The strain was positive for catalase, oxidase, urease and indole production and was negative for starch hydrolysis and mannose utilization. Based on above morphological and biochemical characteristics when compared with standard strain MTCC strain 1934, found very similar to *P. aeruginosa*. Hence, LES4 was identified as *P. aeruginosa*.

Siderophore are low molecular weight proteins which chelates iron in rhizosphere. LES4 produced sidrophore as indicated by the formation of orange zone when inoculated on Chrome Azurol agar plates. The log phase culture filtrate of *P. aeruginosa* LES4 produced hydroxamate-type siderophores as evident by occurrence of major peak at 400 nm. Hydrogen cyanide production indicated by turning the color of yellow filter paper to reddish brown in 3 days of incubation. IAA production evident by the production of pink color with and without addition of tryptophan in both cell as well as cell free culture filtrates. *P. aeruginosa* LES4 develop a clear zone around the bacterial colony on the Pikovskaya's agar plates showed production of phosphatase and solubilization abilities of phosphate after 48 h of incubation. Formation of clear halo around the bacterial colony on chitin supplemented medium indicated that strain LES4 is positive for chitinase activities. Chitinase activity started after 24 h and successively increased and attained maximum at 120 h of incubation. The activity was declined after further incubation. On the other hand, ß-1-3 glucanase activity started after 20 h and observed highest after 36 h of inoculation.

***In vitro* antagonistic activity**

*P. aeruginosa*LES4 firmly inhibited the mycelial growth and vigorously restrict colony expansion of *F. oxysporum* f.sp. *sesami* on dual culture plates 28 ± 1^{o}C and reached maximum after 5 days of inoculation which leads to 69% growth reduction, finally diffidence of *F. oxysporum* f.sp. *sesami* as compared to the control.

Root colonization

Direct correlation has been observed between reduction of diseases incidence and in-*vitro* antagonism activities. *P. aeruginosa* LES4$^{tetra+strept+}$ treated as makers strain vigorously colonized rhizosphere of sesame. Higher root colonization was observed by *P. aeruginosa* LES4$^{tetra+\ strept+}$ in *F. oxysporum* f.sp. *sesami* infested soil as compared to *P. aeruginosa* LES4$^{tetra+\ strept+}$ alone (6.9 x 10^4 and 5.8 × 10^4 CFU ml^{-1}, respectively) after 90 DAS. The colony-forming unit (CFU) increased with incubation from 30 up to 90 DAS (Table 1).

Pot experiments

The seeds bacterized with LES4 resulted in significant (P<0.01) increase in seedling biomass as compared to that of non-bacterized seeds. Growth parameters viz., number of capsules per plants, seed weight and oil contents were significantly influenced by *P. aeruginosa* LES4. Higher numbers of capsules per plants (58) were observed with treatment III (*P. aeruginosa* LES4 + *F. oxysporum* f.sp. *sesami*) which is 48.95% higher in comparison to control. Lesser numbers of capsules (22) were obtained in *F. oxysporum* f.sp. *sesami* invaded soil. An increased seed weight by 79.80% and oil contents by 90.87% has been recorded seedlings emerged with bacterized seeds. In contrast a decline in plant growth, biomass yield and oil content was recorded in *F. oxysporum* f.sp. *sesami* invaded soil. All plants were infected by *F. oxysporum* f.sp. *sesami* grown in infested soil but about 95 % reduction in wilt incidence was recorded with use of LES4 bacterized seeds in *F. oxysporum* f.sp. *sesami* infested pots. Standard strain MTCC-1934 also reduced the disease incidence about 70% (Table 2). Pathogen was re-isolated from infected plants and wilt-sick pots. Even though plants are infected at an early stage, they seem able to "keep fighting" with *Fusarium* wilt until flowering and capsule formation. Symptoms of disease appear 2 to 3 weeks DAS. The preliminary visible indication was the wilting of leaves and loosing normal morphology followed by chlorosis and turning bright yellow before complete wilting but retained on plants (Figure 1 A-D). When the bark of wilted plants peeled off, browning or blacking coloration, blocking of xylem vessels from root system to stem (Fig. 2A & B) and presence of conidia in internal tissues (Fig. 1C) were observed.

Table 1: Population dynamics of *Pseudomonas* LES4^{tetra+} in rhizosphere of sesame (Values are means of three replicate)

Treatments	CFU g^{-1} root segments of sesame		
	30 DAS	60 DAS	90 DAS
Pseudomonas LES-4	1.5 x 10^3	4.5 x 10^4	5.8 x 10^4
Pseudomonas+ *F. oxysporum* f.sp. *sesami*	4.3 x 10^3	6.7 x 10^4	6.9 x 10^4
MTCC1934	2.5 x 10^3	6.3 x 10^4	6.7 x 10^4

CFU- Colony-forming unit

P. aeruginosa LES4 produced siderophore, chitinase, *β*-1,3-glucanase besides hydrogen cyanide, and phytohormone *in-vitro*. Recently, Arora *et al*. (2007) reported that fluorescent pseudomonad from *Solanum tuberosum* rhizosphere exhibited the same plant growth promoting and unsympathetic activities against *Phytophthora capsici* and *Rhizoctonia solani*.

Similarly, *P. aeruginosa* LES4 inhibited the mycelial growth and induced deformities in *F. oxysporum* f.sp. *sesamiin vitro*. *Pseudomonads* exhibits antagonism against phytopathogens via the production of antifungal compounds includes antibiotics, siderophore and HCN. *P. aeruginosa* LES4 reduced the *Fusarium*-wilt incidences in pot experiment and also enhanced the plant growth and yield components of sesame. Furthermore, strain LES4 proved as a competent rhizosphere colonizer, resulting enhance seed germination and seedling emergence (84%) even in presence of *F. oxysporum* f.sp. *sesami*.

Approximately, 56% of fluorescent pseudomonads isolates from tomato rhizosphere inhibited the growth of *F. oxysporum* f.sp. *sesamiin vitro* but most promising effect was caused by LES4. siderophores, chitinase, *β*-1,3-glucanase, HCN and antibiotics etc produced by *P. aeruginosa* LES4 exhibited reduction in growth of phytopathogen. This is proven by facts: (1) inhibition of fungal growth because of diffusible substances (2) in dual culture have all necessary nutrients, hence competition for nutrients can be excluded, (3) chitinase secretion was observed during *in vitro* study, which may be involve in degradation of fungal cell wall, (4) implication of antifungal compound produced by LES4 in the reduction of pathogen growth was established by using supernatant of PGPR to restrict *in vitro* germination of conidia and mycelial growth of phytopathogen.

This study has shown that 69% growth inhibition of *F. oxysporum* f.sp. *sesami* might be cumulative action of all cytosolic antibiosis amalgam of various biochemical such as Hydrogen cyanide, iron chelators, lytic and chitin solubilizing enzymes. Production of antifungal metabolites by fluorescent pseudomonads and its antagonistic

actions on fungal pathogens (Bano and Musarrat 2003; Gupta *et al*. 2001). Similarly, LES4 restrict the conidia and mycelial growth of *F*. *oxysporum*

Fig. 1. Pot trail assay: (A) Soil inoculated with *F. oxysporum*f.sp. *sesami* (B) Soil inoculated with *P. aeruginosa* MTCC100+ *F. oxysporum*f.sp. *sesami*(C) Soil inoculated with *P. aeruginosa* LES4 + *F. oxysporum*f.sp. *sesami*(D) Soil inoculated with *P.aeruginosa* LES4 + *F. oxysporum*f.sp. *sesami*

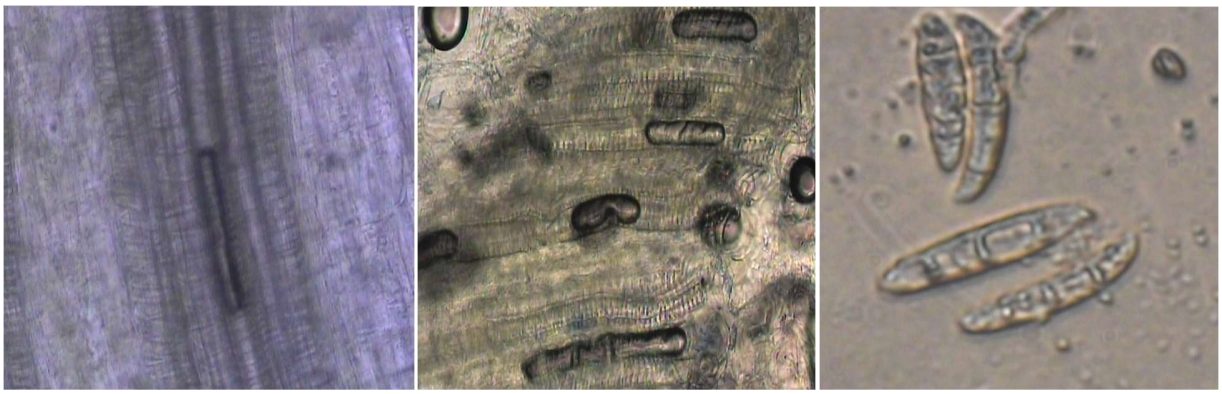

Fig. 2 (A & B) Vessels blocking found in wilted Sesame plant stem inoculated with *F. oxysporum*f.sp. *sesami* (C) *Fusarium* conidia found in the internal tissues of wilted plant parts.

f.sp. *sesami.* Likewise, chitinase, pyrazine, HCN and low molecular weight proteins including iron chelators secreted by pseudomonads are known to restrict the growth of phytopathogens (Lim and Kim 1995; Gupta *et al*. 2006). Loss of structural integrity and solubilization of chitin cell wall by lytic enzyme chitinase is well known (Fridlender *et al*. 1993; Gupta *et al*. 2006). Upadhyay and Jayaswal (1992) reported reduction of conidia germination and mycelial degradation and hyphal lysis of fungal pathogens by *Pseudomonas cepacia* due to production antagonist compounds. Similarly, LES4 also inhibited conidia production and germination and mycelial deformities.

Seed coating with rhizospheric competent fluorescent pseudomonads is well known along with PGP activities. Suppression of plant pathogenic fungi under controlled and field conditions is highly essential for commercial and economic viabilities (Kumar and Dube, 1992). Increase in growth and crop yield because of PGP activities of fluorescent pseudomonads is well documented by several researchers (Kumar *et al*., 2009). Similarly, Hofte *et al*. (1991) reported that *P. aeruginosa* $7NSK_2$ secreted antifungal compounds, aggressively colonize rhizosphere of different vegetables and cereals and enhance growth and yield. But *P. aeruginosa* LES4 showed positive PGP activities (Kumar *et al*., 2009) and significantly influenced all the vegetative as well as yields components of sesame.

First and foremost, for biocontrol agent and plant growth promoting rhizobacteria it is highly essential that particular strain must survive and colonized the rhizosphere of that particular crop. Many workers documented that inadequate colonization leads to decrease biocontrol activities (Kloepper *et al*. 1988; Maheshwari *et al.* 2012).

LES4 exhibited successive survival and colonizing properties in sesame rhizosphere along with enhance seed germination and biological control against the *F. oxysporum* f.*sp. sesami.Pseudomonas* sp. dominating microbiome over other rhizospheric communities due to its fast growing nature and

Table 2: Effect of seed bacterization with *P. aeruginosa* LES4 on seed germination, diseases reduction, growth and yield component of *Sesamum indicum* L. cv. ST-1 after 90 DAS

Test organism	Germination (%)	Root			Shoot			Capsule /Plant^{-1}	1000 seeds weight (g)	Oil Content (%)	Wilt disease (%)
		Length (cm)	Fresh weight (g)	Dry Weight (g)	Length (cm)	Fresh Weight (g)	Dry Weight (g)				
F. oxysporum f.sp. *sesami*	55.00	4.4	11.0	6.2	49.1	73.4	28.5	22.2	2.00	45.0	100
P. aeruginosa LES4	90.00	8.4	25.4	12.5	65.6	101.7	50.8	49.8	2.78	49.2	-
P. aeruginosa LES4+ *F. oxysporum* f.sp. *sesami*	93.00	9.3	26.6	13.5	69.0	108.7	57.5	57.6	3.02	50.4	5
MTCC1934 + *F. oxysporum* f.sp. *sesami*	84.00	7.6	22.8	12.3	62.4	98.0	40.0	34.0	2.29	47.6	20
Control	78.00	5.2	13.7	7.2	54.2	86.0	32.1	28.2	2.14	45.8	2
CD@ 1%	8.94	3.05	1.62	2.36	0.39	1.78	0.95	1.00	0.86	0.75	
± SEM	1.88	0.64	0.34	0.49	1.88	8.43	4.51	4.73	0.40	3.56	

Values are mean of 5 randomly selected plants from each treatment

antibiosis with the help of various organic biochemical (Howell and Stipanovic 1980; Bakker *et al*. 1986). Our results suggest that seed bacterization with *P. aeruginosa* LES4 can protect sesame from diseases caused by a high concentration of the *F. oxysporum* f.*sp. sesami* infested soil and likewise potentially biocontrol agent to reduce the wilt disease in economic and ecofriendly manners. Hence, we might assume that the LES4 is potent biocontrol control agent against the *F. oxysporum* f.*sp. sesami* has exhibited its antagonisms and enhanced plant growth and yield components after bacterization, production of phytohormone (IAA), solubilization of inorganic phosphate, urease, and rhizospheric competent to restrict the fungal growth and growth enhancements. *F. oxysporum* f.*sp*. *sesami* by its extracellular enzyme chitinase, *β*-1,3-glucanase and siderophores production responsible for mycelial deformities, hyphal perforation, cellular lysis and conidia development due to complicity of antifungal compounds perhaps could not be avoided.

Conclusion

The present investigation conclusively revealed that application of rhizospheric competent strain *P. aeruginosa* LES4 have biological control potential for *Fusarium*-wilt and excert positive effect on vegetative growth, productivity and increase oil contents significantly higher in all the treatments in comparison to control in ecofriendly manners probably due to aggressive root colonization, enhancement of nutrient uptakes, production of phytohormone and lytic enzymes to control the fungal pathogen.

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Conflict of interest

The authors declare that they have no conflict of interest.

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