J. Indian bot. Soc. (2024) Vol. 104 (1): 1-12
https://doi: 10.61289/jibs2024.01.10.1195

e-ISSN:2455-7218, ISSN:0019 - 4468
www.indianbotsoc.org

REVIEW ARTICLE

Phytochemistry, Pharmacological, Soil Amelioration, PGPR Attributes, Traditional, Modern and Future Prospects of *Sesbania sesban* (L) Merr.

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Abstract

The destruction of soil soundness and the expansion of soil pollution are serious problems for both the environment and living organisms. For a long time, chemical fertilizers have been used in enormous quantities to increase crop yields and enhance crop productivity. This causes soil health to crumble. The current approaches to maintain and ameliorate soil health via Plant Growth Promoting Rhizobacteria (PGPR) seems a possible alternate to chemical fertilizers. The application of PGPR is exponentially to rise in sustainable farming on account of its coherent and eco-friendly disposition. It is applied as alternative emanation to decline the utilization of fungicides, chemical fertilizers and pesticides. Bio-fertilizers accelerate the entire growth and yield of vegetation in an ecofriendly manner. Rhizobia play considerable task in nitrogen fixation, augmentation and over all development of plants and crops. This review summarise information about *Sesbania sesban* a leguminous plant and their place in agriculture, augmentation of crop production, alternative of chemical fertilizers; soil reclamation, reduce pollutants, phytochemicals and medicinal properties. It has great restorative significance in agriculture. Whole plant is rich in phytochemical constituents such as anti-fungal, anti-diabetic, anti-fertility, anti-oxidant, anti-bacterial activities and inflammatory disorders, polyherbal formulations and phytoremediation and soil conditioning.

Keywords: *Sesbania sesban*, nitrogen fixation, green manure, chemical fertilizers, eco-restoration

Introduction

Sesbania sesban (L) Merr. belong to the family Fabaceae under angiosperms. This family with around 730 genera, 19,400 species and occupy 2nd position from economic and agriculture point of view. Legumes play beneficial role in the N_2 cycle and nitrogen fixation (Mabberley 1997, Wojciechowski 2004). *S. sesban* have great economical values such as soil improvement, bio-fertilizer, growth enhancer, yield improvement of subsequent crops and pharmacological activities. Leguminous plants grown in barren loam are routinely used for soil conditioning in degraded sites in semiarid and arid regions (Rehman and Nautiyal 2002). *Sesbania* has around 60 species, that are found in torrid and subtorrid regions of the world, most of the species is annual herbs, shrubs and some little tree (Bala *et al*. 2002, Goswami *et al*. 2016), usually known as "Egyptian sesban" "Jayanti" (Gomase *et al*. 2012). Due to its rapid growth, this plant produces about ten thousand trees per hectare of biomass. This plant is having capacity to settle 500 - 600 Kg Nitrogen/ha/year and recommended to replenish soil fertility through elevated agroforestry practices all over the world (Degefu *et al*. 2011). Nitrogen present in land and water approximately 6400 kilogram of every hectare (Mahamat *et al*. 2021). The plant part like leaves, root, seeds, pods and whole plant is highly useable in medicine, green manure, and fodder. This plant used in nitrogen fixation, soil reclamation and to increase toleration to heavy metals (Ali *et al*. 2021). At present, biofertilizers are an alternative source to chemical fertilizers for overcoming this global problem. Substance incorporating living microorganisms that occupy the rhizosphere of the plant root to maturate plant growth and development through providing the nutrients. The market of biofertilizers

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How to cite this article: Kumar P, Vashistha H, and Kumar S. (2024). Phytochemistry, Pharmacological, Soil Amelioration, PGPR Attributes, Traditional, Modern and Future Prospects of *Sesbania sesban* (L) Merr. J. Indian bot. Soc., 104 (1): 1-12. Doi: 10.61289/jibs2024.01.10.1195

Source of support: UCOST, Dehradun and NMPB, Ministry of Ayush, Govt. of India, New Delhi.

Conflict of interest: None.

Received: 04/05/2023 **Accepted:** 10/07/2023 **Published online**: 10/01/2024

was 2$ billion in 2019 and it increase ~3.8$ billion till 2025 (Raiz *et al.* 2021). *Sesbania* spp. became a good source of bio-fertilizer and alternate of chemical fertilizer. Rhizobia in maize, rice and wheat crops provide high fertile soil and increase N content as reported by several workers (Kalidurai and Kannaiyan, 1991; Murugaragavan *et al*. 2020, Raiz *et al*. 2021).

Botanical Description

S. sesban plant 1 – 8 meter long, narrow crowned shrub or short-lived tree, roots long go deep into the soil, stem is single or multiple (Nigussie and Alemayehu, 2013). Leaves are peripinnate, compound, and 12-18 cm in length, 6-27 pairs of leaf let, stipules minute or absent. Flowers are alternative, inflorescence is raceme, no of flowers 2-20, and flower is yellow coloured having purple or brown streaks on the corolla, petals long clawed. Pod of this plant green in young stages but at maturation converted into yellowish brown. Length of pod is 10-20cm, cylindrical, rarely oblong (Figure 1). In a single pod 35-40 seeds are formed (Gomase *et al.* 2012). Taxonomic enumeration, vernacular name and synonymous is given in Table 1.

Biophysical Limitations

S. sesban grow well in saline soil, acidulous soil, alkaline soil (pH<10) and also swallow seasonal and permanent waterlogged soil. It is an aboriginal to semi-arid to the sub-humid area, monsoonal with an annual rainfall of about 500-2000 mm. This plant tolerates temperature between 10^0C – 45^0C. It grows in diversity of soils such as loose sand to heavy clay (Orwa *et al.* 2009, Usman *et al*. 2013).

Phytochemical Constituents

S. sesban rich in phytochemicals which perform a key part in various diseases management like inflammation, diabetes, bacterial and fungal infection etc. A large number of phytochemicals such as alkaloids, amino acids, carbohydrates, glycosides, vitamins, proteins, phenolic compounds, pyruvic acid, saponins, steroids, flavonoids, fatty acids, oxalo-acetic and tannins, were reported from *S. sesban* by various researchers (Mani *et al.* 2011, Goswami *et al*. 2016, Akram *et al.* 2021). Leaves and pods of *S. sesban* have kaempferol trisaccharide, chikusetsusaponin IV, cholesterol, beta-sitosterol and campesterol (Dande *et al*. 2010, Rageeb *et al.* 2013). Cyaniding and delphinidin were reported from flower, oleanolic acid, stigmastane 5.24 (28) -diene-3β-O-β-D-galactopyranoside and galactomannan has been reported from seeds (Gomase *et al*. 2012). Root extract of *S. sesban* contains Oleanolic acid 3-β-D-glucuronide (Goswami *et al*. 2016). Pharmacological activities of different plant parts are given in Figure 2. Many phytochemicals from *S. sesban* are used for disease management, anti-microbial and pharmacological activities.

Table 1: (A) Taxonomic enumeration (B) vernacular names and (C) synonyms

Taxonomic Enumeration (A)		*Vernacular Names (B)*		*Synonyms of S. sesban (C)*
Kingdom	Plantae	English	Common sesban, Egyptian rattle pod, sesbania	*Aeschynomene sesban* L.
Division	Angiosperms			*Emerus sesban* (L.) Kuntze
Class	Magnoliopsida	Hindi	Janti, Jait, Rawasan	*Coronilla sesban* (L.) Moench
				Sesbania confaloniana (Chiov.)
Order	Fabales	Bengali	Jainti, Jyanti	*Merus sesban* (L.) Hornem
Family	Fabaceae			*Sesbania pubescens* sensu auct.
Subfamily	Papilionoideae	Sanskrit	Jayanti, Jayantika	*Sesbania aegyptica* Poir.
Tribe	Robinieae			
Genus	*Sesbania*	Arabic	Sesban	*Sesbania tchadica* (A.) Chev.
Species	*sesban* (L.) Merr.			

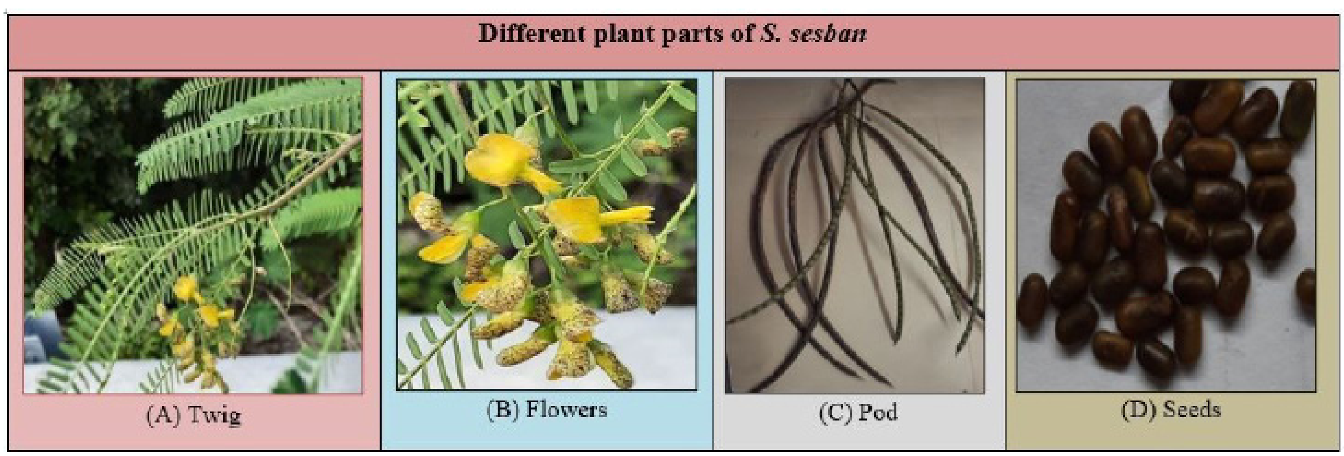
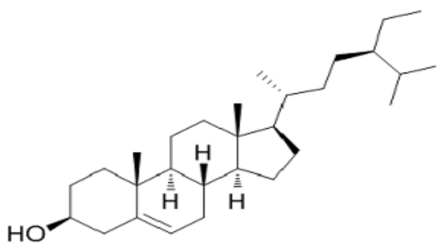
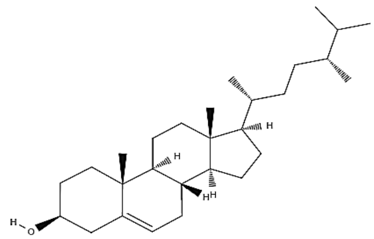


Figure 1: Different plant parts of *S. sesban* (A) Twig (B) Flowers (C) Pod (D) Seeds

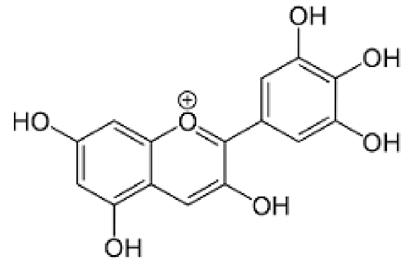
Table 2: Chemical structure of phytochemicals reported from *S. sesban* (https://chemdrawdirect.perkinelmer.cloud/js/sample/index.html).



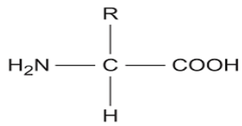
Beta-cholesterol



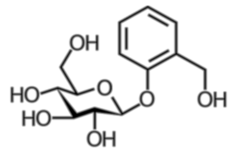
Campesterol



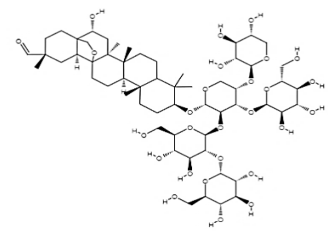
Delphinidin



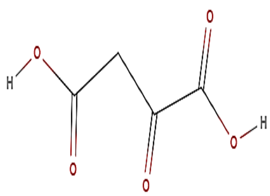
Amino acid



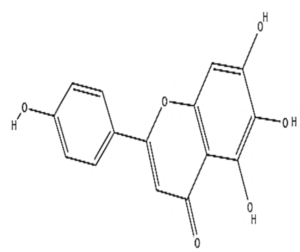
Glycoside



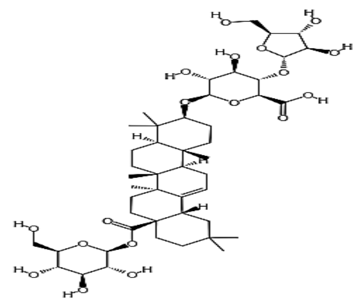
Saponin



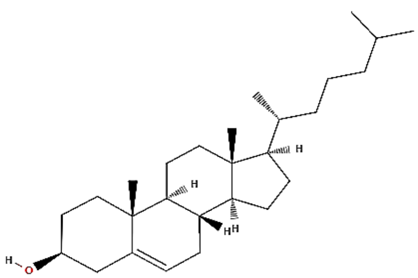
Oxalo-acetic acid



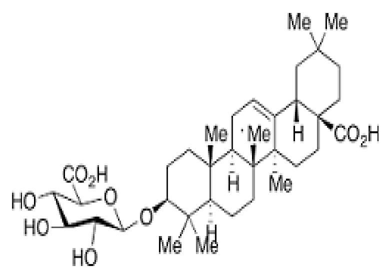
Flavonoid



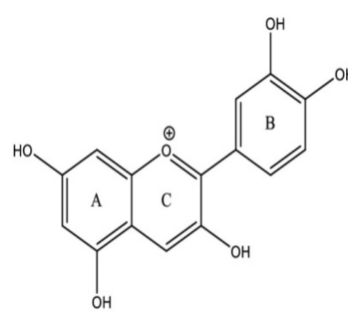
Chikusetsusaponin IV



Cholesterol



Oleanolic acid 3-β-D-glucuronide



Cyaniding

Pharmacological activities

Anti-microbial Activities

Methanolic extract of *S. sesban* flowers exhibited antibacterial activity in case of *Staphylococcus aureus* and *S. saprophyticus* (Gram positive bacteria) (Kathiresh *et al.* 2012). Similarly, methanolic extraction of leaves (n-hexane, carbon tetrachloride and chloroform) showed anti-bacterial activities against gram positive (*B. cereus* and *Sarcina lutea*) and Gram negative bacteria (*E. coli*) (Hossain *et al.* 2007, Maregesi *et al.* 2008). Methanolic extract of this plant hamper the maturation of *Erwina amylovora* and *E. coli* (Mythili and Ravindhran 2012). MeOH extract of root also shows antibacterial activity against *B. cereus* (Maregesi *et al.* 2008). Roots, leaves and bark extract in methanolic and dichloromethane shows antibacterial activity against *S. aureus* and *B. subtilis*, n-Hexane extract of twig of *S. sesban* perform antibacterial activity against *B. cereus* and *K.*

Table 3: Shows anti-bacterial and anti-fungal activity of different plant parts of *S. sesban*

Activities	*Plant part*	*Solvent*	*Effect on Bacteria/Fungi*	*Reference*
Antibacterial activities	Flower	Methanolic	Gram-positive (*staphylococcus aureus* and *S. saprophyticus*)	Kathiresh *et al*. 2012.
	Leaves	Methanolic	Gram-positive (*Bacillus cereus* and *Sarcina lutea*) Gram-negative (*E. coli*)	Hossain *et al*. 2007.
		Ethanolic	*E. coli, P. aeruginosa* and *klebsiella pneumoniae*	Nirosha *et al*. 2019.
			Gram-positive (*Streptococcus, Enterococcus faecales* and *S. aures*) *Gram-negative* (*E. coli, Salmonella typhi, Proteus vulgaris, Pseudomonas aeruginosa* and *K. pneumonia*)	Al-Dawah *et al*. 2014.
	Stem	Methanolic	*Erwinia amylovora* and *E. coli*	Mythili and Ravindhran, 2012.
	Leaves	n-Hexane	Bacillus cereus	Maregesi *et al*. 2008.
	Twig	n-Hexane	*Bacillus cereus* and *K. pneumoniae*	Maregesi *et al*. 2008.
	Root	MeOH	*B. cereus*	Maregesi *et al*. 2008.
	Root, leaves and bark	Methanolic and dichloromethane	*S. aureus* and *B. subtilis*	Maingi and Bill, 2018
Anti-fungal activity	Stem	Methanolic	*Curvularia lunata*, *Fusarium oxysporum*, *Aspergillus fumigates* and *Verticillium glaucum*	Mythili and Ravindhran, 2012.
	Leaves	Methanolic	*A. niger*	Hossain *et al*. 2007.
	Leaves	n-Hexane	*Candida albicans*	Maregesi *et al*. 2008.
	Twig	n-Hexane	*Candida albicans*	Maregesi *et al*. 2008.
	Root, leaves and bark	Methanolic and dichloromethane	*A. niger*	Maingi and Bill, 2018

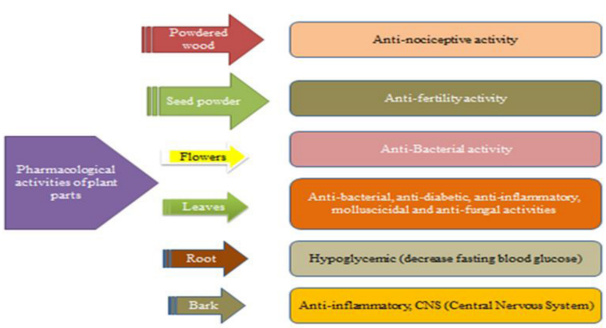


Figure 2: Pharmacological activities were shown as per plant parts.

pneumonia (Maingi and Bill 2018). Ethanolic leaves extract showed anti-bacterial activity against *E. coli*, *P. aeruginosa*, and *K. pneumoniae* (Nirosha *et al*. 2019). Ethanolic extract of leaves of *S. sesban* shows antimicrobial activity against Gram-positive (*Streptococcus, Enterococcus faecales* and *S. aures*) and Gram-negative (*E. coli, S. typhi, Proteus vulgarish, P. aeruginosa* and *K. pneumonia*) (Al-Dawah *et al*. 2014).

Anti-fungal and anti-bacterial *Activities*

S. sesban stem extract showed both anti-bacterial and anti-fungal activities. Methanolic extract of stem tested against 5 fungal species, out of these two *Curvularia lunata* and *Fusarium oxysporum* fungi have been completely hindered. However *Aspergillus fumigates*, *Verticillium glaucum,* and *C. lunata* harshness inhibited at 500µg/ml, by methanolic stem extract of *S. sesban* (Mythili and Ravindhran 2012). On the otherhand, methanolic extract (n-hexane, carbon tetrachloride, chloroform and kanamycin) of leaves of *S. sesban* inhibit the germination of *A. niger* (Hossain *et al*. 2007). n-Hexane extract of twig and leaves shows zone of inhibition versus *C. albicans* (Maregesi *et al*. 2008). Root, leaves and bark of methanolic and dichloromethane having antifungal activity in case of *A. niger* (Maingi and Bill, 2018) (Antibacterial and antifungal activities given in Table 3).

Anti- nociceptive Activities

Nociceptive activity is body reaction to potentially toxic impulses, such as injurious chemicals like (formalin and capsaiun), mechanically injured and upstream temperature (cold and heat) through the nervous system (Qadir *et al*. 2020). Wood of *S. sesban* has anti-nociceptive reaction. The Hot plate test and acetic acid induced writhing test (all extracts showed crucial hampered of writhing reaction induced with acetic acid in comparison to control) confirms that the extract have anti-nociceptive response. Petroleum ether, chloroform and ethyl acetate extract (50 and 100 mg/kg) of powdered wood of *S. sesban* revealed potent anti-nociceptive activity in both test, and prostaglandins and bradykinins are used in nociception (Nirmal *et al*. 2012, Akram *et al*. 2021).

Anti-fertility Activities

The roots extract of *S. sesban* showed presence of glucuronide 3 β-D. and oleanolic acid, it having spermicidal characteristics (Das *et al*. 2011). Minimum concentration of oleanolic acid 3-β-D-glucuronide (OAG) caused confinement of sperm in less than 20 seconds. Afterward resurrection test of motility also observed and find out no chance of rebirth (Singh 1990, Das *et al*. 2011, Akram *et al*. 2021). Seed powder (250 mg/kg and 400 mg/kg dosage are effective) of this plant altering the uterine structure and inhibit the ovarian function hence curb fertility, flowers and leaves also have antifertility activities in mice and albino rats (Singh, 1990).

Anti - inflammatory Activities

Rheumatoid arthritis is a pristine and onward soreness in joints. Novel silk fibroin *in situ* hydrogel was prepared using leaves and flowers extract of this plant, used for the cure of rheumatoid arthritis. It showed high anti-inflammatory activities (Pham *et al*. 2022). Similarly, methanolic leaves extracts of *S. sesban* contained saponin showed anti-inflammatory activities (Dande *et al*. 2010, Tatiya *et al*. 2013). Leaf extract of petroleum ether w/w (2.4%), chloroform (3.2%) and methanol (3.5%) applied in paw edema of rat. Methanolic extract showed impressive lowering in paw edema in comparison to control solvent. Whereas, extract of petroleum ether and chloroform appeared comparatively minor reduction in paw edema in Wistar albino rats for the anti-inflammatory test. Crude saponin leaf extract of *S. sesban* with the help of carrageenan induced rat paw edema. Crude saponin treated with the solution having 1% w/w and 2% w/w, with respect to Diclofenac sodium gel of 1% w/w treated as standard. Saponin extract showed anti-inflammatory activities, while bark extract of *S. sesban* in carrageenan induced inflammation model, among the tested extracts, petroleum ether showed superior anti-inflammatory activities also communicated by several researchers (Dande *et al*. 2010; Fitriansyah *et al*. 2017). Similarly, root and stem extract of ethyl acetate, aqueous and n-butanol reported as most remarkable results whereas, extract of total alkaloids and chloroform having average anti-inflammatory activities (Singh *et al*. 2017).

Anti-diabetic Activities

Aqueous leaves extract of *S. sesban* used to decrease the blood sugar level and lipid profile in STZ - induced diabetic rats, but there was no consequence on normal rats. Aqueous extract of this plant promote serum insulin levels, reduces in triglycerides, LDL, VLDL and total cholesterol was reported and increased in HDL cholesterol (Pandhare *et al*. 2011). Petroleum ether root extract of *S. sesban* tested on diabetic mice, it showed anti-hyperglycemic activities when applied on streptozotocin (STZ) induced diabetic mice (Aggarwal and Gupta 2012).

Anti-oxidant Activity

Anti-oxidants are micronutrients that neutralize free radicles and their action. Anti-oxidant activity is shown by *S. sesban* flowers petals extract in acidified methanol along with anthocyanins. Petals of this plant have anthocyanins important component having free radicle aliment dependant activity for hydroxyl radicle, anion, superoxide and 2, 2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) (Kathiresh *et al*. 2012). *In vitro*, ethanolic extract of leaves of *S. sesban* shows antioxidant activities against free radicle nitric oxide (NO), also strongly exhibit free radicle DPPH, ascorbic acid used as control (Mani *et al*. 2011).

Central Nervous System (CNS) Activities

CNS disorders may disturb brain or spinal cord function which develop psychiatric and neurological disorders. CNS provocative is medicines that enhance physical and mental processes. Bark and root of *S. sesban* used in infirmity nervous disorder and also used as CNS stimulants. Aqueous extract of bark and root of *S. sesban* tested on albino mice that show strong stimulant activities (Naik *et al*. 2011).

Genetic Diversity of S. sesban

Genetic diversity is essential for the survival and well-being of species, ecosystems stability, adaptation to changing environment, conservation of endangered species and ecological services. It plays a crucial role in adaptation, resilience, and the maintenance of healthy, functioning ecosystems. Efforts to conserve and protect genetic diversity are essential for the long-term sustainability of our planet. *S. sesban* is a diploid 2n=2x=12 plant species, and having basic chromosome number X=6. Fluorescence *in situ* hybridization (FISH) was used to physically localise rRNA genes and to examine spacer length variants of 45S rRNA (SLVS) genes in some *Sesbania* species (Kumar *et al*. 2014). Understanding the germplasm, cytological analysis, protein analysis, DNA extraction, random amplified polymorphic DNA (RAPD-DNA) and inter-simple sequence repeats DNA (ISSR-DNA) of *S. sesban* (Soliman *et al*. 2019). Germplasm preserved in the gene bank helps for the long-term preservation and upgrades of the species, as well as for promoting the widespread use of promising genotypes to increase livestock's help for sustainable development via greater yields of improved crops. The International Livestock Research Institute (ILRI) forage gene bank, *S. sesban* collection was used to produce an extensive amount of genotyping data by applying the DArTSeq platform. Diversity analysis by using subsets of beneficial markers indicates the availability of high genetic variability in the collection, with little or no confirmation of genetic shift apropos to the geographical origin of the germplasm. The informative markers may be utilized in gap analysis to receive specialist variation from geographic areas which cannot be well characterize in the collection, as well as in

Table 4: Different species of *Sesbania* harboured by specific rhizobia species

Bacteria associated with various species of *Sesbania*		
Sesbania Spp.	Isolated bacterial Spp.	References
S. sesban	*Allorhizobium, Mesorhizobium, Rhizobium,* and *Sinorhizobim*	Bala *et al*. 2002; Jobby *et al*. 2019.
S. cannabina	*Agrobacterium, Ensifer, Rhizobium,* and *Sinorhizobium*	Ten *et al*. 2001; Cumming *et al*. 2009; Boivin *et al*. 1997; Delajuidie, 1998.
S. bispinosa	*Burkholderia, Escherichia coli, Pseudomonas fluorescens* and *Rhizobium*	Rana and Krishna, 1995.
S. rostrata	*Azorhizobium* and *Sinorhizobium*	Dreyfus *et al*. 1988; Delajuidie, 1998.
S. virgate	*Azorhizobium*	Moreira *et al*. 2005.
S. punicea	*Mesorhizobium*	Vinuesa *et al*. 2005.

future efforts to identify stress-tolerant a genotypes for various agro-ecologies as well as soil features (Negawo *et al*. 2022).

Diversification of Rhizobia with S. sesban

Diverse association of rhizobia have been reported with various species of *Sesbania*, like *S. sesban* harbour *Mesorhizobium, Rhizobium, Sinorhizobium*, and *Allorhozibum* (Bala *et al*. 2002, Jobby *et al*. 2019*),* Similerly *S. cannabina* cherished *Ensifer, Rhizobium, Agrobacterium,* and *Sinorhizobium* (Delajuidie 1998, Boivin *et al*. 1997, Ten *et al*. 2001, Cumming *et al*. 2009), *S. bisponsa Rhizobium, Escherichia coli, Pseudomonas fluorescens, Burkholderia sp*. (Rana and Krishna 1995), *S. rostrata* nestle with *Azorhizobium, Sinorhizobium* (Dreyfus *et al*. 1988, Delajuidie 1998), *S. virgata* panoply *Azorhizobium* (Moreira *et al*. 2005) and *S. punicea* supported *Mesorhizobium* (Vinuesa *et al*. 2005) (Table 4).

Soil Reclamation and PGPR Activity

Habitat of Bacteria – Rhizosphere

The word rhizosphere was first introduced by Lorentz Hiltner in 1904. Hiltner explain rhizosphere as parochial zone of soil surrounds plant's root. In rhizosphere large numbers of microorganisms are found like bacteria, fungi, algae and protozoa. Rhizosphere is suitable area for interaction of plant and microbes. Rhizosphere is the region of soil having high resourceful and active area that contains all required nutrients for healthy plant and its growth and development. Soil is living dynamic system which has essential components for growth and productivity. Rhizosphere is the 1 mm area which surrounds the plant root, and secrete root exuded which influenced biology and chemistry of the rhizosphere various low and high molecular with phytochemicals have been secreted from plants in the form of root exudates (Badari and Vivanco 2009). Root exudates are key signals in rhizosphere secreted by plant roots in surrounding for the beneficial interactions with microbial community. These root exudates help for the interactions (Physical, chemical or biological) into plant roots and surrounding microorganisms. Chemical composition of root exudates based upon plant spp., developmental phase, cultivars and environmental factors like temperature, pH, soil types and microbial association (Table 5). Upper layer of soil has about cells 10^9 per gram bacteria in soil (Torsvik and Ovreas 2002). Hardly 2 - 5% of rhizospheric bacteria enhance plant growth (Antoum and Kloepper, 2001). Rhizospheric bacteria and plant roots perform crucial task in soil amelioration by bio-assisted phytoremediation (Shameer and Prasad 2018). Rhizosphere has three zones (i) the endorhizosphere (ii) the rhizoplane (iii) the ectorhizosphere (Huang *et al*. 2014). *Sesbania* species is well known for nutrient enrichment, and cycling, productivity enhancement in low fertile soil. Root nodulating bacteria (Rhizobia) not only have synergist association with legumes but also exert positive effect in non-legumes to improve the plant growth and crop productivity (Poole *et al*. 2016). Some species of soil bacteria prosper rhizosphere of plant which grows with in or out around the plant tissues, they support in plant growth promoting activities (Vessey 2003). When rhizosphere of *S. sesban* inoculated with *Azotobacter* spp. (*A. chroococcum* and *A. vinelandii*) and *Rhizobium sesbani* with/without urea, they enhance plant growth, chlorophyll content, nitrogen

Table 5: Phytochemicals reported as root exudates

S.N.	*Root exudates*	*S.N.*	*Root exudates*
1	Sugar	8	Aurones
2	Amino acids and amide	9	Glucosinolates
3	Organic acids	10	Anthocyanins
4	Enzymes	11	Indole compounds
5	Flavonols	12	Fatty acids
6	Growth Factors	13	Sterols
7	Lignins	14	Allomones
High Molecular Weight		Low Molecular Weight	
• Polysaccharides • Proteins		• Amino acids • Carbohydrates • Organic acids • Phenolic Compounds • Secondary Metabolites	

Root Exudates (Koo, BJ. 2005; Badri and Vivanco, 2009) fixation and nodule formation (El-Gamal 1992). *Sesbania* spp. accumulates nitrogen rich biomass, which served as biofertilizer and aid in soil exaltation. Bacteria live in synergistic compatibility with plant roots and boost plant growth and development, known as PGPR.

Role of PGPR

The term PGPR was proposed by Kloeper and Schroth (1978). PGPR strain like *Rhizobium, Azorhizobium, Bradyrhizobium Mesorhizobium* and *Pseudomonas* etc. have potence to function like biofertilizers. The colonization of PGPR in the rhizosphere is mainly influenced by pH, soil condition and exudates. They form two types relationship with host plant, (i) endophytic (ii) rhizospheric. PGPR promote soil fertility by different ways, including increase symbiotic association, ampliative to root surface, increase nutrients in vicinage of root and biological nitrogen fixation (BNF) (Raiz *et al*. 2021). In 1998 Professor Bashan introduced two new terms related to favourable bacteria (i) plant growth-promoting bacteria (PGPB) and (ii) biocontrol plant growth-promoting bacteria (Biocontrol-PGPB), PGPB is analogous of PGPR (De-Bashan *et al*. 2020). PGPB are those bacteria that improve plant health and guard from infection, abiotic and biotic stresses through different mechanisms. PGPB and other symbiotic bacteria play key role in sustainable agriculture, and saline soil for salt tolerant (Souza *et al*. 2015). The market of chemical fertilizers is rise day by day across the world. The excess amount of chemical fertilizers is deteriorating soil structure, soil micro-flora and fauna. These chemical fertilizers are harmful for environment, human health, and cost effective. It is mandatory to find out an alternative of these harmful chemicals. PGPR are the group of microbes (heterogeneous) that hurriedly colonize the rhizosphere and procure direct and indirect protection to growing seeds and plants. Plant and soil microbes interaction are attractive all over the world. Bacteria rehouse with plant roots and in the rhizosphere of related crops, enhance plant growth directly by nutrient stabilization and act as defence regulator. PGPR is well documented for improving crop productivity, quality of soil, plant salubrity (Kumari *et al*. 2019). PGPR are the important group of profitable, root nodulating bacteria present in soil abundantly. PGPR extensively used for several biotechnological aspects in agricultural services, such as preparation of biofertilizers, biopesticides, phytostimulants etc. (Swamy *et al*. 2016). Green manure species like *Tephrosia, Vigna, Sesbania* and other leguminous crops which can secure atmospheric nitrogen and able to deposit 75-220 Kg/ha and having 2-3.5% nitrogen in plant body (TNAU Agritech Portal, 2018; Karmegam *et al*. 2021). Biofertilizers are described as "products containing living and dormant microbes". They facilitate the overall growth of plant and enhance

productivity. Each plant of *S. sesban* can fix 0.05 - 0.06g N_2 in waterlogged and 0.12 - 0.13g N_2 in arid soils. Estimation of N_2 fixation by a field of this plant 140,000 plants ha^{-1} reported only 7-8 Kg N_2 or 17-18 Kg N_2 depend on water condition of the field. It can fix 12 tons of biomass (fresh weight) h^{-1} in period of 45 days (Ndoye and Dreyfus, 1988), full plant body and roots are applied as green manure, which enhance the amount of nitrogen in soil (Patra *et al*. 2020). *S. sesban* have capability to remove metals from soil, enhance uptake nitrogen and phosphorous, from wastewater, helping in improving wetland system productivity (Bunma and Balslev, 2019). PGPR have direct and indirect modes of action (Figure 3), Direct mode help in uptakes of phytonutrients, mineral solubilisation, production of phytohormones (IAA, GA, CK), and nitrogen fixation, indirect including phytopathogens, induced systemic resistance (ISR), producing HCN antagonistic substance, and lytic enzymes (Jha *et al*. 2015, Basu *et al*. 2021). Sridevi and Mallaiah (2007) isolate 26 Indole Acetic Acid (IAA) producing bacteria from the root nodules of *S. sesban* at different sites and observed these all were *Rhizobium*. Out of these, only five isolates produce maximum IAA production. Indigenous microbes have capacity of degrading toxic pesticides with the help of their metabolic activities; these types of degradation were eco-friendly and can be reused in the contaminated field (Bhatt *et al*. 2020).

Role in Phytoremediation

In present time bioaugmentation of microorganisms came out as another strategy for bioremediation. *Bacillus xiamenensis* PM14 isolated from sugarcane inoculated with *S. sesban* used for Cr remediation (Zainab *et al*. 2021). In a pot trial *Sesbania* spp. (*S. cannabina, S. grandiflora, S. rostrata* and *S. sesban)* were grown with or without rhizobia inoculation in mine tailing for remediation. *S. sesban* and *S. rostrata* performed better growth than *S. grandiflora* and *S. cannabina*. Both spp. *Sesbania* (*S. sesban* and *S. rostrata)* served as pioneer spp. to change barren environment to fertile land, these pioneer spp. improve soil characteristics with increase organic content and decrease soil toxicity, to form healthy ecosystem (Chan *et al*. 2003). The association of *B. xiamenensis* with *S. sesban* increased metal tolerance capacity. It shows positive effect on inoculated plant such as enhancement in growth attributes and physiological parameters (Din *et al*. 2020). Whenever, *S. sesban* grow in industrial contaminated soil, having heavy metals (Cr and Cd), reduce the growth, biomass, antioxidant activity and photosynthetic pigments. To overcome the problem of

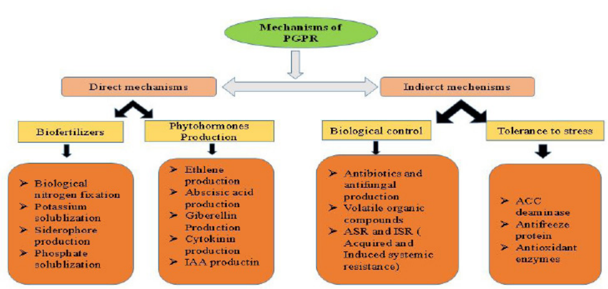


Figure 3: Mechanisms of PGPR

industrial contaminated soil, when *S. sesban* inoculate with PGPR inoculum of ACC, IAA and EPS producing bacterial strains (*B. xiamenensis*, *B. gibsonii* and *B. anthracis*) applied. They reduced the effect of heavy metals and promote plant growth, biomass and photosynthetic pigments in industrial contaminated soil (Zainab *et al.* 2021, Ali *et al.* 2021).

The existence of herbicides residues in *S. sesban*'s soil is likely to have negative repercussions on the plant and microbes' life, and it could potentially lead to soil pollution. Thus, this research demonstrates that *S. sesban* was effective in reducing herbicide residues and enhancing soil fertility (Mahakavi and Baskaran 2016). To overcome on the hazardous coir industrial waste *S. sesban* and cow dung, precomposed to 28 days with *Pleurotus sajor-caju* and accompanying *Eisenia fetida* and also with *Eudrilus eugeniae* for 50 days. Amendment of this combination promotes fertilizing index and nutrient recovery. *Sesbania* (20%) and cow dung (20-30%) is recommended for enriched vermicompost production (Karmegam *et al*. 2021). *S. sesban* does not neatly fit into a sole category as either a phytoextractor or a phytostabilizer for cadmium (Cd) remediation. Nevertheless, in accordance with the USEPA's 2000 guidelines, an ideal plant for phytoremediation should either be a low biomass plant with exceptional metal accumulation abilities or a high biomass plant with an enhanced capacity for metal uptake (Varun *et al*. 2017).

Conventional Uses

In India, *S. sesban* used from centuries as traditional and conventional crop for green manuring and source of fodder and in soil reclamation. The light wood of this plant is used as fuel for cooking and also suitable for charcoal production. In Myanmar, *Sesbania* wood, that is light, soft, and fibrous used for manufacture toys for children's (Bunma and Balslev, 2019). High content of protein in aerial portion of the plant i.e. (leaves and branches) is used as fodder in animal husbandry and also play significant role is the digestion. It is traditional green fodder, and recently reported as alternative source of alfalfa (Farghaly *et al*. 2022). Root and bark is usage in bitter tonic for frailty in nervous disorders, dysuring, urine retention and hepatoprotective activities (Naik *et al*. 2011). Leaves make rich compost, and have high protein (30-40%) and lipid (5-6%) content used as fodder for sheep and cattles (Hossain and Becker, 2001). Leaves, roots, bark, petals and flower have medicinal properties (Desaeger and Rao 2001). *S. sesban* having great applications in pharmacological activities namely antimicrobial, anti-diabetic, anti-inflammatory and antagonisms against both Gram positive and Gram negative bacteria (Mythili and Ravindhran 2012, Nohwar *et al*. 2019, Walekhwa *et al*. 2020).

Role as Green Manure

In India *S. sesban* used as biofertilizer with nitrification interrupter encapsulated calcium carbide (ECC) were used in management of rice-wheat crop production and increase N supply to crops. *S. sesban*, urea and ECC were used in combination to increase nitrogen availability in wheat and rice crop but also effect on soil enzymes like dehydrogenase and nitrate reductase activity in favour of preservation of nitrogen in semi acid area (Patra *et al*. 2006). In nitrogen depleted soil, *S. sesban* is used for replenishing soil fertility and have potential to enhance soil water storage capacity. Quantified soil water balance in maize, prove that *S. sesban* improve maize yield and soil water use in nutrient deficient soil (Phiri *et al*. 2006). *S. sesban* reported as fast growing plant, rotation of this plant with other crops enhance soil fertility, so it used by poor farmers for increasing soil fertility and crop productivity. It increase crop yield, when it used rotationally with maize (Jama *et al*. 1998). On the contrary, Rao and Gill, (1993) noted that *Sesbania* species used in field trials enhanced nodule formation, N_2 fixation, increase in biomass production and absorption of minerals and nutrients. *Rhizobium* spp. isolated from root nodules of *S. sesban* were tested to grow in high NaCl (salt) concentration, pH and temperature, found that for salt (0.1-20% W/V, growth start decline form 0.1-20% but at 30% no growth was found), pH (growth start from pH 4-13, but best growth at pH 7) and temperature is 25-35°C. Based on these characteristics this plant can be used as optional to decline in the utilization of inorganic fertilizers (Nohwar *et al*. 2019).

Role in Ecorestoration

During the monsoonal season, regermination and opulent growth of *S. sesban* have been noted at the lower site of the restored heap. *S. sesban* is an outstanding nitrogen fixer, stabilises the dump, succour scission, and passes away after the monsoon. The immense spread of the leguminous crops likes *S. sesban and Crotalaria juncea*, and parched within 5-6 months leading to a higher accumulation of dry mulch. Their pile also had a significant impact on rhizospheric temperature diminution. Under mulch cover, there was a major decline in rhizospheric temperature of 12-17%, whereas it was only 4% on bare surfaces. Because of their short lifespan periods, *S. sesban* and *C. juncea* can serve as green manure for the soil, adding organic carbon (OC) and nitrogen to the soil afterward desiccation. Rehabilitation and upkeep of the ecorestored centre, especially watering and livestock security is important. Restoration via grass-legume combinations has a major impact on soil stability and nutrient cycling and thus may be used for waste dump ecorestoration. These combinations grow quickly in nutrient-deficient conditions and reach maturity in just a few months. The main sources of soil OC, N, and other nutrients are dry, aboveground parts of grasses (*P. pedicellatum*) and rapidly growing legumes (*C. juncea, S. sesban*). To conserve moisture, the dry parts of these legumes and grasses act as mulch (Maiti and Maiti 2014, 2015, Maiti 2022).

Conclusion and Future Prospects

This study underscores the significance of *Sesbania* plants and their associated rhizobia as an eco-friendly and economically viable approach to enhancing soil fertility, surpassing alternatives like chemical fertilizers, pesticides, and sewage sludge. Soil fertility is a matter of grave concern due to its potential impact on human health, as toxins from fertilizers and pesticides can infiltrate groundwater. *Sesbania* exhibits a range of attributes that make it an appealing multipurpose plant with potential in agricultural systems. *S. sesban* is being used for centuries as a traditional and conventional crop as fodder, *medicine, green* manure, and in soil reclamation. In addition to being a valuable part of providing rural households with firewood sources, it is also being used in soil amelioration. Frequent investigations have been carried out to determine diversification dynamic and their implication for increasing agrarian productivity. As multipurpose crop, it may prove useful in agrarian production due to its multifaceted properties. The main use of PGPR associated with *S. sesban* is potentially enhancing sustainable farming in eco-friendly manner. This plant has been recommended for vermicompost of coir pith. In present scenario, for sustainable agriculture *S. sesban* with PGPR are used as biopesticide and biofertilizer and suggested can be alluring, as eco-safe approach. PGPR protect plant from phytopathogens alongside promote plant growth. PGPR strain enhance biomass, photosynthetic pigments, antioxidant activities and potency to bioremediation of heavy metals in polluted soil, near industrial areas, contaminated soil. Also this plant have various therapeutic benefits such as anti-fertility, anti-microbial, anti-bacterial, anti-fungal, anti-inflammatory, anti-diabetic, CNS, and hypoglycaemic properties.. The miscellaneous therapeutic impact including agriculture utility makes this plant biologically potential shrub. As a result, *Sesbania* emerges as a prime source of optimal fertilization for current and future crops, warranting heightened research interest. The integration of *Sesbania* plants and their corresponding rhizobia as biofertilizers should transition from the laboratory to field application, ensuring sustained soil health and alleviating soil infertility concerns in the coming years. Emerging high-throughput tools and techniques hold promise for deepening our comprehension of *Sesbania* plants and their interconnected microorganisms.

Acknowledgements

The authors are thankful to Uttarakhand State Council for Science and Technology (UCOST), Dehradun, Uttarakhand and NMPB, Ministry of Ayush, Govt. of India, New Delhi, for financial support.

Authors Contribution

Prashant Kumar had the conceptualization of writing original draft preparation, writing review and performed the literature search; Harshita Vashistha editing, data analysis and prepared all figures and tables; Sandeep Kumar resources, supervised and approved. All authors reviewed the manuscript.

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