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Review Article

Biofertilizer from Vegetative Waste and Animal Excretory Waste by Using PGPR - A Way for Sustainable Agriculture

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Abstract

As the world's population continues to grow, the demand for food becomes increasingly important, which results in the use of chemical fertilizers. Chemical fertilizers are used in agriculture to increase crop yields and provide essential nutrients to plants, but they contain harmful chemicals that can have negative effects on the environment, such as degrading soil, reducing fertility, increasing pest resistance, causing heavy metal precipitation in soil, etc., and also have been linked to health problems such as cancer, birth defects, etc. To address these negative effects, there has been a growing movement towards sustainable agriculture practices, such as organic farming and regenerative agriculture. These practices prioritize soil health, crop diversity, and natural pest control methods, which can reduce the need for chemical fertilizers and promote more sustainable food production. Household vegetative waste management has been a major issue in most urban communities. Cow dung causes unpleasant odours, pollutes the environment, can become vectors of disease, and produces the largest greenhouse gas emissions, such as methane gas (CH_4). Biofertilizers are basically microbial inoculants that, when applied to soil, plants, or seeds, boost plant growth and development by increasing the delivery of vital nutrients or chemicals that promote plant growth, as well as increasing soil fertility. PGPR colonizes plant roots and stimulates plant development through a number of processes, such as phosphate solubilization, phytohormone synthesis, antifungal activity, and others. So, the preparation of biofertilizers from household vegetative waste and cow dung (used as a carrier) by using the co-inoculum of PGPR could be an alternative to all existing problems arising due to the use of chemical fertilizers. This review describes problems occurring due to chemical fertilizer, household vegetative waste, and cow dung, and solutions to the problem, i.e., biofertilizer, and the use of PGPR for sustainable agriculture.

Keywords: Biofertilizer; Vegetative Waste; Cow Dung; PGPR; Carrier-Based Biofertilizer

Introduction

Over 58% of India's population relies primarily on agriculture, making it one of the leading players in the world agricultural market. Around half of the population of India is employed in the country's agricultural industry, which is the second-largest agricultural region in the world [24]. In the Indian economy, the agricultural industry is significant. Over the past six years, the agricultural industry in India has expanded at a compound annual growth rate of 4.6%. It increased from 3.3% to 3.0% in 2021-22. For one year, starting on January 1, 2023, the government would provide free grain to almost 81.4 million NFSA beneficiaries. As a result, there is a need to satisfy this enormous food demand. Organic fertilizers are necessary for organic gardening. Chemical fertilizers

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are still commonly used today, though. The high yields required to meet the food needs of this developing nation are produced by the application of artificial fertilizers. Chemical fertilizers, on the other hand, harm both the environment and human health (Agriculture budget report 2022) [2].

Chemical fertilizer: Impacts on human health

The plant macronutrients that chemical fertilizers contain, such as nitrogen, potassium, and phosphorus, may be one of the main health concerns they provide. Chemical fertilizers have the drawback of being able to contaminate surface water and even groundwater through the infiltration of the soil and runoffs into rivers and lakes. For several years, nitrogen can stay in the water, which can lead to an overabundance of nitrates and nitrites. Moreover, methemoglobinemia sometimes referred to as the "Blue Baby Syndrome," is a blood condition that can be brought on by nitrate and nitrite-contaminated water. Methaemoglobin, a kind of haemoglobin, is produced abnormally in this illness, according to medical terminology. According to studies, it arises from giving infants formula made with nitrate-contaminated water. When this occurs, the baby really goes blue and may eventually go into a coma or possibly pass away. Also, a recent study discovered a link between elevated nitrate levels in our environment and diet and an increase in fatalities from diabetes mellitus and Alzheimer's disease. This is because nitrites, which are widely used in fertilizers, react chemically with secondary amines or proteins in humans, resulting in DNA damage, lipid peroxidation, and oxidative stress, all of which can hasten cellular degeneration and even death. The excessive usage of synthetic fertilizer poses a significant risk to one's health by raising the possibility of developing cancer [26].

Effects of Chemical Fertilizer on the Environment

Chemical fertilizers cause water and environmental pollution. Mainly, it affects land because it causes soil erosion, soil acidification, and groundwater contamination. The acidification of soil causes a decrease in organic matter and humus content and alters the pH of the soil; it even leads to the release of greenhouse gases that are harmful to the environment. Prolonged use of chemical fertilizers causes an increase in pests and kills the beneficial microbes present in the soil. High levels of nitrogen and phosphorus cause eutrophication in water bodies. An increase in heavy metals like arsenic, cadmium, and lead decreases the fertility of the soil. One of the harmful effects of fertilizers on the environment can be caused by eutrophication, a process by which a body of water gets an excess amount of nutrients like nitrogen and phosphorus, which mainly happens because of human activities that cause these nutrients to be pushed into the ocean. This process creates a "dead zone" [26]. The main effect of chemical fertilizer is on soil fertility and nutrient content. But though chemical fertilizers are the major cause of sufficient crop production for the world population, their overuse is bringing serious challenges to the present and future generations, like polluted air, water, and soil, degraded lands, depleted soils, and increased emissions of greenhouse gases. When these chemicals are applied in ideal conditions, plants use only up to 50% of the N fertilizer applied; 2-20% gets volatilized, 15-25% reacts with organic compounds in the clay soil, and the remaining 2-10% interferes with surface and groundwater. One of the most important parameters of water pollution is a nitrate, which is the basic component of fertilizer [16]. Soil is a habitat for soil organisms, a nutrient cycling system, and provides many other ecosystem services. Excessive use of chemical fertilizers causes soil acidification and crust, reduces organic matter and humus levels, kills beneficial insects, stunts plant growth, alters soil pH, increases pests, and even causes greenhouse damage [46]. Biofertilizers are beneficial microorganisms that are applied to soil or plant surfaces to improve plant growth and health. They are eco-friendly, cost-effective, and have a minimal negative impact on the environment. The application of biofertilizers can help to mitigate both abiotic and biotic stresses in plants.

Figure 1: Main causes of soil pollution.

Agro waste: A boon for the development of biofertilizer production

Agricultural residues, commonly referred to as agro waste, are produced in large quantities on Indian farms each year. The amount of crop residue produced annually in India is estimated to be over 620 million metric tons [38]. The issue of agricultural waste management is a hot topic globally. The main goal of waste management is to reduce the resulting environmental impact. These environmental impacts are expected to be limited by minimizing waste generation, reuse, recycling, and reclamation. Instead of seeing garbage as a collection of dangerous and unneeded substances and compounds, we need to cultivate the idea that waste is also a resource [54]. Agricultural waste is defined as residues from the growing and processing of raw agricultural commodities such as fruits, vegetables, meat, poultry, dairy, and crops. They are by-products of agricultural production and processing. Agricultural waste consists of animal waste (manure, animal carcasses) and crop residues from food processing (corn stalks, sugar cane bagasse, fruit and vegetable drippings, drumsticks, and clippings) [22]. Agricultural waste accumulation can raise health, safety, environmental, and aesthetic concerns. This, therefore, represents a problem that requires safe disposal. Agro waste contains insoluble chemical components (such as cellulose and lignin) and soluble components (such as sugars, amino acids, and organic acids) and other ingredients are fats, oils, waxes, resins, pigments, proteins, and minerals which can be used as a source of nutrients for the growth of microbes. Agro waste, such as decaying plants, is a major source of organic matter in the soil. Agricultural waste is therefore the cheapest resource that farmers can use to improve soil fertility and as a biofertilizer [24]. Agricultural residues, which farmers commonly treat as waste, are burned in the fields themselves. This is a very cheap, non-labour-intensive, and simple means of treating agricultural waste, but in return it creates a lot of fine dust in the environment, forming smog and smoke. Smoke has a significant negative impact on agroecosystems, polluting the air and disturbing the physical, chemical, and biological structures of soils such as microbial communities, microbiota, and microfauna. It is therefore essential to use crop residues in agricultural production systems to improve soil conditions, crop productivity, and environmental sustainability [49]. Efforts have been made to develop biofertilizers based on agricultural waste in order to produce “nutritious and high-quality food” in a sustainable way while ensuring biosecurity [61]. Agricultural waste, from which biofertilizers are obtained, can be collected from farms where agricultural activities take place. Therefore, it is expected that the demand for organic fertilizers to replace conventional pesticides will increase. Manure, litter, plant stems, leaves, bark, and plants are all forms of agricultural waste. Agricultural waste (agro-waste) is an economic resource that can be effectively used to improve soil fertility. “Biofertilizer” refers to fertilizers that meet the nutritional requirements of plants in a microbiological manner [61].

Cow dung: Source of biofertilizer

Cow dung can be defined as the undigested residues of ingested food excreted by herbivorous cattle. A mixture of faeces and urine in a ratio of 3:1. Mainly composed of lignin, cellulose, and hemicellulose. It also contains 24 minerals, including nitrogen, potassium, traces of sulfur, iron, magnesium, copper, cobalt, and manganese. Indian native cattle also contain higher amounts of calcium, phosphorus, zinc, and copper than crossbred cattle [65]. Cow dung carries a rich microbial diversity, including various species of bacteria (*Bacillus, Corynebacterium,* and *Lactobacillus* spp.), protozoa, and yeasts (*Saccharomyces and Candida)* [25]. In India, where 69.9% of the population lives in rural areas (The Hindu 2011), cattle (*Bos indicus*) are the predominant cattle, producing 9-15 kg of manure per day [65]. Waste is generally destined for disposal as it can be a source of pollution. However, it can be considered a by-product if it is used in another process, such as when used as a raw material. In India, cow dung is used as agricultural by-products such as fertilizers, biofertilizers, biopesticides, and pesticides, as well as an energy source [25]. Cow dung contains essential micro and macronutrients and is considered a potential fertilizer for plant growth, providing an economical alternative to synthetic fertilizers. The addition of cow dung may increase the organic carbon content of degraded soils, further enhancing beneficial soil microbial activity and soil fertility by increasing the availability of nutrients from the soil to plants [42]. Application of cow dung increases the soil organic matter content, resulting in improved water infiltration and water retention capacity, as well as increased cation exchange capacity. Integrating inorganic, organic, and biofertilizers into Anola can increase yields by 50-92%. Manure and urine increase the pH, promoting the decomposition of organic matter and termite activity. When inorganic fertilizers, especially nitrogen, are combined with fertilizers, they reduce soil acidification and improve nutrient buffering capacity and nutrient release. In addition, cow dung plays an important role in maintaining the nutritional status of plants [51].

A solution to the problem - Biofertilizer

There are a lot of helpful soil microbes that help plants absorb nutrients. Human intervention can increase their effectiveness by choosing effective species, cultivating them, and adding them to soils directly or using them to treat seeds. Cultured microorganisms blended with a carrier material for simple handling, long-term storage, and easy application in the field [25]. Hence, the search for an affordable, environmentally responsible, and long-lasting method of enhancing plant growth and yield led to the development and usage of biofertilizers.

What is biofertilizer?

Biofertilizers are microbial inoculants that, when applied to soil, plants, or seeds, promote plant growth and development by increasing the supply of vital nutrients or chemicals that promote plant growth and soil fertility. The most common groups of microbes used for inoculant production are arbuscular mycorrhizal (AM) fungi, PGPR, and nitrogen-fixing rhizobia. These microbes play an important role in soil ecosystem functions such as nutrient richness restoration and preservation, nitrogen fixation, nutrient solubilization and mobilization, phytohormone production, microbial community diversification, and soil physicochemical property improvement [50,52].

Organic farming and sustainable agriculture practices frequently use bio-fertilizers due to their numerous benefits, which include increased crop yields, improved health and fertility of the soil, reduced environmental pollution, and enhanced plant resistance to diseases and pests. The use of bio-fertilizers also promotes sustainable agriculture practices and helps reduce reliance on synthetic fertilizers, which can have negative environmental and human health effects [28].

Biofertilizer technology has recently gained popularity among agronomists and soil scientists due to its numerous advantages, particularly in sustainable agriculture. Argentina, Canada, China, Europe, India, and the United States are driving the global biofertilizer market. These countries have realized the benefits of biofertilizers and are actively promoting their use, resulting in a well-established biofertilizer market [50,52].

What is the need for using biofertilizers?

The application of biofertilizers can help restore soil fertility. Long-term use of chemical fertilizers degrades soil quality and reduces crop yield. The nitrogen content of the soil is increased by using biofertilizer. PSB biofertilizer improves soil phosphorus availability. Azolla and BGA biofertilizers reduce the toxic effects of fertilizers and pesticides while also controlling soil salinity. Biofertilizer improves soil fertility, soil health, and crop yield by improving the physical, chemical, and biological properties of soil. They also aid in the growth and survival of other beneficial microorganisms. Biofertilizer also gives protection against a variety of soil-borne diseases and pests. They act as a buffer against rapid pH changes in the soil and increase the amount of available P, Zn, and Fe [29].

Types of biofertilizers on the basis of microbes

Microbial fertilizers are categorized into various types depending on their function and mode of action. Nitrogen-fixing agents (N-fixing agents), potassium-solubilizing agents (K-solubilizing agents), phosphorus-solubilizing agents (P-solubilizing agents), and plant growth-promoting rhizobacteria (PGPR) are the most commonly used microbes as biofertilizers. The presence of microbes in soil is determined by the physical and chemical properties of the soil, the organic matter and phosphorus content of the soil, and the cultural activity of the soil [45,52].

Nitrogen fixing biofertilizer

Nitrogen is the limiting trophic factor for plant growth. Although 80% of the nitrogen in the atmosphere is free, most plants are unable to utilize it. So, inert N2 is transformed into a plant-usable organic form by biological nitrogen fixers. Each year, about 175 × 10^6 tonnes of nitrogen are fixed globally by nitrogen-fixing bacteria [18]. Nitrogen fixation can provide 300-400 kg N/ha/year and increase the crop yield by 10-50%. 25% of total nitrogen in plants comes from N-fixation [45]. Nitrogenous biofertilizers help increase crop productivity by increasing BNF, the availability or uptake of nutrients, and stimulating plant growth through hormonal action or antibiosis [18]. N2 colonizers are divided into commensal organisms such as free-living bacteria (*Azotobacter* and *Azospirillium*), Cyanobacteria, *Rhizobium, Frankia*, and *Azolla* [45,47,52].

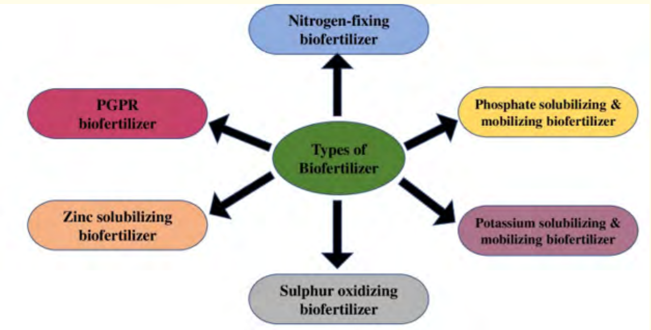

Figure 2: Types of biofertilizer.

Phosphate solubilizing and mobilizing biofertilizer

Phosphorus is crucial for plant growth and development, but it is the least mobile nutrient and is often present in insoluble forms in the soil. However, phosphate solubilizing bacteria (PSB) can convert these insoluble forms into soluble ones by producing organic acids, chelation, and ion exchange reactions. The phosphate solubilizing activity of PSB is 1-50%, and that of fungi is only 0.1-0.5%. PSB also protects the plant from a variety of diseases by synthesizing the enzyme that kills the pathogens [47,52]. The well-known phosphate-solubilizing bacteria are from the genera *Pseudomonas, Bacillus, Rhizobium, and Enterobacter*, and the fungi are from *Penicillium* and *Aspergillus*. Phosphate-mobilizing microbes can mobilize the immobile forms of phosphorous from the soil layers to the root cortex. The best example of phosphate-mobilizing fungi is arbuscular mycorrhiza. Sometimes PSB acts as phosphate mobilizers [45].

Potassium solubilizing and mobilizing biofertilizer

The second most common and most important phytonutrient after nitrogen and phosphorus is potassium. Only 1-2% of K is available to plants; the rest is present as mineral K that cannot be taken up by plants. So, continuous replenishment of the K is required. The plants will grow slowly, have poorly developed roots, and produce small seeds and low yields if K is not supplied in adequate quantity. To solubilize insoluble K into soluble forms, a variety of mechanisms are utilized by microbes, such as the production of acids, chelation, acidolysis, complexolysis, and exchange reactions. *Bacillus* and *Aspergillus niger* are examples of potassium-soluble microorganisms. They can also act as potassium mobilizers [45]. *Bacillus pseudomycoides*, a potassium-solubilizing strain, improved K uptake in tea plants grown in mica waste-treated soil by increasing potassium availability [48].

Sulphur oxidizing biofertilizer

Plants require one-tenth the amount of sulphur (S) as nitrogen (N). Sulphur is required for many plant growth functions, such as nitrogen metabolism, enzyme activity, and protein and oil synthesis. Because sulphur is immobile in the plant, a constant supply of sulphur is required from crop emergence to crop maturity. Sulphur deficiency can result in lower yields at any stage of growth. Sulphur-deficient plants typically have short and/or spindly stems, as well as yellowing of the young (top) leaves [30]. Sulphur, in low amounts, is also used as a buffering agent in places with high pH values. Sulphur-oxidizing microbes such as *Thiobacillus* spp., *Thiobacillus thioparous*, and *T. thioxidans* can oxidize sulphur to plant-usable sulfates. The reduced form of sulphur pollutes the environment so Sulphur oxidizing microbes cause the biological elimination of sulphur pollution and thus play significant roles in environmental protection [45].

Zinc solubilizing biofertilizer

Zinc is an essential micronutrient required for plant growth and reproduction at relatively low concentrations (5-100 mg/kg). An imbalance in fertilizer application, intensive agriculture practices, and poor soil health can lead to zinc deficiency in plants. It causes stunted shoot growth, reduced membrane integrity and leaf size, chlorosis, and increased susceptibility to light, heat, and fungal infections, as well as affecting grain yield, root development, pollen formation, and water uptake and transport [45]. Microbes such as *Mycorrhiza, Saccharomyces* spp., *Pseudomonas* spp., and *Bacillus* spp. are reported to increase Zn availability in soil by solubilizing complex forms of zinc with chelated ligands and oxidoreductive systems. Moreover, they create phytochromes, antibiotics, vitamins, and antifungal compounds, all of which benefit the plant in various ways. Rice plants inoculated with a suitable combination of Zn-solubilizing bacterial strains, increased growth attributes and rice yield and were found to be more efficient in acquiring Zn from the soil than non-inoculated plants [45]. In a recent study, it was reported that biofertilizers containing Zn-solubilizing bacteria boost maize production [32].

PGPR biofertilizer

PGPR are bacteria found in the rhizosphere that inhabit plant roots and promote plant growth and development in various positive ways. They promote growth by various direct mechanisms such as increased nutrient uptake, phosphate and potassium solubilization, exopolysaccharide and phytohormones production, fixation of Nitrogen, and Indirect mechanisms such as the production of siderophore, HCN, Antibiotic, lytic enzymes, and Induced systemic resistance [52]. *Agrobacterium, Arthrobacter, Alcaligenes, Azotobacter, Acinetobacter, Actinoplanes, Bacillus, Frankia, Pseudomonas, Rhizobium, Micrococcus Streptomyces, Xanthomonas, Enterobacter, Cellulomonas, Serratia, Flavobacterium, Thiobacillus*, and other genera are represented in PGPR [48,52].

Method for the production of biofertilizer

Composting is an effective method for preparing biofertilizers at the personal use level, but at the production scale, it may or may not be effective, so the need for a scalable method for biofertilizer production is required. Biofertilizer production is economical and straightforward as compared to chemical fertilizers. Microbial strains, formulation type, carrier materials, and field applications are the key factors that must be considered during biofertilizer production [50].

Biofertilizers are usually prepared as carrier-based inoculants, which enable easy handling, long-term storage, and high effectiveness of biofertilizers. Carrier material should be sterilized to remove contamination so that a high number of inoculant bacteria can survive on it for a longer period of time. Sterilization could be done by gamma irradiation or autoclaving [43].

The standardization of the process of commercial production of biofertilizers should be done after considering the six steps below:

- The first step is to isolate, identify, and functionally characterize potentially active and non-toxic microbes that can promote plant growth. Microbial strains are usually isolated from their natural habitats, such as bulk soil, the rhizosphere, or plant tissues (leaves, stems, roots, seeds, and flowers). The microbial strains' functional characterization is carried out using general laboratory techniques such as differential culture media or qualitative testing [50].
- In the second step, based on the desirable functions of biofertilizers in the field, such as nutrient solubilization and mobilization, nitrogen fixation, phytohormone production, or a combination of these functions, the selection of a pure culture of the target strain(s) is undertaken. The suitability of the chosen strain(s) is further tested *in vitro*, including growth on selective media and quantitative testing to determine potency. Before field tests and application, the strains are put to the test in a greenhouse experiment as part of the selection phase to gauge their effectiveness [50].
- The third step involves the selection of suitable carrier materials for the formulation of liquids or carrier-based materials such as granular, powder, or slurry. The carrier is critical for keeping the microbes alive and in an appropriate quantity [50]. Compost, biogas slurry, crushed corn cobs, biochar, peat, zeolite, perlite, lignite, talc, etc. are used as carriers. Various types of vegetative waste, plant remains, or animal excretory waste can also be used as carrier materials.
- The fourth step entails selecting a viable propagation method for the cultivation and multiplication of the selected strain(s) in the laboratory under optimal conditions in order to preserve the inherent properties of the microbial strains for effective field performance [50]. Monitoring the microbial growth profile under various conditions yields optimal conditions. Typically, strain multiplication is accomplished through the use of a traditional fermenter system [62].
- The fifth step includes creating different product formulations and testing them. This step ensures that the best type of product is chosen for efficient field performance [50].
- In the last step, the formed product was tested in the field on a large scale to determine the actual efficiency and limitations of the product under diverse ecological regions and conditions before the formulation of a standardized method for commercial production [50].

Plant growth promoting rhizobacteria (PGPR)—The eco-friendly and sustainable soil microbes

The word "rhizosphere" was initially used by Hiltner to refer to the region of microbial activity around roots. The plant rhizosphere, the thin zone of soil around the developing plant root system, is a hotspot for soil microbial activity. The rhizosphere is home to a variety of microbial taxa, including both prokaryotes (archaea, bacteria, and viruses) and eukaryotes (fungi, oomycetes, nematodes, protozoa, algae, and arthropods), with bacteria and fungi being the most numerous species. PGPR are free-living soil bacteria that live in the rhizosphere, actively colonizing plant roots and promoting plant development [27].

Various PGPR strains can improve seedling emergence, stimulate nodulation in legumes, display biocontrol, increase resistance to foliar diseases, and increase crop yields. The following genera included in PGPRs that have been reported are *Acinetobacter, Aeromonas, Alcaligenes, Arthrobacter, Azospirylium, Azotobacter, Azoarchus, Bacillus, Beijerinchia, Burkholderia, Clostridium, Enterobacter, Erwinia, Flavobacteirium, Gluconacetobacter, Klebsiella, Pseudomonas, Serratia, and Rhizobium* [27].

Characteristics of an ideal PGPR

Strains are considered putative PGPRs if they have specific plant growth-promoting properties and can promote plant growth upon inoculation. An ideal PGPR strain should meet the following criteria:

- It must be very friendly to the rhizosphere and the environment.
- It should colonize the roots of a significant number of plants at the time of inoculation.
- It should be able to promote plant growth.
- It should have a wide spectrum of activity.
- They must be compatible with other bacteria in the rhizosphere.
- They must withstand physical and chemical factors such as heat, dryness, radiation, and oxidants.
- They should be more competitive against existing rhizosphere bacterial communities [15].

Direct effects of PGPR

Biological nitrogen fixation

Nitrogen is well known as an important nutrient essential for plant growth and development. In the past decade, the use of PGPR for sustainable and environmentally friendly agriculture has increased significantly in different regions of the world. Microorganisms are gaining importance in agriculture to facilitate the cycling of plant nutrients and reduce the need for chemical fertilizers. Rhizosphere-associated N-fixing bacteria are increasingly used in non-legume species such as sugar beet, sugar cane, rice maize, wheat, etc. [27]. The nif and fix genes are involved in symbiotic nitrogen fixation and the symbiotic effectiveness of different legumes varies depending on the host and rhizobial strains. It is estimated that 100-175 million metric tons of nitrogen are fixed through the biological nitrogen fixation process, in which SNF contributes 70 million metric tons annually or 24 to 584 kg N per hectare per year [63]. PGPRs and endophytes such as *Enterobacter, Klebsiella, Burkholderia, and Stenotrophomonas* have recently received attention for their important crop relevance and their potential to enhance plant growth. Several greenhouse and field experiments have repeatedly shown the transmission of *Azospirillum species*. For example, when compared to the non-inoculated control, Rhizobium strain CHB1121 dramatically increased the number of nodules per plant by 42.9% [40]. Successful application of PGPR, when used as a fertilizer, requires consideration of strain, soil type, climate, development of appropriate formulations, and field trial strategies [27].

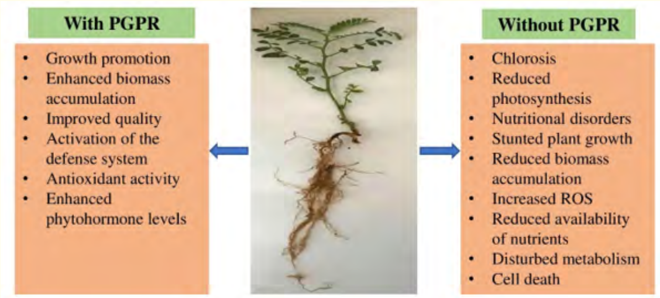

Figure 3: Effects on Plant growth with and Without PGPR.

Along with nitrogen, phosphorus is one of the main nutrients limiting plant growth. PSB was also present in the soil rhizosphere which converts insoluble phosphate into soluble forms through acidification, chelation, exchange reactions, and the production of gluconate [45]. The plant growth-promoting effects of two Bacillus strains *OSU-142* (N-fixing) and *M3* (N-fixing and phosphate-solubilizing), alone or in organically grown Primocane fruit raspberries reported that plant biomass was increased in *Serratia marcescens EB 67* and *Pseudomonas CDB 35* in both greenhouse and field conditions [36]. Seed treatments with *EB 67* and *CDB 35* also increased grain yield in field maize by 85 and 64%, respectively, compared to unvaccinated controls**.** First described as PSB after confirming its ability to solubilize significant amounts of tricalcium phosphate in the medium by secretion of organic acids reported that *Mesorhizobium mediterranean* strain PECA21 could efficiently mobilize phosphorus from barley and chickpeas when tricalcium phosphate was added to the soil [33,47,52].

Plant growth regulators

Multiple stages of plant growth and development, like cell Division, cell elongation, tissue differentiation, and apical dominance are controlled by plant hormones, especially auxins, and cytokinin. Biosynthesis and the mechanism of action of auxins and cytokinins have been the subject of intensive investigation. Auxins and cytokinins can be synthesized by both plants and microorganisms. Although the role of plant hormone biosynthesis by microorganisms is unknown**.** In the full description, a direct mechanism of plant growth via PGPR has been found to be involved. Production of phytohormones such as auxin, cytokinin, and GA, and reduction in plant ethylene levels [36,49].

Effects on plant growth

In recent decades, the response to agriculturally important crops has increased. PGPR inoculation has been studied in numerous fields, and greenhouse trials have been conducted in various countries. Based on the data provided, it was concluded that PGPR vaccination can influence plant growth and yield in a variety of ways to enhance nutritional benefits. Reproductive growth has been documented in many crops, such as cereals and maize. Treatment with PGPR increased germination rate and seedling growth strength, emergence, plant stand, root and shoot growth, total plant biomass, seed weight, early flowering, grain, forage, and fruit yields, etc. [14].

Nutrient uptake

One of the recent applications of PGPR is for increasing yield and eco-friendly production of crops. Spraying of PGPR strains *Pseudomonas BA-8* and *Bacillus OSU-142* on the flower and leaf of apple trees significantly increased yield per stem cross-sectional area. Therefore, the combination of *Bacillus M3* and/or *OSU-142* and/or *Microbacterium FS01* may increase the yield and growth of apple trees [36]. *Pseudomonas BA-8*, *Bacillus OSU-142*, and *M3* improved shoot length, yield, and fruit quality in apricot, sweet cherry, and raspberry suggesting that greenhouse inoculation with PGPR increased sugar beet root weight, leaf, root, and sugar yields increased by 15% from bacterial inoculation [31,55].

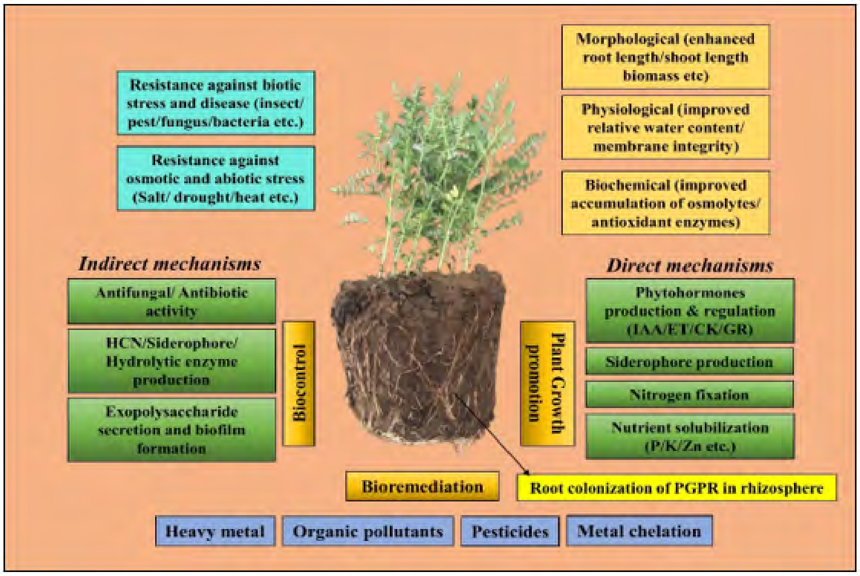

Figure 4: Direct and Indirect effects of PGPR.

Indirect effects of PGPR

- Induced systemic resistance
- Suppression of Plant Diseases, Insects, and Nematodes by PGPR
- Bacterial plant diseases
- Fungal plant diseases
- Viral plant diseases
- Nematodes

Recently, biological control has been viewed as an alternative strategy for controlling soil-borne plant diseases. The available literature has demonstrated the positive effects of specific rhizobia strains on the growth of many plant species in soils where more or less defined pathogens cause significant loss. For this reason, some rhizobacteria have been widely used as biological agents to control many soil-borne plant pathogens. Plant-root-inducible rhizobia are thought to spread systemically within the plant and generate signals that enhance the ability of distant tissues to defend against subsequent infection by pathogens [32]. Thus, ISR extended the protective effects of PGPR from the antagonistic activity against soil-borne pathogens in the rhizosphere to protective stimulatory effects on the surface of soil tissue against leaf pathogens. ISR appears to be phenotypically similar to SAR [49]. This is a phenomenon in which, once a plant is infected with a pathogen and can effectively resist it, it becomes more resistant and, in some cases, even resistant to subsequent challenges with the pathogen. The same as other pathogenic insects. However, ISR is only one of the mechanisms that can be recruited to combat plant pathogens in an environmentally friendly and sustainable manner. Integrating ISR-inducing PGPR in combination with other strategies into disease control programs is an approach worth considering. Control of Plant Diseases, Insects, and Nematodes by PGPR Biocontrol is the process of maintaining pathogenic organisms at low inoculum densities or controlling or eradicating them with beneficial organisms. Elimination or eradication of diseases from production areas, strong chemical agents, or biological control of plant diseases have all been proposed to protect plants from fungal pathogens. Recently, PGPR has become more widely used for the biological control of fungal diseases [9,36].

Here is a list of examples of plant growth-stimulating plant hormones produced by PGPR: shown in Table 1.

Phytohormones	PGPR	References
Gibberellin	*Rhodobacter sphaeroides* EU410423	Kang and Imran., *et al.* (2022)
	Bacillus pumilis	Kaloterakis and van Delden., *et al.* (2021)
	Bacillus ceres	
	Bacillus macroides	
IAA	*Pseudomonas* spp.	Saif and khan., *et al.* (2018)
	Bacillus sp., B. sonorensis, B. cereus, B. subtilis, Brevibacillus sp. B. safensis, B. paramycoides, Bacillus sp., B. cereus B. tequilensis	Saleem and Iqbal., *et al.* (2021)
	Burkholderia spp.	Dashti and Al-Sarraf., *et al.* (2021)
ACC	*Pseudomonas frederiksbergensi (DR5)*, *Enterobacter soli,* *Pseudomonas fluorescens,* *Achromobacter ruhlandii,* *Pseudomonas corrugata* *Enterobacter soli*	Duan and chen., *et al.* (2021) Martynenko and Arkhipova., *et al.* (2022)
Cytokinin	*Pseudomonas fluorescens G20-18*	Mekureyaw and Pandey., *et al.* (2022)
	Paenibacillus polymyxa strain B2	Daud and Rosli., *et al.* (2019)

Table 1: Of plant growth-stimulating plant hormones produced by PGPR.

Application of carrier-based biofertilizer under biotic and abiotic stress

Plant stress is defined as an external factor that affects growth, development, or productivity. Due to their immobile structures, plants are constantly exposed to environmental stress. It causes a variety of events, including changes in cell metabolism, gene expression, growth rate, and crop yield. Plants have evolved effective strategies and mechanisms to cope with environmental stress. Stress response mechanisms contribute to stress tolerance at various morphological, biochemical, and molecular levels. Plant stresses are summarised in two important types i.e. 'abiotic' and 'biotic' stress [44,47].

Biotic stress

Biological factors include microbial (fungal, bacterial, and viral) infections and animal attacks. Biotic and abiotic stresses have been shown to reduce average plant productivity by 65-87%, depending on the plant type [59]. Viruses, bacteria, fungi, nematodes, insects, arachnids, and weeds are known organisms that cause biological stress in plants. Organisms that cause biological stress can cause plant death by directly depriving the host of nutrients. Biological stress is of great importance in agriculture because of pre and post-harvest losses. In general, biological stresses from biting insects and viral infections affect photosynthesis and reduce the rate of photosynthesis [44]**.** An increased abundance of pests and pathogens in nature can be caused by climate change. For example, elevated temperatures are known to facilitate the spread of pathogens. At the same time, many abiotic stress conditions weaken plant defense mechanisms, thereby increasing susceptibility to pathogenic infections [52].

Abiotic stress

Nature is sensitive to balance but the absence or deviation from the normal occurrence of these conditions causes stress to ecosystems and threatens the well-being of organisms.

It is one of the fundamental abiotic components of the agroecosystem that it affects.

These abiotic stresses affect not only plants but also microorganisms. Abiotic stressors, or environmental factors such as drought, heavy metals [60], cold, heat, salinity [60], and malnutrition, are among the factors that reduce agricultural productivity [44,47].

Solution to stresses

PGPR are essential microbes with the unique ability to, directly and indirectly, support plant health. To survive in the rhizosphere, these microbes expanded their biological activities, which influence plant survival and growth. A number of these microbes, along with the enzyme machinery required for the breakdown of plant exudates, can protect the plant from stress caused by water scarcity and salt pollution. Deaminase enzyme, plant hormone indole acetic acid, production of siderophore**,** phosphate solubilizing enzyme, salicylic acid**,** and releasing microbiocidal/ biostatic enzyme [27,44].

Conclusion

By reviewing the literature, it can be said that chemical fertilizer has a very bad impact on the environment since it pollutes the environment, threatens human health, and depletes the natural soil. Vegetative waste is a reliable source of nutrients and other additives that support the growth of microorganisms. Producing biofertilizer from this vegetative waste and cow dung is like fulfilling two objectives at once because the environmental effects of its accumulation might be detrimental. Additionally, it aids in supplying the country's food demands and advances the green revolution by boosting crop yield. Chemical fertilizers can be replaced with biofertilizers, by inoculating PGPR consortia. PGPR aids in plant growth by solubilizing phosphate, boosting plant disease resistance, raising crop yields, and improving plants' ability to absorb nutrients. The productivity of plants is reduced by 65-85% under biotic and abiotic stress situations. In addition to producing the plant hormone indole acetic acid, siderophores, and microbiocidal enzymes that aid in the growth and development of the plant. Additionally, it has been reported that tomato plants treated with *Azotobacter* species, *Nitrobacter* species, and *Nitrosomonas* had higher values for all growth parameters measured, including plant height, stem width, root length, and internode of the plant, compared to control plants that received no inoculant treatment.

Bibliography

1. Abo-Elyousr KA and Mohamed HM. "Note biological control of Fusarium wilt in tomato by plant growth-promoting yeasts and rhizobacteria". *The Plant Pathology Journal* 25.2 (2009): 199-204.
2. Agriculture budget report 2022; agriculture and food management; from food security to nutritional security.
3. Akgül D S and Mirik M. "Biocontrol of Phytophthora capsici on pepper plants by Bacillus megaterium strains". *Journal of Plant Pathology* (2008): 29-34.
4. Akhtar M S and Siddiqui Z A. "*Glomus intraradices*, *Pseudomonas alcaligenes*, and *Bacillus pumilus:* effective agents for the control of root-rot disease complex of chickpea (*Cicer arietinum* L.)". *Journal of General Plant Pathology* 74 (2008): 53-60.
5. Akhtar M S and Siddiqui Z A. "Use of plant growth-promoting rhizobacteria for the biocontrol of root-rot disease complex of chickpea". *Australasian Plant Pathology* 38 (2009): 44-50.
6. Alam MS., *et al*. "Grain yield and related physiological characteristics of rice plants (Oryza sativa L.) inoculated with free-living rhizobacteria". *Plant Production Science* 4.2 (2001): 126-130.
7. Alexander M. "Introduction to soil microbiology". Wiley, New York (1977).
8. Aliye N., *et al*. "Evaluation of rhizosphere bacterial antagonists for their potential to bioprotect potato (*Solanum tuberosum*) against bacterial wilt (*Ralstonia solanacearum*)". *Biological Control* 47.3 (2008): 282-288.
9. Altindag M., *et al*. "Biological control of brown rot (*Moniliana laxa* Ehr.) on apricot (*Prunus armeniaca* L. cv. *Hacıhalilog˘lu*) by Bacillus, Burkholdria, and Pseudomonas application under in vitro and in vivo conditions". *Biological Control* 38 (2006): 369-372.
10. Amir H G., *et al*. "Enhancement in nutrient accumulation and growth of oil palm seedlings caused by PGPR under field nursery conditions". *Communications in Soil Science and Plant Analysis* 36.15-16 (2005): 2059-2066.
11. Andreoglou F I., *et al*. "Influence of temperature on the motility of Pseudomonas oryzihabitans and control of Globodera rostochiensis". *Soil Biology and Biochemistry* 35.8 (2003): 1095-1101.
12. Antoun H and Prévost D. "Ecology of plant growth promoting rhizobacteria". *PGPR: Biocontrol and Biofertilization* (2006): 1-38.
13. Arshad M., *et al*. "Inoculation with Pseudomonas spp. containing ACC-deaminase partially eliminates the effects of drought stress on growth, yield, and ripening of pea (*Pisum sativum* L.)". *Pedosphere* 18.5 (2008): 611-620.
14. Bashir T., *et al*. "Plant growth-promoting rhizobacteria in combination with plant growth regulators attenuate the effect of drought stress". *Pakistan Journal of Botany* 52.3 (2020): 783-792.
15. Basu A., *et al*. "Plant growth promoting rhizobacteria (PGPR) as green bioinoculants: recent developments, constraints, and prospects". *Sustainability* 13.3 (2021): 1140.
16. Chandini K R., *et al*. "The impact of chemical fertilizers on our environment and ecosystem". *Chief Ed* 35 (2019): 69.
17. Dabhi J., *et al*. "Bioremediation of Heavy Metals: A brand New Methodology to Sustainable Agriculture". *International Journal of Innovative Research in Science, Engineering, and Technology* 10.6 (2021): 6031-6049.
18. Daniel AI., *et al*. "Biofertilizer: the future of food security and food safety". *Microorganisms* 10.6 (2022): 1220.
19. Dashti N., *et al*. "Isolation and characterization of novel plant growth-promoting rhizobacteria (PGPR) isolates from tomato (*Solanum lycopersicum* L.) rhizospherical soil: A novel IAA producing bacteria". *Kuwait Journal of Science* 48.2 (2021).
20. Daud NS., *et al*. "Paenibacillus polymyxa bioactive compounds for agricultural and biotechnological applications". *Biocatalysis and Agricultural Biotechnology* 18 (2019): 101092.
21. Duan B., *et al*. "1-Aminocyclopropane-1-carboxylate deaminase-producing plant growth-promoting rhizobacteria improve drought stress tolerance in Grapevine (*Vitis vinifera* L.)". *Frontiers in Plant Science* 12 (2021): 706990.
22. El-Ghamry A M., *et al*. "Organic Fertilizers Derived from Farm By-Products for Sustainable Agriculture. -A Review". *Journal of Soil Sciences and Agricultural Engineering* 10.12 (2019): 815-819.
23. Enebe MC and Babalola OO. "The influence of plant growth-promoting rhizobacteria in plant tolerance to abiotic stress: a survival strategy". *Applied Microbiology and Biotechnology* 102 (2018): 7821-7835.

24. Gaur VK., *et al*. "Assessing the impact of industrial waste on environment and mitigation strategies: A comprehensive review". *Journal of Hazardous Materials* 398 (2020): 123019.

25. Gupta K K., *et al*. "Current status of cow dung as a bioresource for sustainable development". *Bioresources and Bioprocessing* 3 (2016): 1-11.

26. Arcuri A and Hendlin Y H. "The chemical anthropocene: glyphosate as a case study of pesticide exposures". *King's Law Journal* 30.2 (2019): 234-253.

27. Hassan M K., *et al*. "The interactions of rhizodeposits with plant growth-promoting rhizobacteria in the rhizosphere: a review". *Agriculture* 9.7 (2019): 142.

28. https://agriculturistmusa.com/importance-uses-of-biofertilizers

29. https://vikaspedia.in/agriculture/agri-inputs/bio-inputs/bioinputs-for-nutrient-management/biofertilizers

30. https://www.ibef.org/industry/agriculture-india

31. https://www.saskatchewan.ca/business/agriculture-natural-resources-andindustry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-andnutrients/sulphur-fertilization-in-crop-production

32. Hussain A., *et al*. "Production and implication of bio-activated organic fertilizer enriched with zinc-solubilizing bacteria to boost up maize (*Zea mays* L.) production and biofortification under two cropping seasons". *Agronomy* 10.1 (2019): 39.

33. Ibiene A A., *et al*. "Plant growth promoting rhizobacteria (PGPR) as biofertilizer: Effect on the growth of Lycopersicum esculentus". *Journal of American Science* 8.2 (2012): 318-324.

34. Kaloterakis N., *et al*. "Silicon application and plant growth promoting rhizobacteria consisting of six pure Bacillus species alleviate salinity stress in cucumber (*Cucumis sativus* L)". *Scientia Horticulturae* 288 (2021): 110383.

35. Kang S M., *et al*. "Growth and Photosynthetic Characteristics of Sesame Seedlings with Gibberellin-Producing *Rhodobacter sphaeroides* SIR03 and Biochar". *International Journal of Plant Biology* 13.3 (2022): 257-269.

36. Kaymak HC. "The potential of PGPR in agricultural innovations". *Plant Growth and Health Promoting Bacteria* (2011): 45-79.

37. Kumar R., *et al*. "Chapter-5 the impact of chemical fertilizers on our environment and ecosystem". *Chief Ed* 35 (2019): 69.

38. Maji S., *et al*. "Agricultural waste: Its impact on environment and management approaches". *Emerging Eco-Friendly Green Technologies for Wastewater Treatment* (2020): 329-351.

39. Martynenko E., *et al*. "Effects of phytohormone-producing rhizobacteria on casparian band formation, ion homeostasis and salt tolerance of durum wheat". *Biomolecules* 12.2 (2022): 230.

40. Matse D T., *et al*. "Effects of co-inoculation of Rhizobium with plant growth promoting rhizobacteria on the nitrogen fixation and nutrient uptake of Trifolium repens in low phosphorus soil". *Journal of Plant Nutrition* 43.5 (2020): 739-752.

41. Mekureyaw M F., *et al*. "The cytokinin-producing plant beneficial bacterium *Pseudomonas fluorescens* G20-18 primes tomato (*Solanum lycopersicum*) for enhanced drought stress responses". *Journal of Plant Physiology* 270 (2022): 153629.

42. Mishra O P., *et al*. "Cow dung an undeciphered boon: An overview" (2020).

43. Mohammadi K and Sohrabi Y. "Bacterial biofertilizers for sustainable crop production: a review". *ARPN Journal of Agriculture and Biological Sciences* 7.5 (2012): 307-316.

44. Mumtaz M Z., *et al*. "Role of plant growth-promoting rhizobacteria in combating abiotic and biotic stresses in plants". In Microbial BioTechnology for Sustainable Agriculture Volume 1 (2022): 43-104.

45. Nosheen S., *et al*. "Microbes as biofertilizers, a potential approach for sustainable crop production". *Sustainability* 13.4 (2021): 1868.

46. Pahalvi H N., *et al*. "Chemical fertilizers and their impact on soil health". Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs (2021): 1-20.

47. Prajapati M., *et al*. "Rhizobacterial - Plant Interaction Approaches that Enhance Plant Growth Under Abiotic Stress". *Acta Scientific Agriculture* 6.5 (2022): 67-74.

48. Pramanik P., *et al*. "An indigenous strain of potassium-solubilizing bacteria Bacillus pseudomycoides enhanced potassium uptake in tea plants by increasing potassium availability in the mica waste-treated soil of North-east India". *Journal of Applied Microbiology* 126.1 (2019): 215-222.

49. Pratap Singh D and Prabha R. “Bioconversion of agricultural wastes into high-value bio compost: a route to livelihood generation for farmers”. *Advances in Recycling and Waste Management* (2017): 137.

50. Raimi A., *et al*. “Biofertilizer production in Africa: current status, factors impeding adoption and strategies for success”. *Scientific African* 11 (2021): e00694.

51. Raj A., *et al*. “Cow dung for eco-friendly and sustainable productive farming”. *Environmental Science* 3.10 (2014): 201-202.

52. Rochlani A., *et al*. “Plant Growth Promoting Rhizobacteria as Biofertilizers: Application in Agricultural Sustainability”. *Acta Scientific Microbiology* 5.4 (2022): 12-21.

53. Saleem S., *et al*. “Phytobeneficial and salt stress mitigating efficacy of IAA producing salt tolerant strains in *Gossypium hirsutum*”. *Saudi Journal of Biological Sciences* 28.9 (2021): 5317-5324.

54. Sapronova Z., *et al*. “Use of municipal vegetative waste as raw material for sorbent production”. In IOP Conference Series: Materials Science and Engineering 687.6 (2019): 066061.

55. Saraf MS., *et al*. “Production and optimization of siderophore from plant growth promoting Rhizobacteria”. Scholar press (2017): 1-85.

56. Shaikh NB., *et al*. “Rhizobacteria that Promote Plant Growth and their Impact on Root System Architecture, Root Development, and Function”. *Acta Scientific Microbiology* 5.4 (2022): 53-62.

57. Sharma S., *et al*. “Biofilm: Used as A Brand-new Technology in Bioremediation”. *Vidya; A Journal of Gujarat University* 16.2 (2021b): 9-116.

58. Sharma S., *et al*. “Phytomining of Heavy Metals: A Green Technology to Sustainable Agriculture”. *International Journal of Innovative Research in Science, Engineering and Technology* 10.6 (2021a): 7527-7538.

59. Sharma S., *et al*. “Salinity Management in Glycine Max L. Using Cytokinin from Rhizobacteria Isolated from Mines and Dump Sites”. *Current Trends in Biomedical Engineering and Biosciences* 20.5 (2022c): 556047.

60. Sharma S and Saraf M. “Isolation, Screening, and Biochemical characterizations with multiple traits of Heavy Metal Tolerant Rhizobacteria from Mining Area and Landfill site”. *Advances in Bioresearch* 13.1 (2022a): 147-156.

61. Sharma P and Badhan R. “Employment of agro waste to develop biofertilizer and its effect on *Solanum melongena* var. depressum cv. Pragati (Chu Chu)”. *International Journal of Agriculture and Plant Science* 2.3 (2020): 15-21.

62. Suthar H., *et al*. “Fermentation: a process for biofertilizer production. Microorganisms for Green Revolution: Volume 1”. *Microbes for Sustainable Crop Production* (2017): 229-252.

63. Swarnalakshmi K., *et al*. “Significance of plant growth promoting rhizobacteria in grain legumes: Growth promotion and crop production”. *Plants* 9.11 (2020): 1596.

64. Tavallali V., *et al*. “Zinc alleviates salt stress and increases antioxidant enzyme activity in the leaves of pistachio (Pistacia vera L. ‘Badami’) seedlings”. *Turkish Journal of Agriculture and Forestry* 34.4 (2010): 349-359.

65. Vij S and Mishra M RD. “Cow Dung for Sustainable Development”. *Elementary Education Online* 20.4 (2021): 2677-2677.