*Forage Res.*, **51**(2) : pp. 151-157 (2025) **http://forageresearch.in**

# HARNESSING PGPB FOR SUSTAINABLE CROP PRODUCTION AND ENVIRONMENTAL PROTECTION - A REVIEW

**THULASI BAI VADITHE[1], SEVA NAYAK DHEERAVATHU[1]*, SRINIVASAN R.[3], SRINIVAS A.[1], KETHAVATH MADHUDEEPIKA[1], SRAVANTHI G.[1&2], SAIDA NAIK VADITHE[4], BANDEPPA S.[5] AND A. JYOTHI[6]**

[1]ICAR-Indian Institute of Millets Research, Hyderabad-500030 (Telangana), India
[2]Department of Crop Physiology, Agricultural College, Bapatla-522101 (Andhra Pradesh), India
[3]ICAR-Indian Grassland and Fodder Research Institute, Jhansi-284003 (UP), India
[4]ANGRAU-Agricultural Research Station, Jangameswarapuram, Palanadu-522415 (Andhra Pradesh), India
[5]Indian Institute of Rice Research, Hyderabad-500030 (Telangana), India
[6]Department of Microbiology, Visakha Government Degree College for Women (A)
Visakhapatnam-530020 (Andhra Pradesh), India
**(e-mail: sevanayak2005@gmail.com)*

**(Received : 9 September 2025; Accepted : 29 September 2025)**

## SUMMARY

Microorganisms are indispensable for sustainable agriculture, as they perform multiple vital functions within the soil–plant ecosystem. They influence soil fertility, crop productivity, and plant health through diverse ecological and biochemical processes. In agricultural systems, microbes act as natural fertilizers, biocontrol agents, and soil engineers, thereby maintaining the balance and productivity of agroecosystems. By facilitating nutrient cycling, decomposing organic matter, and enhancing plant resilience, microorganisms significantly reduce dependence on chemical fertilizers and pesticides. This not only minimizes environmental pollution but also promotes eco-friendly and sustainable farming practices. Among beneficial microorganisms, Plant Growth-Promoting Bacteria (PGPB) represent a distinct group capable of colonizing plant roots and improving overall plant performance. PGPB exert their beneficial effects through both direct and indirect mechanisms: Direct mechanisms: Biological nitrogen fixation, Phosphate solubilisation, Phytohormone production (auxins, cytokinins, gibberellins), Mobilization of essential nutrients. Indirect mechanisms: Suppression of pathogens through antibiotic production and competition, Siderophore production for iron acquisition, Induction of systemic resistance against various biotic stresses, Mitigation of abiotic stresses such as salinity, drought, and heavy metal toxicity. In this review, we discuss the various direct and indirect mechanisms employed by PGPB that contribute to plant growth, soil health, and sustainable crop production.

**Key words:** Plant Growth-Promoting Bacteria (PGPB), Biological nitrogen fixation, Phosphate solubilisation Phytohormone, abiotic stress and Biological Nitrogen Fixation (BNF)

Nitrogen is an essential macronutrient required for plant growth and development, as it forms a key component of amino acids, proteins, nucleic acids, and chlorophyll (Singh *et al* 2010). Atmospheric nitrogen (N, ) exists in a highly stable, inert form that plants cannot directly utilize. Biological Nitrogen Fixation (BNF) is a natural process carried out by certain microorganisms that convert atmospheric nitrogen (N, ) into ammonia (NHƒ ), a plant-available form of nitrogen. Plant Growth-Promoting Bacteria (PGPB), particularly diazotrophic bacteria, play a vital role in Biological Nitrogen Fixation (Table 1).

**Phosphate Solubilization:** Phosphorus (P) is a vital macronutrient required for plant growth and development, playing a key role in energy transfer, signal transduction, and nucleic acid synthesis. Most soil phosphorus exists in insoluble, unavailable forms. As a result, crops often suffer from phosphorus deficiency despite its abundance in the soil. Backer et al. (2018) reported that phosphate-solubilizing bacteria (PSB) are widely distributed in soil and converting bound phosphorus into soluble forms that can be readily absorbed by plants. Several endophytic bacterial genera have been identified as potent phosphate solubilizers, including *Bacillus,* *Burkholderia, Enterobacter, Pantoea, Erwinia, Pseudomonas, Citrobacter,* and *Azotobacter* (Idriss *et al.*, 2002; Rodriguez *et al.*, 2006; Park *et al.*, 2010, Dheeravathu, et al., 2021, Thulasi *et al*., 2023) (Table 1). The mechanism of phosphate solubilization largely involves the secretion of organic acids (such as gluconic acid, citric acid, and oxalic acid), which chelate cations bound to phosphate, releasing it into a soluble form. The type of organic acid produced depends on the carbon source available. Maximum solubilization has been reported when glucose, sucrose, or galactose serve as the sole carbon source (Khan *et al*., 2009; Park et al., 2010). Endophytic bacteria can also solubilize inorganic phosphates such as tricalcium phosphate via extracellular acidification and enzymatic activity (Kuklinsky-Sobral *et al.*, 2004; Long *et al*., 2008; ThamizhVendan *et al*., 2010; Patel *et al.*, 2012).

**Phytohormone Production**

Plant Growth-Promoting Bacteria influence plant development not only by improving nutrient availability but also by producing phytohormones such as auxins, cytokinins, and gibberellins. These bacterial-derived compounds mimic or enhance the plant's own hormonal balance, leading to improved growth, development, and stress tolerance. Auxins (Indole-3-Acetic Acid, IAA) are the most commonly reported phytohormones produced by PGPB. Auxins stimulate root elongation, lateral root initiation, and root hair formation, which increases the root surface area for nutrient and water uptake. *Azospirillum, Bacillus, Pseudomonas, and Enterobacter* are well-known IAA producers (Table 1). Cytokinins regulate cell division, shoot initiation, and leaf expansion. Cytokinin-producing bacteria improve shoot growth and delay leaf senescence, thereby enhancing photosynthetic activity. Endophytic bacteria like *Bacillus subtilis* and *Pseudomonas fluorescens* have been reported to release cytokinins (Table 1). Gibberellins (GA) stimulate stem elongation, seed germination, and flowering. Several rhizobacteria, such as *Azospirillum brasilense* and *Herbaspirillum seropedicae,* have been documented to produce GA, which helps plants overcome growth restrictions under stress (Table 1).

**Solubilization of other Essential Nutrients**

Apart from nitrogen fixation and phosphate solubilization, Plant Growth-Promoting Bacteria (PGPB) also enhance plant growth by mobilizing other essential nutrients that are otherwise poorly available in soil. These include potassium (K), zinc (Zn), iron (Fe), and sulfur (S), which are vital for plant metabolism and productivity. Large amounts of potassium in soils exist in insoluble mineral forms such as feldspar and mica. Potassium-solubilizing bacteria (KSB), including *Bacillus mucilaginosus* and *Frateuria aurantia*, release organic acids and enzymes that dissolve these minerals, making K available for plant uptake. Enhanced potassium uptake improves drought tolerance, enzyme activation, and disease resistance in crops (Table 1). Zinc is critical for enzyme function, protein synthesis, and auxin metabolism, yet much of it is insoluble in soil. *Pseudomonas* spp. and *Bacillus* spp. can solubilize zinc compounds (e.g., ZnO, ZnCOƒ), thereby improving crop growth and yield (Table-1). Iron is often present in insoluble ferric forms ($Fe^{3+}$). PGPB secrete siderophores (small molecules that chelate Fe$^{3}$z ),. PGPB not only enhances plant nutrition but also limits iron availability to pathogens, indirectly contributing to disease suppression (Table-1). Sulphur (Oxidation) is essential for amino acids, proteins, and vitamins. Certain PGPB (e.g., *Thiobacillus* spp.) oxidize elemental sulfur to sulfate (SO„ $^{2}${ ), a plant-usable form.

**Indirect mechanisms:** Plant Growth-Promoting Bacteria (PGPB) synthesize secondary metabolites with antimicrobial activity, such as 2,4-diacetylphloroglucinol (DAPG), phenazines, pyrrolnitrin. which inhibit the growth of fungal and bacterial pathogens.

Siderophore Production for Iron Acquisition: Iron is an essential micronutrient for plants, required for processes such as chlorophyll biosynthesis, respiration, and enzymatic activity. In aerobic soils, iron predominantly exists as insoluble ferric ions ($Fe^{3+}$), making it poorly available to plants. Plant Growth-Promoting Bacteria (PGPB) overcome this limitation by producing siderophores-low-molecular-weight, high-affinity iron-chelating compounds.

**Iron Solubilization and Uptake:** Siderophores bind Fe$^{3}$z in the soil and form soluble complexes, these complexes are taken up by bacterial or plant receptors, ensuring adequate iron availability to both the microbes and their plant hosts. The common siderophores include catecholates (enterobactin), hydroxamates (ferrichrome), and carboxylates (rhizobactin). Dual Role in Plant Growth and Disease Suppression: Siderophore-producing bacteria such as *Pseudomonas*, *Bacillus*, *Azotobacter*, *Burkholderia* enhance plant vigor, photosynthesis, and yield (Table 1).

TABLE 1
Direct and Indirect Mechanisms of PGPB with Representative Genera and Effects on Crops

| Mechanism | Representative Genera | Mode of Action | Reported Effects on Crops |
|---|---|---|---|
| **Direct Mechanisms** | | | |
| Biological Nitrogen Fixation | *Azotobacter, Azospirillum, Rhizobium, Bradyrhizobium* | Conversion of atmospheric $N_2$ into plant-available ammonia | Enhanced N availability, improved yield in legumes, cereals |
| Phosphate Solubilization | *Bacillus, Pseudomonas, Burkholderia, Enterobacter, Citrobacter* | Production of organic acids and phosphatases to solubilize inorganic and organic P | Increased P uptake, improved growth in maize, sugarcane, oilseed crops |
| Phytohormone Production (auxins, cytokinins, gibberellins) | *Azospirillum, Bacillus, Pseudomonas, Klebsiella* | Modulation of root architecture, cell division, elongation | Enhanced root and shoot growth, better nutrient acquisition |
| Mobilization of Essential Nutrients (Zn, K, Fe) | *Bacillus, Pseudomonas, Paenibacillus* | Solubilization/mobilization of micronutrients through organic acids and enzymes | Improved micronutrient uptake, enhanced crop quality and yield |
| **Indirect Mechanisms** | | | |
| Pathogen Suppression | *Pseudomonas, Bacillus, Streptomyces* | Antibiotic production, competition for space and nutrients | Reduced soil borne diseases, healthier plants |
| Siderophore Production | *Pseudomonas, Azotobacter, Burkholderia* | Sequestration of $Fe^{3+}$, limiting pathogen access | Improved iron uptake, suppression of phytopathogens |
| Induction of Systemic Resistance (ISR) | *Pseudomonas fluorescens, Bacillus subtilis* | Activation of plant defense pathways (salicylic acid, jasmonic acid, ethylene) | Enhanced resistance against fungal, bacterial, and viral diseases |
| Mitigation of Abiotic Stress (salinity, drought, heavy metals) | *Bacillus, Pseudomonas, Arthrobacter, Azospirillum* | Production of ACC deaminase, exopolysaccharides, antioxidant enzymes | Increased plant tolerance to stress, stable yields under adverse conditions |

**Induction of Systemic Resistance in Plants:** In addition to directly promoting plant growth, many Plant Growth-Promoting Bacteria (PGPB) enhance plant immunity through a phenomenon known as Induced Systemic Resistance (ISR). ISR is a plant defense mechanism activated by beneficial microbes that primes the plant to respond more effectively against a wide range of pathogens and pests. Unlike pathogen-triggered resistance, ISR does not rely on hypersensitive responses but instead strengthens the plant's innate immune system.

**Mechanism of ISR:** ISR is mediated through jasmonic acid (JA) and ethylene (ET) signaling pathways, distinct from the salicylic acid (SA)-dependent systemic acquired resistance (SAR). PGPB such as *Pseudomonas fluorescens*, *Bacillus subtilis*, and *Azospirillum* release microbial elicitors (lipopolysaccharides, flagellin, siderophores, and antibiotics) that trigger ISR in plants. Primed plants show faster and stronger defense responses when challenged by pathogens or environmental stress.

**Identification of climate resilient crops:** The climate resilient crops such as grasses: guineagrass, bajra - napier hybrids and tri-specific hybrids, dinanath grass, (Dheeravathu *et al*., 2018, Singh *et al*., 2020, Dheeravathu *et al*., 2021a, Dheeravathu *et al*., 2021b, Dheeravathu *et al*., 2021c., Dheeravathu et al., 2022a, Dheeravathu *et al*., 2022b), forage cereals including millets: pearl millet sorghum, kodo millet, (Malathi *et al*., 2022, Dheeravathu and Vadithe, 2024a, Dheeravathu and Vadithe, 2024b, Sravanthi *et al*., 2024, Sravanthi *et al*., 2025), pulses: cowpea, berseem, clitoria, centrosema, siratro (Dheeravathuet *et al*., 2017a, Dheeravathu et al., 2017b, Dheeravathu *et al*., 2022c., Dheeravathu *et al*., 2023), have been proven to be climate smart.

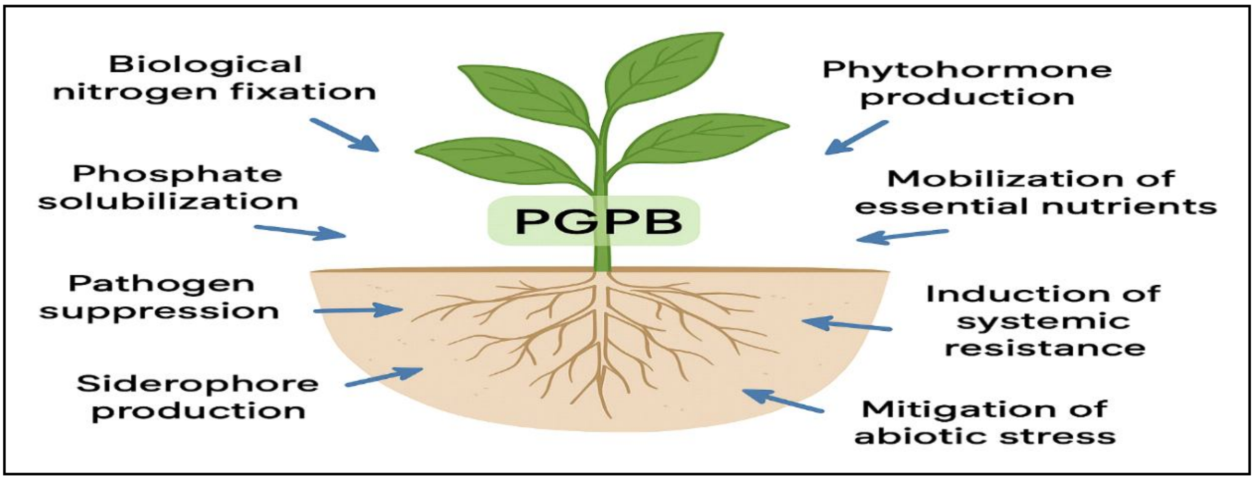


Fig. 1. Schematic diagram of the Plant growth prompting bacteria.

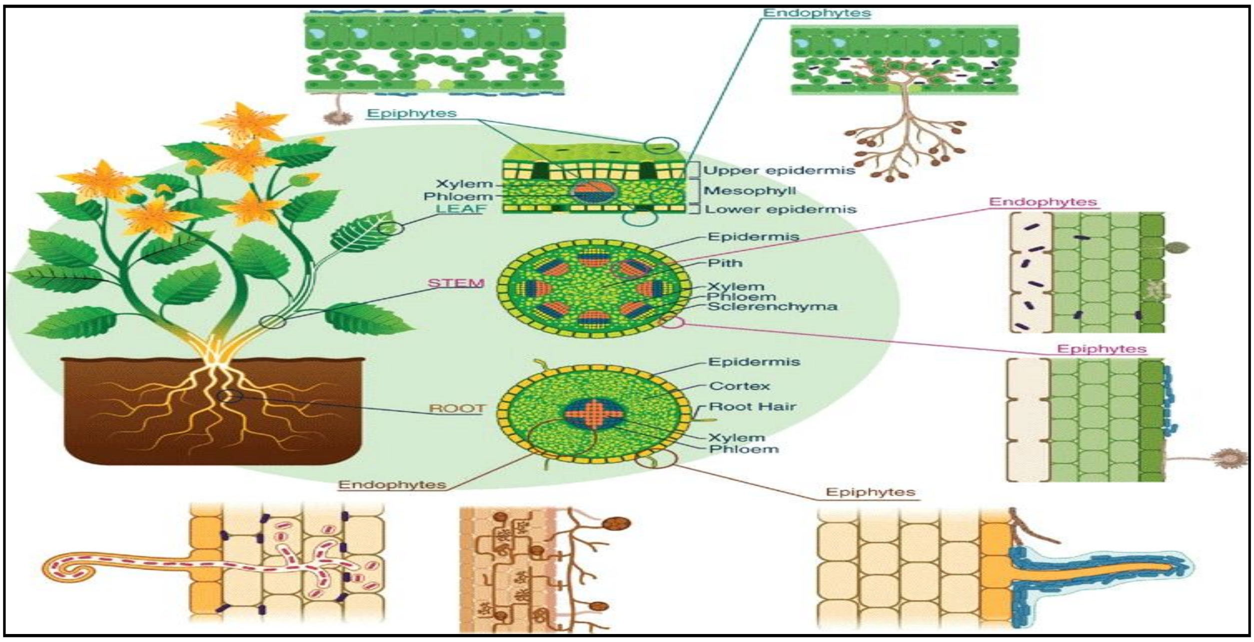


Fig. 2. Schematic diagram of the penetration and colonization of Endophytes into the host.

## Mitigation of Abiotic Stresses

Apart from promoting plant nutrition and pathogen resistance, Plant Growth-Promoting Bacteria (PGPB) also play a crucial role in helping plants cope with abiotic stresses such as salinity, drought, and heavy metal toxicity. These stresses severely limit agricultural productivity worldwide, and microbial interventions provide an eco-friendly alternative to chemical amendments.

**Salinity Stress and drought stress mitigation:** PGPB alleviate salinity stress through, Production of ACC deaminase, which lowers plant ethylene levels and prevents stress-induced growth inhibition. Exopolysaccharide (EPS) production, which binds excess sodium ions and improves soil aggregation, reducing salt toxicity. Enhanced uptake of Kz , $Ca^{2+}$, and $Mg^{2+}$ to maintain ion homeostasis. Example: *Halotolerant Bacillus* and *Pseudomonas* strains improve rice and wheat growth under saline conditions (Table 1). Drought Stress Alleviation: Under water deficit, plants suffer from reduced photosynthesis, stomatal closure, and oxidative stress. PGPB enhancing root growth and architecture for better water uptake (Table 1).

**Heavy Metal Stress Management:** Heavy metals (Cd, Pb, Hg, As, Cr) disrupt cellular metabolism and accumulate in edible plant parts.

*Pseudomonas putida* and *Bacillus megaterium* mitigate toxicity through transformation of toxic metals into less bioavailable forms (e.g., $Crv^{6+} \rightarrow Cr^{3+}$): (Table 1).

### Volatile Compounds

Endophytic bacteria can produce diverse volatile organic compounds (VOCs) that contribute to signaling, microbial inhibition, and plant growth promotion (Wheatley, 2002; Kai et al., 2009). For instance: *Bacillus* spp. produce 2,3-butanediol and acetoin, which stimulate growth in *Arabidopsis thaliana* (Ryu *et al.,* 2003). *Burkholderia pyrrocinia* releases volatiles such as indole, 1-hexanol, and pentadecane under stress, promoting significant growth enhancement.

### Plant Growth Promotion case studies

Jha and Kumar, 2007 inoculated *Klebsiella oxytoca* GR-3 to rice seeds and observed that the root length, shoot height, and chlorophyll content were improved in rice seedlings. Long *et al.* (2008) reported that increased seed germination and seedling vigor in inoculated endophytes *Solanum nigrum*. Co-inoculation of *Pseudomonas fluorescens* and *Bacillus* spp. increased banana yields by over 50% compared to controls, while also improving chlorophyll content and resistance to banana bunchy top virus (Harish *et al.*, 2009). *Bacillus subtilis* HC8 enhanced tomato growth and protected against root rot disease (Marfanova *et al*., 2011).

### Biological Control Agents

PGPB and other beneficial microbes also act as biological control agents, providing an eco-friendly alternative to chemical pesticides. *Trichoderma*-based formulations have been used in cacao to control black pod disease while also improving flowering and pod development (Tondje *et al*., 2007; Deberdt *et al*., 2008). Successful biocontrol formulations must ensure economical production, stability, easy application, and long shelf life. Various carriers such as diatomaceous earth, organic manure, alginate pellets, and starch granules have been explored for delivering these agents effectively (Raj *et al*., 2003; Schisler *et al*., 2004).

## CONCLUSION

Plant Growth-Promoting Bacteria (PGPB) play a vital role in fostering sustainable agriculture and protecting environmental health. They improve nutrient uptake, boost plant stress tolerance, produce beneficial bioactive compounds, and minimize reliance on harmful agrochemicals. As a result, PGPB stand out as essential allies in building greener, more resilient, and eco-friendly agricultural systems for the future.

## ACKNOWLEDGEMENTS

The authors sincerely acknowledge the ICAR–Indian Institute of Millets Research, Hyderabad, and Science and Engineering Research Board (SERB)-Core Research Grant (CRG), New Delhi for support and carrying out the search work. for their support and facilitation in carrying out the present research work.

## REFERENCES

Brookie, K. L., G. I. Best, and T. S. Conner, 2018: Intake of raw fruits and vegetables is associated with better mental health than intake of processed fruits and vegetables. *Frontiers in psychology*, **9**: 487.

Deberdt, P., C. V. Mfegue, P. R. Tondjé, M. C. Bon, M. Cucamp, C. Hurard, B. A. D. Begoude, M. Ndoume-Nkeng, P. K. Helbar and C. Cilas, 2008: Impact of environmental factors. Fungicides and biological control on cocoa pod on cocoa pod production dynamics and black pod diseases (*Phytophthora megakarya*) in Cameroon. *Biol. Control*, **44**: 149-159.

Dheeravathu S. N., M. H. Hanamant, T. B. Vadithe, S. N. Vadithe, K. Singh, N. Dikshit, T. N. Usha, T. Singh, Reetu, and R. Gajghate, 2021c: Salinity tolerance of forage cowpea (*Vigna unguiculata* (L.) walp.) during germination and early seedling growth. *Forage Res*., **47**: 213-221.

Dheeravathu S. N., T. Singh, and A. Radhakrishna, 2017b: Effect of drought stress on biomass and drought adaptive traits in Berseem (*Trifolium alexandrinum* L.), National symposium-new directions in managing forage resources and livestock productivity in 21st century: challenges and opportunity: 4-17.

Dheeravathu, S. N., and T. B. Vadithe, 2024a: Potential and scope of sorghum cultivation in rice-fallows - an ideal strategy under climate change: a review. *Forage Res*., **50**(1): 1-4.

Dheeravathu, S. N., E. Antony., R. V. Koti, and M. B. Doddamani, 2017a: Salinity tolerance of Forage range legumes during germination and early seedling growth. *Progressive Res. J.*, **12**: 1357-1360.

Dheeravathu, S. N., G. Sravanthi., V. Thulasi Bai., M.D. Kethavath and V. Saida naik. 2024b: Physiological study of kodo millet under imposed salinity stress at seedling stage. *Forage Res.*, **50**(3): 330- 336.

Dheeravathu, S. N., K. Singh, P. K. Ramteke, Reetu, N. Dikshit, M. Prasad, D. Deb, and T. B. Vadithe, 2021b : Physiological responses of Bajra-Napier hybrids and a tri-specific hybrid to salinity stress. *Trop. Grassl. Forrajes Trop.* **9**: 337-347.

Dheeravathu, S. N., P. Singh, R. Srinivasan, and V. K. Yadav, 2022a: Open Top Chamber: An innovative screening technique for temperature stress tolerance in forage oat (*Avena sativa*). *Forage Res.*, **47**: 513-516.

Dheeravathu, S. N., T. B. Vadithe, N. Dikshit, T. N. Usha, S. N. Vadithe, R. Venkateswarlu, V. Manasa and S. Bandeppa, 2022b: Effect of elevated $CO_2$ and temperature on physiological and biochemical changes in forage crops: A review. *Forage Res.*, **48**: 22-27.

Dheeravathu, S. N., T. Singh, A. Radhakrishna, Reetu, R.Gajghate, S. R. Kantwa, and H. A. Bhargavi, 2021a: Effect of salinity stress on different seed vigour indices in single and multicut berseem (*Trifolium alexandrinum*) varieties. *Forage Res.* **46**: 368-373.

Dheeravathu, S. N., V. C. Tyagi, C. K. Gupta, and A. Edna, 2018: Manual on Plant Stress Physiology. ICAR Indian Grassland and Fodder Research Institute, Jhansi. Stress assessment formulas and stress related terminology: 1-87.

Dheeravathu, S.N., P. Singh., R. Srinivasan., A. Kuma., D. Deb., T.B. Vadithe and V.K. Yadav 2023: Open top chamber: an innovative screening technique for temperature stress tolerance of morphophysiological and fodder yield traits in forage cowpea varieties. *Range Management and Agroforestry,* **44**(1): 58-65.

Dheeravathu, S. N., Kajal Singh, Pramod W Ramteke, Reetu, Nilamani Dikshit Mahendra Parasad and Dibyendu Deb E. 2021: Physiological response of Bajra-Napier Hybrids and Tri-Specific Hybrid to salinity stress. *Tropical Grasslands-Forrajes Tropicales,* **9**: 337-347.

Dheeravathu, S. N., M. Chaudhary, N. Dikshit, V. Manasa, R. Srinivasan, T. N. Usha, T. B Vadithe, S. N., Vadithe, G.Vijayakumar, S.Bandeppa, and Satpal, 2022c: Effect of elevated $CO_2$ and temperature on soil health and forage crops -A review. *Forage Res.*, **48**(3): 285-289

Harish, S., M. Kavino, N. Kumar, P. Balasubramanian and R. Samiyappan, 2009: "Induction of defense-related proteins by mixtures of plant growth promoting endophytic bacteria against Banana bunchy top virus". *Biol. Control.,* **51**: 16-25.

Idriss, E. E., O. Makarewicz, A. Farouk, K. Rosner, R. Greiner, H. Bochow, T. Richter and R. Borriss, 2002: Extracellular phytase activity of Bacillus amyloliquefaciens FZB45 contributes to its plant-growth-promoting effect. *Microbiol.,* **148**: 2097-2109.

Jha, P. N. and A. Kumar, 2007: Endophytic colonization of Typhaaustralis by a plant growth promoting bacterium Klebsiellaoxytoca strain GR-3. *J. Appl. Microbiol.,* **103**: 1311-1320.

Kai, M., M. Haustein, F. Molina, A. Petri, B. Scholz and B. Piechulla, 2009: Bacterial volatiles and their action. *Appl. Microbiol. Biotechnol.,* **81**: 1001-1012.

Khan, M. S., A. Zaidi, P. A. Wani and M. Oves, 2009: Role of plant growth promoting rhizobacteria in the remediation of metal contaminated soils. *Environ. Chem. Lett.,* **7**: 1-19.

Kuklinsky-Sobral, J., W. L. Araujo, R. Mendes, I. O. Geraldi, A. A. Pizzirani-Kleiner, and J. L. Azevedo, 2004: Isolation and characterization of soybean associated bacteria and their potential for plant growth promotion. *Appl. Environ. Microbiol.*, **6**: 1244-1251.

Long, H. H., D. D. Schmidt and I. T. Baldwin, 2008: Native bacterial endophytes promote host growth in a species specific manner phytohormone manipulations do not result in common growth responses. *PLoS ONE,* **3**: 2702.

Malathi, M. V., S. N. Dheeeravathu, R. Venkateswarlu,T. N. Usha, T. B. Vadithe, S. N. Vadithe, D. Venkateshwarlu, G. Vijayakumar, N. Dikshit and Satpal, 2022: Climate change: Molecularadaptation strategies in cereals and foragecrops–A review. *Forage Res.*, **48**(2): 137-145

Malfanova, N., F. Kamilova, S. Validov, A. Shcherbakov, V. Chebotar, I. Tikhonovich and B. Lugtenberg, 2011: Characterization of Bacillus subtilis HC8, a novel plantbeneficialendophytic strain from giant hog weed. *Microbial Biotechnol.*, **4**: 5

Park, K. H., O. M. Lee, H. I. Jung, J. H. Jeong, Y. D. Jeon, D. Y. Hwang, C. Y. Lee and H. J. Son, 2010: Rapid solubilization has of insoluble phosphate by a novel environmental stress-tolerant burkholderiavietnamiensis M6 isolated from ginseng rhizospheric soil. *Appl. Microbiol. Biotechnol.,* **86**: 947-955.

Patel, H. A., R. K. Patel, S. M. Khristi, K. Parikh and G. Rajendran, 2012: Isolation and characterization of bacterial endophytes from Lycopersiconesculentum plant and their plant growth promoting characteristics. *Nepal J. Biotech.,* **2**: 37-52.

Raj, N. S., S. A. Deepak, P. Basavaraju, H. S. Shetty, M. S. Reddy and W. J. Kloepper, 2003: Comparative performance of formulations of plant growth promoting rhizobacteria in growth promotion and suppression of downy mildew in pearl millet. *Crop Protection* **22**: 579-588.

Rodriguez, H., R. Fraga, T. Gonzalez and Y. Bashan, 2006: Genetics of phosphate solubilization and its potential applications for improving plant growth promoting bacteria. *Plant Soil*, **287**: 15-21.

Ryu, C. M., M. A. Farag, C. H. Hu, M. S. Reddy, H. X. Wei, Pare, P. W. and J. W. Kloepper, 2003: Bacterial volatiles promote growth in Arabidopsis. *Proc. Natl. Acad. Sci. U.S.A.*, **100**: 4927-4932.

Singh, B., S. N. Dheeravathu and K. Usha, 2010: Micronutrient Deficiency: A Global Challengeand Physiological Approach to Improve Grain Productivity under Low Zinc availability, In: Plant stress. Global science book UK, (Special issue -2) **4**: 76-93.

Singh, K., S. N. Dheeravathu, P. W. Ramteke, Reetu, N. Dikshit, and T. B. Vadithe, 2020: Effect of salt stress on morpho-physiological and green fodder yield of Bajra Napier Hybrids and Tri Specific Hybrid. *Forage Res.*, **46**: 241-247.

Sravanthi, G. S. N. Dheeravathu, P. Latha, S. Avinash, J. Jacob and G. Vijaya Kumar, 2025: Effect of heat stress on sorghum genotypes at seedling stage. *Forage Res*., **51**(1) : 144-149.

Sravanthi G. S. N. Dheeravathu, P. Latha, S. Avinash, J. Jacob, G. Vijaya Kumar and T. B. Vadithe, 2024: Screening of sorghum germplasm for high temperature stress tolerance at seedling stage, *Forage Res*., **50**(2) : 189-196.

ThamizhVendan, R., Y. J. Yu, S. H. Lee and Y. H. Rhee, 2010: Diversity of endophytic bacteria in ginseng and their potential for plant growth promotion. *J. Microbiol.* **48**: 559-565.

Thompson, D. C. 1996. Evaluation of bacterial antagonist for reduction of summer patch symptoms in Kentucky blue grass. *Plant Dis*., **80**: 856-862.

ThulasiBai, V., D. Seva Nayak and A. V. Amrutha 2023: Efficacy of Endophytic Bacterial Bioformulations on Plant Growth Promotion and Biocontrol of *Fusarium* Wilt in Tomato *The Journal of Research ANGRAU* **2**: 39-51

Tondje, P. R., D. P. Roberts, M. C. Bon, T. Widmer, G. J. Samuels, A. Ismaiel, A. D. Begoude, T. Tchana, E. Nyemb-Tshomb, M. Ndoumbe-Nkeng, R. P. Bateman, D. Fontem and K. P. Hebbar, 2007: Isolation and identi fi cation of mycoparasitic isolates of Tricho- derma asperellum with potential for suppression of black pod disease of cacao in Cameroon. *Biol. Control*, **43**: 202-212.

Wheatley, R. E., 2002: The consequences of volatile organic compound mediated bacterial and fungal interactions. *Antonie Van Leeuwenhoek*, **81**: 357-364.