Chapter 5
Management of Soil-Borne Diseases of Grain Legumes Through Broad-Spectrum Actinomycetes Having Plant Growth-Promoting and Biocontrol Traits

Subramaniam Gopalakrishnan and Vadlamudi Srinivas

Abstract Chickpea (*Cicer arietinum* L.) and pigeonpea (*Cajanus cajan* L.) are the two important grain legumes grown extensively in the semiarid tropics (SAT) of the world, where soils are poor in nutrients and receive inadequate/erratic rainfall. SAT regions are commonly found in Africa, Australia, and South Asia. Chickpea and pigeonpea suffer from about 38 pathogens that cause soil-borne diseases including wilt, collar rot, dry root rot, damping off, stem canker, and *Ascochyta*/*Phytophthora* blight, and of which three of them, wilt, collar rot, and dry root rot, are important in SAT regions. Management of these soil-borne diseases are hard, as no one control measure is completely effective. Advanced/delayed sowing date, solarization of soil, and use of fungicides are some of the control measures usually employed for these diseases but with little success. The use of disease-resistant cultivar is the best efficient and economical control measure, but it is not available for most of the soil-borne diseases. Biocontrol of soil-borne plant pathogens has been managed using antagonistic actinobacteria, bacteria, and fungi. Actinobacterial strains of *Streptomyces*, *Amycolatopsis*, *Micromonospora*, *Frankia*, and *Nocardia* were reported to exert effective control on soil-borne pathogens and help the host plants to mobilize and acquire macro- and micronutrients. Such novel actinomycetes with wide range of plant growth-promoting (PGP) and antagonistic traits need to be exploited for sustainable agriculture. This chapter gives a comprehensive analysis of important soil-borne diseases of chickpea and pigeonpea and how broad-spectrum actinomycetes, particularly *Streptomyces* spp., could be exploited for managing them.

S. Gopalakrishnan (✉) · V. Srinivas
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India
e-mail: s.gopalakrishnan@cgiar.org

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5.1 Introduction: Soil-Borne Pathogens of Chickpea

Chickpea affected by more than 170 plant pathogens including bacteria, fungi, nematodes, mycoplasmas, and viruses, whereas only 38 of these, associated with 19 genera of fungi, cause soil-borne diseases, such as wilt, collar rot, dry root rot, canker, damping-off, and blight. The three most important of them, wilt, collar rot, and dry root rot, are briefed here.

5.1.1 Wilt

The causal organism of wilt in chickpea is *Fusarium oxysporum* Schl. emend. Snyd. and Hans. f. sp. *ciceri* (Padwick; FOC). Other species of *Fusarium* also reported to cause wilt and produce toxins (Gopalakrishnan et al. 2005; Gopalakrishnan and Strange 2005). Wilt is the third most important disease of chickpea throughout the world and is reported in about 32 countries (Dubey et al. 2007). It is a serious problem of chickpea between the latitudes 30°N and 30°S of the equator, where the season is warm and dry (semiarid), but common in all growing areas of the world (Dubey et al. 2007). Wilt causes total yield loss (up to 100%) in chickpea under favorable conditions (Landa et al. 2004). FOC is a facultative saprophyte and thus can survive in soil and/or crop residues for 6 years as chlamydospores. The typical symptoms of wilt include drooping of leaves, petiole, and rachis and browning of xylem vessels (Gopalakrishnan et al. 2005). Pigeonpea, lentil, and pea are symptomless carriers of FOC. Usage of resistant cultivar is the best option to manage this disease, but it is limited by the presence of eight races in FOC (Jimenez-Gasco et al. 2002). *Fusarium* wilt can be managed to some extent with a blend of benomyl 30% and thiram 30% at 1.5 g kg^{-1} seed (Haware et al. 1996). However, fungicides are not economical against soil-borne pathogens such as FOC. Further, it has also led to environmental degradation and pollution, imbalance in the microbial community in the rhizosphere soil, pathogen resistance, and increased risk to animal and human health (Li et al. 2012; On et al. 2015).

5.1.2 Collar Rot

It is caused by *Sclerotium rolfsii* Sacc. This pathogen attacks more than 100 crop species including chickpea, groundnut, vegetables, fruits, and ornamental crops (Aycock 1966). Collar rot generally occurs where the soil moisture is high, temperature above 30 °C, and up to 6 weeks after sowing. It is one of the most important diseases of chickpea that causes mortality of seedlings up to 95% under favorable conditions (Sharma and Ghosh 2017). This is one of the important reasons why collar rot is a major problem in areas where chickpea follows rice. *S. rolfsii* survives in the infected plant tissues and crop debris for years. Sclerotia usually attack collar

s.gopalakrishnan@cgiar.org

region of the host plants. The disease symptoms of collar rot include dark-brown lesions on the root surface (at collar region), and yellowing and wilting of leaves leads to death of the plant (Nene et al. 1991). Elimination of *S. rolfsii* in the field is not possible due to its ability to produce large numbers of sclerotia in short time and persist in the soil for decades (Punja 1988). Synthetic chemicals such as thiram are used for collar rot management, but yield losses still persist (Singh and Gaur 2016). High levels of resistant cultivar against collar rot of chickpea were not available (Tarafdar et al. 2018). Hence, combination of cultivar with low level of genetic resistance and a biocontrol product or fungicide may be advised as an alternate strategy for the management of collar rot.

5.1.3 Dry Root Rot

It is caused by *Rhizoctonia bataticola* in chickpea. It is endemic in both tropical and temperate regions of the world and cause the disease in over 500 different crops. Dry root rot causes up to 100% yield losses under favorable conditions. *R. bataticola* normally causes the disease when the day temperature is high (above 30 °C) and under dry conditions. In chickpea, the dry root rot symptoms include brown discoloration of lower leaves and stems, black-colored taproots, rotten, and devoid of the lateral and fine roots. When the dried chickpea stem (of the collar region) is split open vertically, sclerotia (minute and dark colored) are seen along with sparse mycelium in the pith (Nene et al. 1991). Although many control measures are available to manage dry root rot in chickpea, soil-borne nature, persistence in soil, and a wide host range of *R. bataticola* make this disease difficult to control. High levels of resistant cultivar are not available. Many biological control products are being evaluated to control dry root rot disease in chickpea.

5.2 Soil-Borne Pathogens of Pigeonpea (*Cajanus cajan* L.)

Diseases are one of the major concerns for the production of pigeonpea as more than 60 pathogens such as bacteria, fungi, nematodes, mycoplasma, and viruses are reported to infect it (Reddy et al. 2012). The four most important soil-borne diseases of pigeonpea include *Fusarium* wilt, collar rot, and dry root rot, and *Phytophthora* blights are briefed here.

5.2.1 Fusarium Wilt

Wilt in pigeonpea is caused by *Fusarium udum* Butler. It is distributed in India, Bangladesh, Ghana, Kenya, Malawi, Myanmar, and Nepal. The annual losses due to *Fusarium* wilt have been estimated at US$ 5 million in Eastern Africa and US$

71 million in India (Reddy et al. 2012). *Fusarium* wilt in pigeonpea is seed- and soil-borne and can survive in plant debris or soil for more than a decade. Disease incidence of wilt is more severe on Vertisols (black soils) than Alfisols (red soils) and occurs when plants are 1–2 months old and when plants are flowering or podding. Symptoms of *Fusarium* wilt include patches of dead plants during flowering/podding of the crop, purple band extending upward from the base of the main stem (seen with green stems), and partial wilting of the plant. When the main stem or branches are split open, browning or blackening of the xylem is visible. Fungicides such as benomyl, bavistin, and thiram are extensively sprayed to manage wilt of pigeonpea but with less success (Meena et al. 2002). Since *F. udum* is a soil-borne, synthetic chemical control is not useful (Maisuria et al. 2008). Hence, much reliable and sustainable control measure needs to be explored.

5.2.2 Collar Rot

It is caused by a soil-borne pathogen called *Sclerotium rolfsii* Saccardo. It is mainly distributed in South Asian countries such as India, Sri Lanka, and Pakistan and other countries including Venezuela, Puerto Rico, the USA, and Trinidad and Tobago. Collar rot causes severe yield losses when undecomposed organic matter is left in the field. It can be a serious problem when the soil is having high moisture and temperature above 30 °C. Collar rot appears within a month of sowing under field conditions. The symptoms are rotting in the collar region and turn chlorotic when they die. Brown or white sclerotia are usually found in the collar region of the plant (Reddy et al. 2012). Collar rot disease can be reduced by removing the stubble of previous crop, selecting well drained fields and doing deep summer ploughing. Biocontrol agents are being explored for controlling this disease without much success.

5.2.3 Dry Root Rot

It is caused by *Macrophomina phaseolina* (Tassi) Goidanich and/or *Rhizoctonia bataticola* (Taub.) Butler. It is distributed in Sri Lanka, Nepal, Myanmar, India, Trinidad and Tobago, and Jamaica. This is a serious problem for short-duration pigeonpea sown in rainy season, particularly in the reproductive stage. Temperature above 30 °C and dry weather helps disease development. Dry root rot is found more on Vertisols than on Alfisols. Symptoms include sudden and premature dry up and rotten and shredded roots upon uprooting. Dark sclerotial bodies can be seen underneath the bark. Spindle-shaped lesions are seen on stems which coalesce and cause the entire plants to dry out (Reddy et al. 2012). Dry root rot disease can be reduced by removing the stubble of previous crop and planting on time. Biocontrol agents are being explored for controlling this disease.

5.3 *Phytophthora* Blight

The causal organism of *Phytophthora* blight is *Phytophthora drechsleri* Tucker f. sp. *cajani* in pigeonpea. *Phytophthora* blight is the third important disease of pigeonpea after wilt and sterility mosaic disease (Kannaiyan et al. 1984). It is distributed in India, Kenya, Dominican Republic, Puerto Rico, and Panama. The pathogen survives as oospores, chlamydospores, and dormant mycelia on soil and plant debris. It is predominant on Alfisols than Vertisols. Continuous drizzling, cloudy weather, and water-logged soils with temperature around 25 °C favor this disease infection and spread. Plants infected with *Phytophthora* blight show symptoms of brownish black and sunken lesions on stems and petioles and water-soaked lesions on leaves. Infected leaves lose turgidity and desiccate, while stems and branches break leaving the foliage above the lesion to dry up (Reddy et al. 2012). Low level of resistance in cultivated and wild germplasms is available against *Phytophthora* blight (Pande et al. 2011). Not many management options are available, for this disease.

5.4 Management of Soil-Borne Diseases of Chickpea and Pigeonpea

Management of soil-borne diseases are difficult, as not one control measure is completely effective. Traditionally, soil-borne pathogens of chickpea and pigeonpea were managed through synthetic chemicals which lead to the development of resistance to wide range of synthetic chemicals, environmental degradation, and contamination (On et al. 2015). Soil-borne pathogens were managed to some extent with a blend of benomyl 30% and thiram 30% at 1.5 g kg^{-1} seed (Haware et al. 1996). Advanced sowing date, solarization of soil, and use of disease-free seed are the cultural control measures usually used but with limited success. High levels of resistant cultivars against majority of soil-borne pathogens are also not available (Tarafdar et al. 2018). Hence, there is an urgent need for looking environmentally viable and human- and animal health-friendly approaches for managing soil-borne diseases. The use of microbial biocontrol products could be one of such alternative options for the management of these diseases (Jiménez-Fernández et al. 2015). Biocontrol of soil-borne diseases has been addressed using antagonistic bacteria and fungi such as *Bacillus* spp., *Pseudomonas* spp., *Pantoea* spp., and *Trichoderma* spp. These agents were reported effective not only to manage plant pathogens but also to help the plants to mobilize and acquire macro- and micronutrients (Postma et al. 2003; Perner et al. 2006; Maisuria et al. 2008; Kothasthane et al. 2017). Microbial biocontrol agents reported for soil-borne diseases of chickpea and pigeonpea are summarized in Table 5.1. However, this chapter is focused only on actinomycetes.

Table 5.1 Biocontrol agents against soil-borne pathogens of chickpea and pigeonpea

Crop	Disease	Causal organism	Biocontrol agents	References
(a) Biocontrol agents against soil-borne pathogens of chickpea				
Chickpea	*Fusarium* Wilt	*Fusarium solani* f. sp. *Pisi*	*Streptomyces* sp.	Mahboobeh et al. (2016)
		Fusarium oxysporum f. sp. *ciceri*	*Streptomyces* sp.	Amini et al. (2016)
			Streptomyces sp.	Gopalakrishnan et al. (2011)
			Streptomyces sp.	Anusha et al. (2018, submitted)
			Streptomyces sp.	Sreevidya and Gopalakrishnan (2013)
			Trichoderma viride, *Trichoderma harzianum*, *Trichoderma virens*, *Bacillus subtilis* *Aspergillus niger AN27*	Singh (2014)
			B. subtilis	Kumar (1999)
			Pseudomonas aeruginosa PNA 1	Anjaiah et al. (2003)
			Pseudomonas fluorescens	Vidhyasekaran and Muthamilan (1995), Saikia et al. (2009)
	Collar rot	*Sclerotium rolfsii*	*Streptomyces griseus*	Singh and Gaur (2016)
			Streptomyces sp.	Sreevidya and Gopalakrishnan (2013)
			T. viride, T. harzianum, *P. fluorescens*	Singh (2014)
	Dry root rot	*Rhizoctonia bataticola*	*Streptomyces* sp.	Anusha et al. (2018, submitted)
			T. harzianum, T. viride	Mishra et al. (2018)
		Macrophomina phaseolina	*T. viride* and *P. fluorescens*	Manjunatha et al. (2013)
	Wet root rot	*Rhizoctonia solani*	*T. harzianum* (PDBCTH 10) and *T. viride* (PDBCTV)	Prasad et al. (2002a)

(continued)

Table 5.1 (continued)

Crop	Disease	Causal organism	Biocontrol agents	References
(b) Biocontrol agents against soil-borne pathogens of pigeonpea				
Pigeonpea	*Fusarium* Wilt	*Fusarium udum*	*T. harzianum*	Prasad et al. (2002a, b)
			Alcaligenes xylosoxydans	Vaidya et al. (2003)
			T. harzianum, T. viride, P. fluorescens, B. subtilis	Goudar and Srikanth (2002)
			Pantoea dispersa	Maisuria et al. (2008)
			B. subtilis	Siddiqui and Mahmood (1995)
			P. fluorescens	Siddiqui et al. (1998)
			B. subtilis AF1	Manjula and Podile (2001)
			T. harzianum, T. hamatum, T. viride, T. koningii, B. subtilis	Mishra et al. (2018)
		Fusarium Oxysporum	*P. aeruginosa* PNA 1	Anjaiah et al. (2003)
	Phytophthora stem blight	*Phytophthora drechsleri* f. sp. *Cajani*	*T. harzianum, T. hamatum, Glomus mosseae*, *P. fluorescens*, *B. subtilis*	Mishra et al. (2018)

5.5 Actinomycetes and Their Role in Biocontrol and Plant Growth-Promoting Traits

Actinomycetes, a group of Gram-positive (Gram +ve) bacteria with a high G+C content, are found commonly in marine and fresh water, compost, and soil. They are known to decompose organic residues and produce secondary metabolites of commercial interest in agriculture and medical field. Actinomycetes are also reported to play a key role in the plant protection and plant growth promotion (PGP). The PGP actinomycetes directly influence crop growth by producing growth hormones (including auxin and gibberellins), fixing nitrogen in the roots of leguminous plants (through symbiotic nitrogen fixation), and solubilizing phosphorous, iron, zinc, and potassium, thereby increasing nutrient availability for the plants. They also promote crop growth indirectly by producing 1-aminocyclopropane-1-carboxylate (ACC) deaminase (a stress-relieving enzyme), antibiotics (such as pyocyanin, pyoluteorin, viscosinamide, 2,4-diacetylphloroglucinol, streptomycin, kanosamine, pyrrolnitrin, phenazine-1-carboxylic acid, and neomycin A), siderophores (for iron uptake and antagonistic traits against plant pathogens in the vicinity), hydrocyanic acid (HCN; inhibits electron transport system and disrupts energy supply to the plant pathogenic cells), hydrolytic enzymes (including chitinase, cellulase, β-1,3-glucanase, lipase and protease; lyse cell walls of plant pathogens), and inducing systemic resistance (by producing phenylalanine ammonia-lyase (PAL) and antioxidant enzymes such as catalase, peroxidase, lipoxygenase, polyphenol oxidase, superoxide dismutase, and ascorbate peroxidase) in plants (Gopalakrishnan et al. 2016).

5.6 Broad-Spectrum Actinomycetes Having Biocontrol and PGP Traits

Soil-borne pathogens such as *F. oxysporum*, *S. rolfsii*, and *R. bataticola* affect many agriculturally important crops including chickpea and pigeonpea that lead to significant yield losses. For instance, *S. rolfsii* and *R. bataticola* attack more than 100 and 500 crop species, respectively. It is very hard to breed variety with resistance to a wide range of plant pathogens; however, identifying a biocontrol agent with broad-spectrum of activities is relatively easy. Therefore, there is an urgent need to identify broad-spectrum biocontrol and PGP microorganisms for the control of multiple plant diseases in a single crop, and thereby the productivity (yield traits) can also be enhanced. This is very important as one microbial treatment solves more than one pathogen problem apart from promotion of plant growth. For instance, endophytic *Streptomyces* spp. were reported to colonize on the nodules of soybean with *Rhizobium* to increase nodulation, nitrogen fixation, and grain yield (Soe et al. 2010). Strains of *Streptomyces* spp. were demonstrated to provide broad-spectrum of antagonistic traits and protect mycorrhizal roots from mycorrhizal fungal competitors and parasites (Schrey et al. 2012). The usefulness of actinomycetes (such as *Streptomyces*) and their secondary metabolites for biocontrol of plant pathogens and PGP are widely reported in many crops (Jetiyanon and Kloepper 2002; Ryu et al. 2007; El-Tarabily 2008; Soe et al. 2010; Sadeghi et al. 2012; Alekhya and Gopalakrishnan 2016, 2017; Sathya et al. 2017; Vijayabharathi et al. 2018).

Actinomycetes are widely reported as inducers of host-plant resistance and plant immunization against many soil-borne plant pathogens including *Phytophthora*, *Fusarium*, *Rhizoctonia*, *Colletotrichum*, and *Pythium* (Raaijmakers et al. 2009). Endophytic actinomycetes such as *Streptomyces* were reported to manage diseases of potato scab and wheat under the field conditions (Liu et al. 1996; Coombs et al. 2004). Endophytic *Streptomyces* sp. EN 27 and *Micromonospora* sp. EN 43 were reported to induce resistance in *Arabidopsis thaliana* by upregulating genes involved in systemic acquired resistance (SAR; Conn et al. 2008). Studies on *Streptomyces* induced host-plant resistance was demonstrated on wide range of crops including vegetable crops such as potato (Arseneault et al. 2014) and *Arabidopsis* (Bernardo et al. 2013) and woody trees such as oak (Kurth et al. 2014) and *Eucalyptus* (Salla et al. 2016). Such actinomycetes are needed for soil-borne pathogens of grain legumes including chickpea and pigeonpea.

5.7 ICRISAT's Experience in Dealing with Broad-Spectrum Actinomycetes Having Biocontrol and PGP Traits

ICRISAT, Patancheru, Hyderabad, and Telangana, India, reported five strains of *Streptomyces* spp. (CAI-24, KAI-32, KAI-90, CAI-121, and CAI-127), isolated from compost of bitter guard, chrysanthemum, and garlic foliage and rice straw, having antagonistic potential against *Fusarium* wilt of chickpea under both glasshouse and field experiments (Gopalakrishnan et al. 2011). The details of the five strains including their NCBI accession numbers and sources of isolation were shown in Table 5.2.

The five FOC antagonistic *Streptomyces* spp. strains were also reported to produce HCN, siderophore, β-1,3-glucanase, lipase, indole acetic acid (IAA; except KAI-90), and chitinase (except CAI-121 and CAI-127), whereas two strains produced protease (CAI-24 and CAI-127) and cellulase (KAI-32 and KAI-90) (Gopalakrishnan et al. 2011, 2013). Three of the *Streptomyces* strains (CAI-24, CAI-127 and KAI-90) were also found to produce ACC deaminase (unpublished data). These enzymatic activities and secondary metabolites are well known for their role in biocontrol and have been demonstrated against many plant pathogens. Actinomycetes having these biocontrol and PGP traits can be used for managing soil-borne pathogens.

Two of the selected five *Streptomyces* spp. strains (KAI-32 and KAI-90) inhibited *Macrophomina phaseolina* (causes charcoal rot in sorghum), whereas three strains

Table 5.2 *Streptomyces* spp. strains used for the management of *Fusarium* wilt of chickpea

Strains	Scientific name	NCBI accession number	Source of isolation
CAI-24	*Streptomyces tsusimaensis*	JN400112	Bitter gourd foliage compost
CAI-121	*Streptomyces caviscabies*	JN400113	*Chrysanthemum* foliage compost
CAI-127	*Streptomyces setonii*	JN400114	Garlic foliage
KAI-32	*Streptomyces africanus*	JN400115	Rice-straw compost
KAI-90	*Streptomyces* sp.	JN400116	Rice-straw compost

(KAI-90, CAI-24, and KAI-32) inhibited *R. bataticola* (causes dry root rot in chickpea) in the dual culture assay (Gopalakrishnan et al. 2011). All five strains were also found to inhibit *Botrytis cinerea*, which causes *Botrytis* gray mold (BGM) disease in chickpea (unpublished data). Hence, it is concluded that the selected five FOC antagonistic strains displayed broad-spectrum biocontrol potential.

Under in vitro conditions, the selected five FOC antagonistic *Streptomyces* spp. strains were able to grow in temperatures between 20 and 40 °C, NaCl up to 6% and at pH values between 5 and 13. All were sensitive to captan, thiram, benlate, Radonil, and benomyl but highly tolerant to bavistin at field application levels (Gopalakrishnan et al. 2013). It is concluded that the selected five actinomycetes are capable of surviving in harsh environmental conditions and compatible with the fungicide bavistin and thus can be used in integrated pest and/or disease management (IPM/IDM) programs.

Under field conditions, on 2 consecutive years in chickpea, the selected five FOC antagonistic *Streptomyces* spp. strains significantly enhanced nodule number and weight (up to 70% and 82%, respectively), root weight (up to 7%), and shoot weight (up to 21%) over the control (uninoculated) plots (Table 5.3). At crop maturity, the five strains significantly enhanced stover and grain yields (up to 39% and 12%, respectively) over the control plots (Fig. 5.1). All other traits including pod number, pod weight, total dry matter, seed number, and seed weight were also found to enhance over the uninoculated control. The detailed results and discussion of this experiment can be seen in Gopalakrishnan et al. (2015). Similar results were obtained in pigeonpea under field conditions. In pigeonpea, the traits including nodule weight, root weight, shoot weight, stover yield, and grain yield were found significantly enhanced over the uninoculated control (Table 5.3; Fig. 5.1; Unpublished data). Soe et al. (2010) reported similar kind of results in soybean where endophytic *Streptomyces* spp. were shown to colonize on the nodules of soybean and have beneficial association with *Rhizobium* and increased nodules, nitrogen fixation, and grain yield.

5.8 Conclusion

Among the important diseases of chickpea and pigeonpea, soil-borne diseases including *Fusarium* wilt, collar rot, dry root rot, and *Phytophthora* blight are important and cause severe damages to the crop. Management of such soil-borne diseases are extremely difficult, as no one control measure is completely effective. Biocontrol of soil-borne plant pathogenic fungi using actinobacteria such as *Streptomyces* spp. was reported effective not only to manage soil-borne pathogens but

Table 5.3 Evaluation of the five *Streptomyces* spp. strains for their nodulation and shoot and root weights of chickpea and pigeonpea, at 30 days after sowing

Strains	Chickpea				Pigeonpea			
	Nodule number (plant^{-1})	Nodule weight (mg plant^{-1})	Root weight (g plant^{-1})	Shoot weight (g plant^{-1})	Nodule number (plant^{-1})	Nodule weight (mg plant^{-1})	Root weight (g plant^{-1})	Shoot weight (g plant^{-1})
CAI-24	13	58	1.75	1.60	6	133	2.00	2.03
CAI-121	25	53	1.76	1.90	5	200	1.90	2.03
CAI-127	17	24	1.46	1.43	5	167	2.23	2.38
KAI-32	17	48	1.84	1.74	5	167	2.20	2.11
KAI-90	31	75	1.96	1.51	5	133	2.24	2.33
Control	12	29	1.71	1.35	5	130	1.84	2.02
Mean	21	46	1.75	1.58	5	155	2.07	2.15
SE±	1.5***	4.4***	0.08***	0.070**	0.3**	14.0*	0.058**	0.061**
LSD (5%)	4.8	14.0	0.25	0.222	0.8	43.0	0.184	0.191
CV%	14	16	8	8	10	15	5	5

* statistically significant at 0.05, ** statistically significant at 0.01, *** statistically significant at 0.001

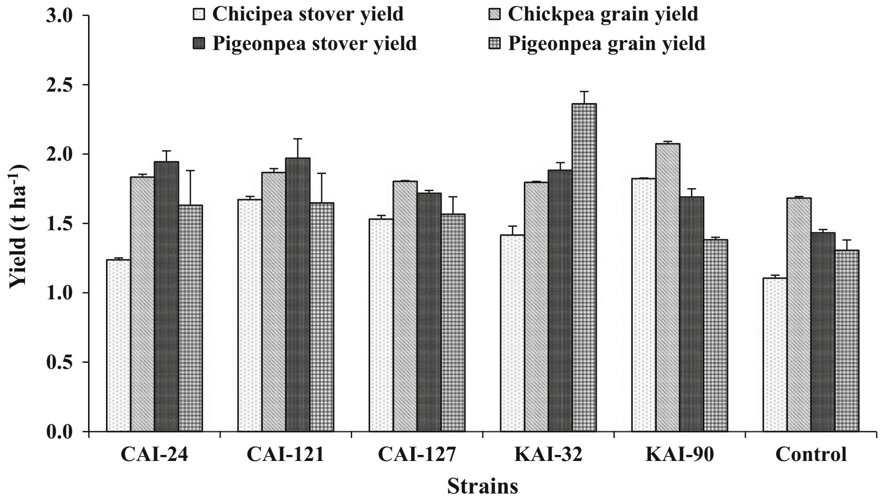

Fig. 5.1 Influence of the five *Streptomyces* spp. strains on stover and grain yields (t ha^{-1}) of chickpea and pigeonpea under field conditions

also promote crop growth and yield. ICRISAT reported five strains of *Streptomyces* spp. (CAI-24, KAI-32, KAI-90, CAI-121, and CAI-127), not only having antagonistic potential against *Fusarium* wilt of chickpea under both greenhouse and field experiments but also having PGP potentials on chickpea and pigeonpea. Such novel bacteria with broad-spectrum PGP and biocontrol traits needs to be exploited for sustainable agriculture.

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