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A Review of Endophytes' Ability to Promote Plant Development on Medicinal Herbs

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Abstract: Countless microbes live in the bodies of animals and plants. Plant growth is aided by the interaction between microbes and plants. They can be used as bio-fertilizers because of their nutrient intake and nitrogen-fixing capacity. These bacteria produce important metabolites and secondary metabolites that can be used to treat cancer and other chronic human diseases. They play a key role in the decomposition of heavy metals in the soil. In other words, they have a positive impact on agriculture, medicine, biotechnology, and food science. Plant growth-promoting rhizobacteria (PGPR) are commonly used to improve the growth of a wide range of crops, such as seed germination, plant weight, and harvest yields. Plant development is triggered by PGPR colonization because bacteria produce plant hormones such as indole-3-acetic acid, cytokinin, and gibberellins, as well as enhanced mineral and nitrogen availability in the soil. They are also known to defend their host plants from harmful bacteria in some cases. The role of PGPR in connection to medicinal plants and their impact on the development of botanicals is an area where there is still a lot of research to be done. This review highlights the potential PGPR–medicinal plant interactions that could boost the medicinal plant's effectiveness, particularly in farmed plants. The significance of medicinal plant endophytic microbes for bioactive potentials.

Keywords: Endophytes, Plant growth-promoting rhizobacteria (PGPR), Medicinal plant, Bioactive compounds, Biocontrol

I. INTRODUCTION

There has been a lot of interest in plant-microbe interactions that support plant growth and health. For endophytic organisms, plants provide a vast array of niches. Among the microorganisms, endophytic bacteria occupy the internal tissues of plants without causing damage to their hosts. An understanding of the mechanisms enabling these microorganisms to interact with plants will be essential to fully realizing the biotechnological potential of efficient plant–bacterial partnerships for a range of applications (Wilson, 1995). Hence, a review of the work done on endophytic organisms is presented hereunder.

Endophytes are abundant and have been detected in all plant species studied so far, yet the majority of endophyte-plant relationships are unknown. Endophytes are endosymbionts that have existed within a plant for a long time, usually as bacteria or fungi. At least for a portion of its life, without causing visible symptoms. Because they spread similarly, horizontally transmitted endophytes are frequently connected to diseases. They are pathogenic bacteria, despite not being pathogenic themselves. Some of them are doable. Endophytes, on the other hand, are known to colonize a wide range of plant species. The word "endophyte" refers to bacteria and fungi that spend all or part of their lives in plant tissues and produce no visible diseases (Wilson, 1995).

Endophytes have been found in medicinal plants that protect their hosts against infectious agents while also allowing them to adapt and thrive. Under difficult environmental conditions, it's crucial to figure out what kind of endophyte we have. Many thousands of endophytes are thought to be beneficial to humanity, yet few scientists are working in this sector, and forests and other natural places Many valuable endophytes for healing diseases are being rapidly depleted, threatening biodiversity. Before they are identified, they may be irreversibly lost for therapeutic purposes (Monaghan *et al.*,1995). Due to the loss of host plants and air pollution, the microbial diversity in the forest is deteriorating. Climate change, rainfall, and overexploitation are all factors. Each year, hundreds of plant species disappear even before they are discovered. Because of their habitat, they have a scientific universe (Monaghan *et., al* 1995).

A. History and Definition of Endophytic Organism

The term endophyte was coined from the Greek words "endon" (inside) and "phyton" (plant). Endophytes are endosymbionts that live within a plant for at least part of its life cycle without producing illness. They are commonly bacteria or fungi. Endophytes are found all around the world. However, the majority of endophytes' and plant parasites' interactions are not fully understood (Hardoim *et al.*,2015).

Johann Heinrich Friedrich Link, a German botanist, was the first to describe endophytes in 1809. They were originally assumed to be plant-parasitic fungi, but were later reclassified by Beacham, a French scientist, who coined the term "microzymas." Plants were thought to be beneficial to one's health. Victor Galippe did not find bacteria until 1887, under sterile conditions. Plant tissues normally have normal cell viability. Johann Heinrich Friedrich Link, a German botanist, was the first to describe endophytes in 1809. They were originally assumed to be plant-parasitic fungi, but were later reclassified by Béchamp, a French scientist, who coined the term "microzymas." Plants were thought to be beneficial to one's health. Victor Galippe did not find bacteria until 1887, under sterile conditions. Plant tissues normally have normal cell viability (Hardoim *et al.*, 2015).

Bacterial endophytes have been studied for over a century. The presence of microorganisms in the tissues of healthy plants was discovered. It was first documented in 1926(Hallman *et al.*,1997). Endophytic growth is a stage in the life of bacteria that has been recognized. It is defined as an advanced stage of infection with a close relationship to Mutualistic symbiosis a partnership involving mutualistic symbiosis. Perotti was the first to do so in 1926. Henning and Villforth (1940) discovered bacteria in the water, leaves, stems, and roots of healthy plants. Microorganisms that can be separated from surface-sterilized plant parts are known as endophytes. Since the 1940s, several publications on endophytic bacteria have been published in various journals (Hallmann *et al.*,1997).

Among the various definitions for endophytic bacteria, those by Hallmann et al.(1997) appear to be the most appropriate. According to Hallmann (1997), all bacteria that may be discovered are considered endophytic bacteria. Surface-sterilized plant tissues that have been removed from within plants have no discernible negative impact on the host plants. This is a definition that covers both internal colonists who appear to be neutral and external colonists who appear to be hostile. Symbionts Bacteria that travel back and forth would also be included, throughout their endophytic relationship between the plant's surface and its inside phase. The endophyte's interaction with its host plant could be complicated (Hallmann,1997).

Bacterial endophytes are classified as "obligate" or "facultative" depending on their life strategies. Endophytes that are required to be present are called "obligatory endophytes." Their development and survival are reliant on the host plant, and vertical or vector-based transmission to other plants is possible. Facultative Endophytes have a stage in their life cycle where they live outside of their host. Plants that serve as hosts of Bacterial phytopathogens could be dangerous in the extreme. Because they are so common, they are classified as (facultative or obligatory) endophytes. In plants, in avirulent forms. Very virulent plant pathogens should be avoided. As a result, they will be classified as endophytes, whilst virulent variants of them will be classified as pathogens. Organisms should be excluded from the equation (Monaghan *et al.*,1995) (Ahemad *et al.*, 2008).

B. Transmission

Endophytes can be passed down either vertically (from parent to child) or horizontally (from offspring to parent) among individuals. Fungal endophytes that are transported vertically are usually fungal hyphae piercing the embryo within the host's body and are considered clonal, and they transmit via fungal hyphae penetrating the embryo within the host's body. The fungus reproduces through asexual conidia or sexual spores, while seeds are produced by sexual spores. Endophytes can spread horizontally between plants in a population or vertically between plants in a population. Vertical transmission is the technique through which endophytes are passed down from generation to generation via seeds (Abdelfattah, 2021). Mutualism between endophytes and plants is common. Endophytes largely assist the host plant's health and survival with difficulties such as pathogens and disease, as well as water stress, heat stress, nutrient availability, and poor soil quality, are all factors to consider. In exchange for herbivory and salinity, the endophyte receives carbon from the plant in exchange for energy. host. Plant-microbe interactions aren't always mutualistic; endophytic fungus, for example, can cause problems When a plant is stressed, diseases or saprotrophs emerge. Endophytes have the potential to become active and multiply in specific environmental circumstances or when their host plants are active. Endophytes get stressed or senesce, decreasing the amount of carbon available to them(Rai, 2016).

Endophytes may help host plants by avoiding the colonization of harmful or parasitic organisms. Endophytes can infiltrate plant tissues widely. Other possible infections will be pushed out as a result of the competition. Some bacterial and fungal endophytes have Plant growth and hardiness have both been shown to improve (Hardoim, 2008). Studies have discovered that endophytic fungi grow near the host plant cells of their host. Flattened or wedged fungal hyphae have been observed growing against plant cells. The growth pattern suggests that the fungal hyphae are firmly connected to the cells of the plant host. wall, but they don't get into plant cells. Endophytic fungal hyphae appear to proliferate at the same rate as endophytic fungal hyphae. within the intercellular gaps of the plant tissue, as their host leaves (Christens, 2008).

The presence of certain fungal endophytes in the meristems, leaves, and reproductive structures of their hosts has been demonstrated to significantly improve their hosts' permanence. As a result, the endophytic synthesis of secondary metabolites contributes significantly to survivability. Increased nutrition absorption and protection from herbivory According to research, endophytes have a key role in plant growth and development when used in experiments. Plants appear to rely more on their photosynthesis in low-light situations, and they appear to be more reliant on their photosynthesis. In these circumstances, endophytic symbionts (Davit, 2010).

C. Diversity of Endophytes

Bacterial endophytes have been discovered in every plant species examined so far. As a result, in the natural world, the endophyte-free plant is a rare occurrence. A plant that lacks the associated beneficial microorganisms would be less capable of dealing with the situation. Phytopathogens make them more vulnerable to stress. A variety of plant species have been found to have diverse endophytic bacterial communities. Reinhold-Hurek (2011) defines domineering as endophytes that are most typically found in the *Actinobacteria, Bacteroidetes,* and *Firmicutes* groups. *Bacillus, Burkholderia,* and *Microbacterium* are the most commonly isolated bacterial genera. Endophytic bacteria from the leaves of traditional medicinal plants have been found to have anti-phytopathogenic effects. Sixteen isolates from eight therapeutic plants were identified, with the most common being anti-phytopathogenic activity. The anti-phytopathogenic activity was tested on fourteen isolates. The results of 16S rRNA gene sequencing indicated the phylum Firmicutes. (Sykria *et al.,* 2019).

D. Types of Endophytic Bacteria

Bacteria (actinomycetes or mycoplasma) and fungus are the most common endophytic microbes found in plants. Endophytic bacteria live in the internal tissues of plants and play a role in their growth. It has a crucial role in promoting plant development and guarding off illness. Numerous species of gram-positive and gram-negative endophytic bacteria have been found in numerous plants. *Achromobacter, Acinetobacter, Agrobacterium, Bacillus,* and others are among them. *Brevibacterium, Microbacterium, Pseudomonas,* and other bacteria are examples. Endophytic Actinobacteria, Proteobacteria, and Firmicutes are the three major phyla of microorganisms (Zhao *et al*., 2015). The intermediate forms between fungi and bacteria are known as actinomycetes. They are members of the Actinobacteria phylum. *Streptomyces* is one of the most common bacteria. Hollants (2011) found that it can be isolated as an endophyte synthesis of bioactive metabolites.

Endophytic bacteria have been found to contain active chemicals such as munumbicins (A and B), daptomycin (A and K), cethromycin, tobramycin, kakadumycins (A and B), and kanamycins (Zhao *et al.*, 2015). *Mycoplasma* species are also found in the environment. Some red algae, such as Bryopsis, have been reported as endophytes with a symbiotic relationship. Endophytic fungi are divided into two groups: There are clavicipitaceous endophytes, which infect some grasses, and nonclavicipitaceous endophytes, which infect other grasses. endophytes, which come from nonvascular plants, ferns, and allies' asymptomatic tissues, angiosperms, and conifers (Jalgaonwala *et al*., 2011).

II. MEDICINAL PLANT and ENDOPHYTES

India is known as the "world's botanical garden" because it is the world's largest producer of medicinal herbs. Approximately 250000 medical practitioners are currently registered. In comparison, the Ayurvedic system has a population of roughly 700,000 people, and contemporary medicine has a population of about 700,000 people. 70% of the population in rural India relies on traditional medicine. Ayurveda is a conventional Indian medical system. Traditional medications are made from medicinal herbs, but herbal medications are made entirely of medicinal plants and do not contain any minerals or organic substances. The drugs were taken in the form of basic drugs such as tinctures, teas, and poultices. Herbal extracts, powders, and other herbal preparations (Balick and Cox, 1996).

Knowledge of the individual plants to be utilized and how they should be applied to specific illnesses was passed down. Medicinal plants constitute the "backbone" of traditional medicine, which is used daily by more than 3.3 billion people in developing nations. Medicinal plants are regarded as being rich sources of components that can be employed in a variety of products. Drug development and synthesis are two of the most important aspects of the pharmaceutical industry. Medicinal plants play a unique role in the human body. The evolution of human cultures all around the world The Indian subcontinent has a diverse range of cultures. In a wide range of environments, there is a tremendous diversity of plant species. There are around 8,000 species of higher plants that are considered. It is used as a medicinal plant by rural and tribal populations. Ayurveda is the name given to it, which has a lengthy and illustrious history (Davidson-Hunt, 2000).

In many countries, medicinal plants (MPs) are used in long-standing traditional medicine practices. Traditional medicine includes all procedures based on theories, convictions, and customs and the viewpoints of individuals from many cultures and time periods. It's frequently inexplicable and used to keep things running smoothly. Encourage disease prevention, detection, and treatment (Firenzuoli, 2007). MPs have become an important part of modern medicine, and they are now widely used. Atropine is employed as a source of chemical substances, either directly (e.g., atropine, morphine, etc.) or indirectly (e.g., aspirin semi-synthesis chemo-pharmaceuticals (e.g., acetylsalicylic acid, paclitaxel, etc.). Additionally, when it is proven that a specific MP extract has a Phyto complex, it is used. The pharmacological action of a group of chemicals differs from that of a single agent. constituents. At different times of the year, there was a substantial difference in the colonization frequencies of endophytic species, showing environmental influences such as the influence of rainfall and air humidity on the host plant (Vinu and Jayashankar, 2017). Murugeswaran investigated the main source of medicines in Unani medicine (Murugeswaran et al., 2015).

The survey was carried out in the forests of the Chamarajanagar Division of wildlife. There are around 119 different Unani medicinal herbs. There are 105 genera in 60 families. The herbs utilized in Unani medicine Arthritis, diarrhoea, dysentery, gastric ulcers, and headaches are just a few of the ailments that can be treated. Pain, inflammation, skin problems, stomach ailments, and urinary diseases, to name a few examples. According to Niranjan (2011), the BR Hills have a variety of medicinal plants, some of which are used by the Soliga tribe to treat various maladies. The medicine of the past One of the most important medicinal plants is Chlorophytum laxum, R. Br. In this location, the plant is known as "Bhoomi Sakkara," which means "earth sugar" in Soliga's language. Tribes from the Liliaceae family have been utilized to cure piles and other ailments. Soliga tribes use it as an astringent. The species is quickly disappearing from its natural habitat. Because the tubers' therapeutic value has been over-exploited Leaf samples yielded a total of 115 cultivable, colonizing bacterial isolates. In the northern part of the peninsular, samples of 72 different plant species were collected. The majority of the surface has been decontaminated (Niranjan 2011). Table I lists a few endophytic microbes that have been thoroughly investigated along with their host plant.

Table I Endophytes With Respect To Their Host Medicinal Plants

SR. NUMBER	MEDICINAL PLANT NAME	ISOLATED ENDOPHYTIC BACTERIA	REFERENCE
1.	Panax ginseng	*Micrococcus luteus and Lysinibacillus fusiformi*	Vendan *et al.*, 2010
2.	Lavanduladentata	*Variovorax sp.*	Pereira *et al.*,2016
3.	Teucriumpolium	*Bacillus cereus and Bacillus subtilis*	Hassan, 2017
4.	Panaxnotoginseng	*Bacillus amyloliquefaciens*	Hong *et al.*, 2018
5.	Curcuma longa	*Bacillus sp.*	Jaykumar *et al.*, 2019
6.	Euphorbia mili	*Citrobacter putida*	Khaksar *et al.*, 2016
7.	Caranthus roseus	*Achromobacter xylosoxidans*	Karthikeyan *et al.*, 2012
8.	Limonium sinense	*Glutamicibacter halophytocola*	Qin *et al.*, 2018
9.	Glycine max	*Streptomyces sp.*	Jaykumar *et al.*, 2019
10.	Alium tuberosum	*Streptomyces sp.*	Qin *et al.*, 2018

A. Isolation and Colonization of Endophytic Bacteria

Compared to bacteria in the rhizosphere or other bacterial pathogens generally, endophytic bacteria have lower population densities (Hallmann et al., 1997). There are many benefits to the endophytic specialism. The environment is shielded from bacteria that can colonise. These bacteria typically invade the intercellular space. They have been separated from the remaining parts of the plant, such as the seeds. Sugar beet and maize are two examples of such plants, which are distinguished from monocotyledonous and dicotyledonous plants. These plants include herbaceous crop species, species of oak and pear trees, and dicotyledonous and monocotyledonous plants. In-depth research has been done on the diversity of bacteria. After disinfecting plant surfaces with sodium nitrate, endophytes have focused on identifying the traits of isolates from internal tissues by incorporating different microbial techniques. Endophytic bacteria from various kinds of plants have been discovered in a variety of environments in plant tissue, where each gramme contains 102–104 live bacteria (Kobayashi *et al.*, 2000).

B. Advantages of endophytic bacteria for host plants

Plant growth-promoting rhizobacteria (PGPR) belong to the 4044 beneficial microorganisms that can be found in the biosphere, on the surface of roots, or in close proximity to them. They can help plants grow more quickly and defend them from abiotic and microbial threats. After being surface sterilised, endophytes—bacteria or fungi that reside in a plant's internal tissues—can be isolated from the plant and have no detrimental effects on the plant's growth. Because they live inside the roots and promote growth and activity, endophytes are effective inoculants. The plant tissues' intercellular spaces, which are rich in inorganic nutrients, amino acids, and carbohydrates, are where the endosymbiotic relationships take place. In general, PGPR works in three ways: by creating specific compounds for plants, by making it easier for plants to absorb certain nutrients from the soil, and by shielding plants from disease. The production of phytohormones like Indole 3 acetic acid (IAA) and gibberellic acid is known to promote plant growth (GA). The solubilization of insoluble phosphate; the potential plant growth-promoting properties of various endophytic bacteria. They encourage the growth of plants. Improved nutrient absorption and mineral cycling, including nitrogen, phosphate, and other elements. One of them is the solubilization of Phosphate. The production of siderophores and the synthesis of indole acetic acid are best known in contrast to endophyte activity. Important nutrients can also be supplied by plants that have endophytic organisms. In addition, a number of other endophytes have been linked to beneficial effects on plant growth, including osmotic modulation, stomatal regulation, modification of root morphology, increased mineral absorption, and changes in nitrogen metabolism and accumulation. IAA was discovered in the culture filtrate of Typha australis endophytes, with IAA present in seven out of ten endophytes. Endophytes can also increase plant growth in an effort to compete with pathogen-induced cell death (Hallmann, 2006). Endophytes' ability to digest xenobiotics, act as vectors, or display natural resistance to soil pollutants can benefit the plant's primary host. (Siciliano *et al*., 2001).

III. PLANT GROWTH PROMOTION THROUGH an INCREASE in NUTRIENT AVAILABILITY

A. Figure 1 illustrates the mechanism that endophytes have developed to support plant growth.

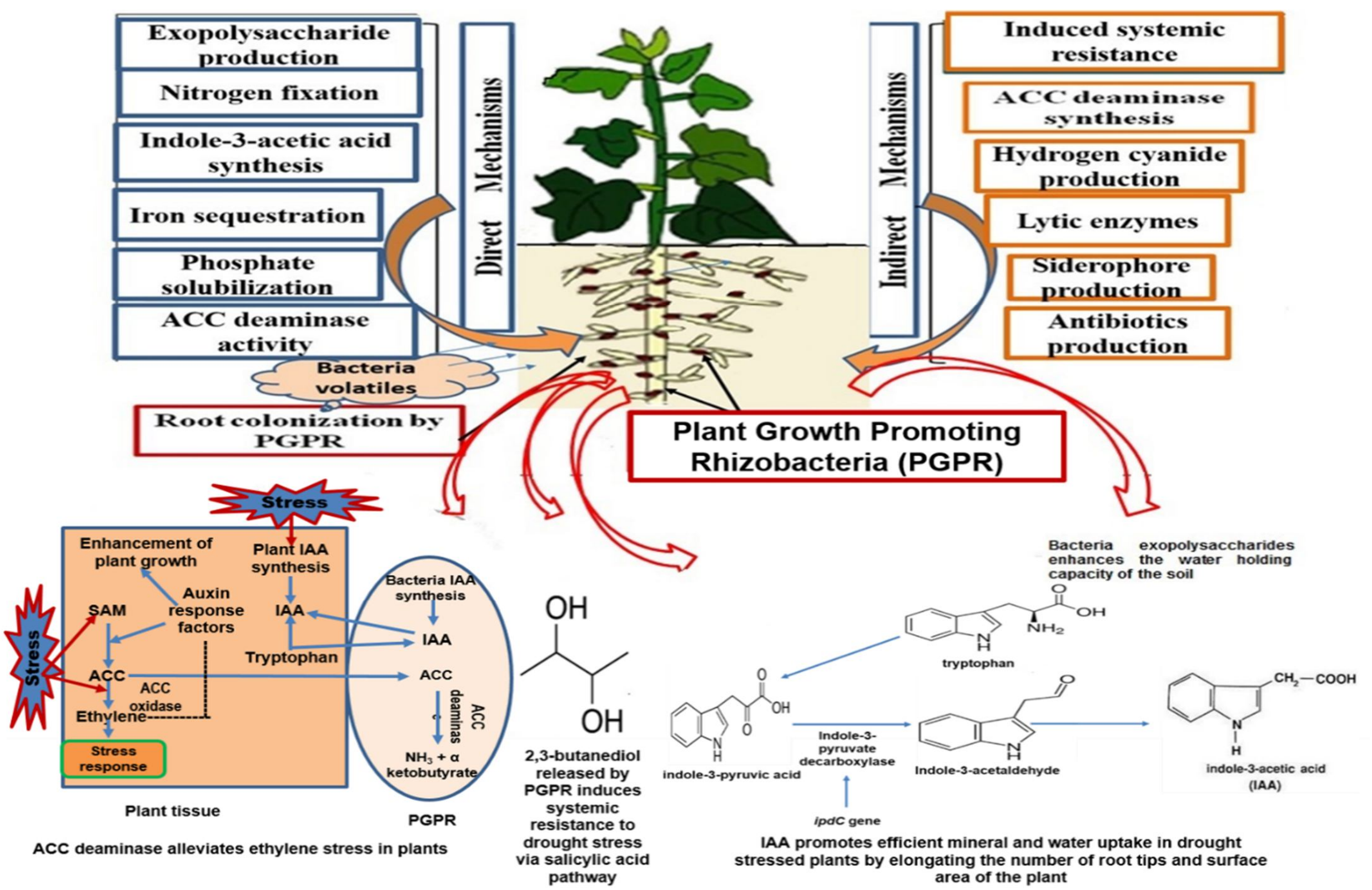

Fig. 1 The mechanism used by PGPR in alleviating plant growth promotion (omena *et al*., 2019)

The five areas in which PGPR improves the nutritional status of host plants are as follows: (1) biological nitrogen-fixing, (2) increased nutrient availability in the soil rhizosphere, (3) increasing root surface area, and (4) improving other favorable effects of symbiotic relationships with the host, and (5) a combination of the aforementioned forms of action. According to Vesey (2003) and Podile, plant nutrition can be improved by using PGPB and supplying specific nutrients to plants, particularly nitrogen, phosphorus, potassium, iron (Fe), and zinc (Zn) (Chung *et al*., 2005).

1) Biological Nitrogen Fixation

The most crucial nutrient for plant growth is nitrogen, which is needed for the synthesis of essential substances like amino acids and nucleic acids. Numerous scientists have provided descriptions of the capacity to fix nitrogen and increase nitrogen availability. Rhizospheres in soil, rhizoplanes, and the rhizosphere itself all contain PGPR (Vessey, 2003). The capacity to provide nitrogen to host plants through biological nitrogen fixation is known as PGPB, according to Dixon and Kahn (2004). Diazotrophic bacteria, which can transform air nitrogen into a form that plants can use, are currently carrying out one of the most important biological processes for plant growth. In 1988, *Acetobacter diazotrophicus*, an acid-tolerant nitrogen-fixing bacteria, made a connection with sugarcane and discovered that it provided a significant amount of nitrogen to the ecosystem. Nearly half of the fixed nitrogen can be excreted in a potentially useful form by the crop sugarcane. In 2002, bacteria including Azospirillum, Bacillus, Klebsiella, and others were isolated from the sugarcane rhizosphere and roots (France,2009). The biological nitrogen fixation process is shown in Figure II.

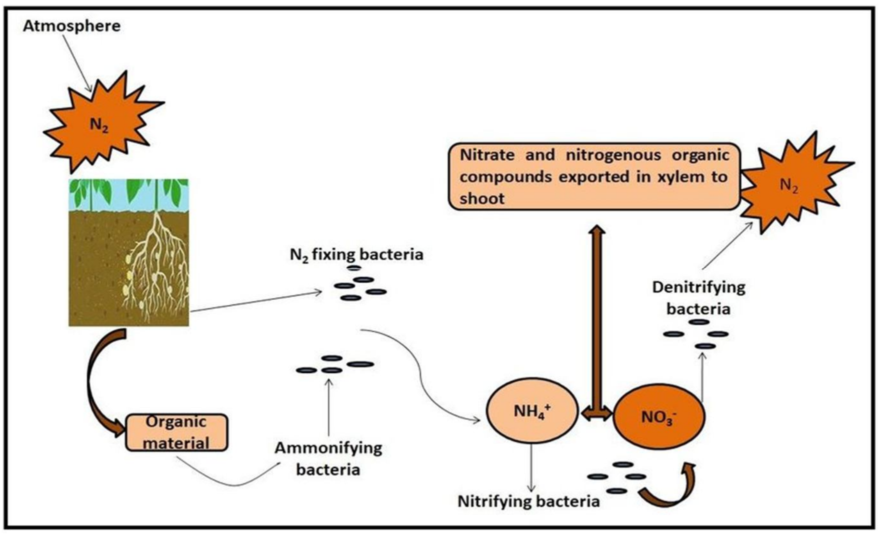

Fig. II biological nitrogen fixation (Babar, 2008)

The complex enzyme nitrogenase is made up of the Mo-Fe protein, also known as dinitrogenase protein, and the Fe protein, also known as dinitrogenase reductase protein. The dinitrogenase protein is a heterotetramer composed of two subunits with an overall molecular weight of 240kDa. Two different kinds of metal centers can be found in this protein: the P-cluster pair and the FeMo cofactor. Dinitrogen binds to the FeMo cofactor at its active site, and the P-cluster promotes electron transfer between the Fe protein and the FeMo cofactor. The dinitrogenase reductase protein is a homodimer with two identical subunits and a total molecular mass of about 60 kDa. There is one Fe4-S4 cluster and two ATP/ADP molecules.

To summarize the overall mechanism of action of nitrogenase, consider a crucial metabolic cycle with five phases:

a) The reduction of Fe protein by electron carriers like flavodoxin or ferredoxin;

b) The association of the reduced Fe protein (including two MgATP complexes) with the Mo-Fe protein in preparation for electron transfer;

c) The hydrolysis of MgATP, which allows the transfer of one electron to the Mo-Fe protein (via Fe4S4 and the P-cluster);

d) The transfer of electrons to dinitrogen and subsequently its reduction

e) Exchange of ATP back into the Fe protein, dissociation of the two protein molecules, and rereduction of the Fe protein.

The structure and function of the nitrogenase enzyme are encoded by twenty genes, collectively known as N-fixation genes (nif genes), which span a total of 24 kb and are organized in seven operons (nif cluster). These genes fall into the three categories of structural, regulatory, and supplemental genes or can be found on plasmids. The nifD and nifK genes code for the Mo-Fe protein, whereas the nifH gene yields the Fe protein. nifD, nifH, and nifK are referred to as structural nif genes because they are the genes that encode the aforementioned structural subunits. As a model for understanding nitrogenase enzyme regulation, synthesis, and assembly, the majority of nif genes have been studied in the nif cluster of the free-living bacterium Klebsiella pneumoniae (Babar, 2008).

2) Phosphate Solubilizing

The majority of agricultural soils contain phosphorus (P), a macronutrient that is necessary for plant growth and development but is insoluble and unavailable to plants, in insoluble forms. Recent research has revealed several phosphate-solubilizing bacteria. There are reports that the processes of acidification, release, and exchange, which make use of protons, siderophores, and hydroxyl ions as examples of organic acids, can change the state of P from the insoluble to the soluble state. In the rhizosphere, where they produce organic acids to dissolve the inorganic mineral phosphate, phosphate-solubilizing bacteria are frequently found (Bolan *et al*., 1994). In the soil's root and rhizosphere, Granada *et al*. (2013) found bacteria that can dissolve phosphate.

Phosphate-solubilizing bacteria that are associated with plants frequently belong to the genera Bacillus, *Pseudomonas*, *Rhizobium*, as well as *Enterobacter*, *Klebsiella*, *Salmonella*, *Agrobacterium*, *Micrococcus*, *Flavobacterium*, *Proteus*, *Burkholderia*, *Serratia*, and *Azotobacter*. An enzyme called phosphatase transforms both organic and inorganic phosphates in soil into a soluble form that plants can be utilized (Bolan *et al*., 1994).

The body contains more Ca3(PO4)2 than FePO4 or AlPO4 does (Chung et al., 2005). Additionally, several phosphate-solubilizing bacteria strains from the genera of *Bacillus*, *Rhodococcus*, and *Streptococcus* were described by Chen and associates in 2006. Some of the most prevalent bacteria include *Arthrobacter*, *Serratia*, *Chryseobacterium*, *Gordonia*, *Phyllobacterium*, and *Delftia*. Among them are 101 isolates and about 336 strains of *Burkholderia*, *Cedecea*, *Cronobacter*, *Enterobacter*, *Pantoea*, and *Pseudomonas* that were found in rice plants. These bacteria solubilized tricalcium Phosphate. According to Ambrosini and collegues (2012), $Ca_3(PO_4)_2$, was dominated by *Burkholderia* strains associated with sunflower plants.

By dissolving insoluble phosphate through the secretion of organic acids, chelation, and/or ion exchange, endophytes improve plants' access to Phosphorus. The ability to release P-solubilizing enzymes like phosphatase, phytase, and C—P lyase is another trait of endophytes. The secretion of organic acids like citric, malonic, fumaric, tartaric, gluconic, acetic, or glycolic acid is thought to be the main mechanism by which P is solubilized. The pH value of the medium typically decreases as a result of the bacteria's P-solubilizing activity, though this varies depending on the species of bacteria (figure III).

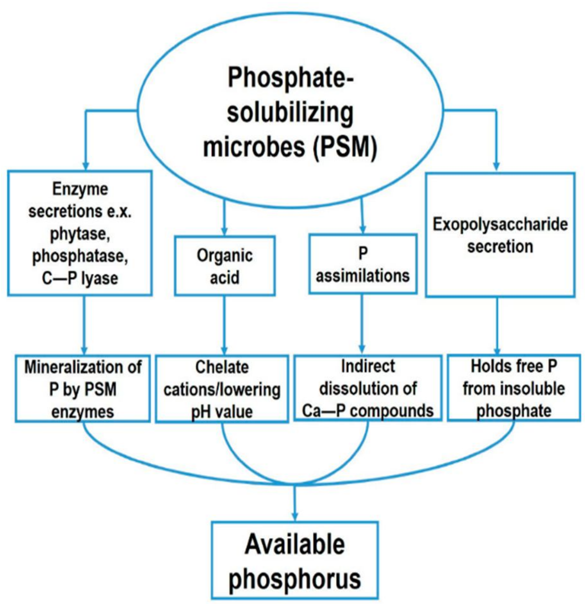

Fig. III Phosphate-solubilizing microorganisms solubilize phosphate through a variety of methods (Bolan *et al*., 1994)

3) Potassium Solubilizing

Potassium ranks third on the list of essential nutrients for plant growth (K). It is required for enzyme activation, protein synthesis, and photosynthesis. Some soil microbes can solubilize "unavailable" forms of potassium-bearing minerals such as mica, illite, and orthoclase by excreting organic acids that either dissolve or dissolve in water. For plants to flourish, potassium is necessary. By involving themselves in the control of plant cellular osmotic pressure and compound transportation in plants, soil microorganisms play a key role in ion cycling and soil fertility by influencing the availability of soil minerals. *Pseudomonas aeruginosa*, *Pseudomonas*, *Burkholderia*, *Acidothiobacillus ferroxidase*, *Bacillus mucilaginous*, *Bacillus edaphic*, *B. edaphic*, *B. edaphic*, *B. edaphic*, *B. circulants*, and *Paenibacillus sp.* have been found to release potassium in a form that can be consumed (Liu *et al.*, 2015). Figure- IV shows mechanism of Potassium Solubilization.

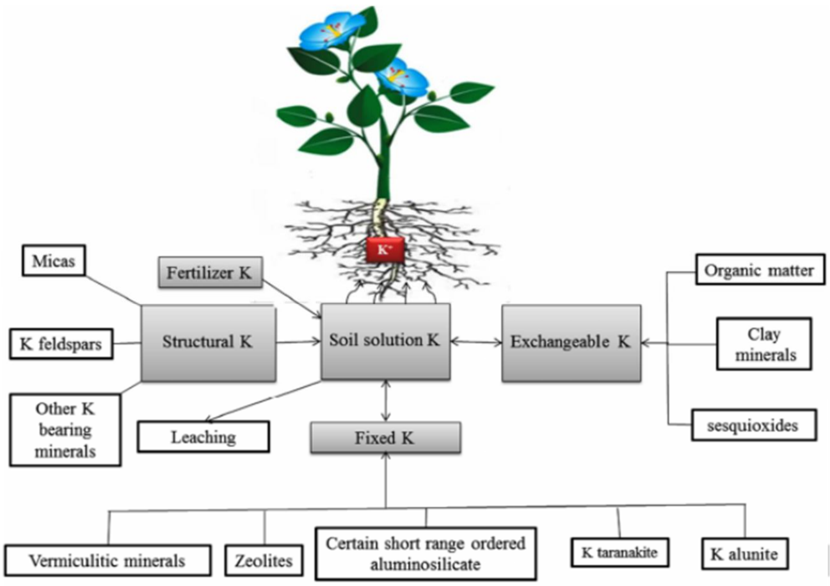

Fig. IV Rout of Potassium solubilization

Soil microbes can release soluble K from K-bearing minerals such as K-feldspar, mica, and illite. These microbes release organic acid, which quickly dissolves rock and chelates silicon ions, releasing K ions into the soil. The use of K-solubilizing microbes to increase the concentration of available K ions in the soil may mitigate K deficiency. The application of K-solubilizing bacteria (KSB) and K-bearing minerals increases the amount of available potassium in the soil and promotes plant uptake of potassium. The release of non-exchangeable potassium to the third exchangeable form occurs when the level of exchangeable potassium is decreased by crop removal, runoff, erosion, and/or leaching. The application of K solubilizing microorganisms (KSM) is a promising approach for increasing potassium availability in soil. It was shown that KSB increased potassium availability in soils and increased mineral uptake by plants. Production of carboxylic acids like citric, tartaric, and oxalic acids is also associated with feldspar solubilization by microorganisms (Liu *et al.*, 2015).

4) Zinc Solubilizing

Microorganisms and plants both require zinc as a micronutrient. It is found in 0.008 percent of the Earth's crust. Zinc is essential for both eukaryotic and prokaryotic feeding. In several enzyme systems, organisms act as cofactors or metal activators. Zinc's importance is for numerous activities, as well as its involvement in nutrition and physiology. Hughes and Poole, 1989 conducted extensive research on enzymes. Metals are known to be immobilized by bacteria through precipitation and adsorption. The ability to disintegrate There is a significant amount of immobilized zinc, such as zinc phosphate, zinc oxide, and zinc carbonate. On the soil surface, this is not a typical trait among the cultivable bacteria. There are only a few Zn-solubilizing plants. *Thiobacillus trioxidanes* and *Thiobacillus ferroxidans* are two bacterial genera. Due to high soil pH, low soil moisture, and poor organic matter, 50% of agricultural soils have low levels of accessible zinc. The membrane permeability of the root cell is increased during a Zn deficit, which might be related to the function of Zn in the membranes of cells (Parker *et al.*, 1992). Because of the alkaline and calcareous soil, Zn is a limiting element in crop yield. Improving, as a result, cereal belt production is critical for maintaining nutritional security and grain security.

(Singh *et al.*, 2005). Endophytic bacteria such as *Acinetobacter, Bacillus,* and *Pseudomonas* have been found to solubilize zinc. In nodules, endophytic bacteria coexist with symbiotic bacteria. They also don't form nodules and are immune to environmental and microbiological stressors. The host plant is putting up a fight. Endophytic bacteria have some favorable effects on the body. host plants, such as plant growth stimulation, nitrogen-fixing, and resistance induction by pathogens that infect plants (K.K. Ghevariya and P.B. Desai, 2015).

5) Phytohormone Production

Plant growth regulators (phytohormones) are low molecular-weight natural compounds that work at micromolar concentrations to influence fundamental physiological and biochemical processes. A process that occurs during the life cycle of a plant. Some of the PGPR auxins, cytokinine, and other phytohormones that encourage plant development are produced by some strains. Gibberellins are known to be anti-inflammatory. Root initiation, cell division, and cell expansion are all aided by this protein. Auxin, gibberellin, and abscisic acid synthesis are thought to be common features of PGPB. One of the most plausible modes of action on plant growth and development has also been proposed (Zahir *et al.*2004).

6) Production of Indole Acetic acid Compound

Significant IAA-producing bacteria have the ability to promote plant development, making them ideal for use as biofertilizers. It is crucial to investigate bacteria as a potential source of biological fertiliser. Endophytes of different sorts and their potential for supporting plant growth can be collected from a variety of plants and researched. According to the findings of Glickmann and Dessaux (1995), all 23 isolates of endophytic bacteria found in Cinchona plant roots were capable of producing IAA hormone. When the Salkowski's reagent is dropped, endophytic bacteria with the capacity to make IAA will cause pink coloration in bacterial supernatants. IAA content can be checked using the colouring reagent Salkowski. Sukmadewi *et al.* affirm that bacteria produce a lot of IAA during the stationary phase. When bacterial growth is not ideal and tryptophan precursors are present, IAA is produced as a secondary metabolite. Reduced growth circumstances, a lack of carbon availability, and environments with an acidic pH will all result in an increase in IAA production. When bacteria reach the stationary phase, this situation develops.

7) Gibberellic acid Acid Production

The bacteria that produce gibberellins are poorly understood. Bacteria's ability to produce gibberellins was originally discovered in *Azospirillum, Brasiliense*, and *Rhizobium*, respectively. Since then, they've been found in a variety of bacterial taxa, including *Azotobacter, Arthrobacter,* and others. *Micrococcus, Azospirillum, Pseudomonas, Bacillus, Acinetobacter, Flavobacterium*, Azospirillum, Azospirillum, *Agrobacterium, Clostridium, Rhizobium, Burkholderia,* and *Xanthomonas* are some of the bacteria that can be found in soil. An increase in gibberellin concentration in plant tissues is linked to biomass. From the rhizosphere of *A. glutinosa, Bacillus pumilus* and *Bacillus licheniformis* were recovered and have demonstrated the ability to create substantial amounts of the gibberellins GA1, GA3, GA4, and GA20 in a laboratory setting. *Acetobacter* production of gibberellins has been proven (Gamalero *et.al*., 2011).

B. Biocontrol Activity

More than $200 billion in annual crop yield losses are attributable to plant diseases. Bacteria promoting the growth of other microorganisms is a method known as biocontrol. Examples of secondary metabolites include the production of ammonia and indirect plant development by inhibiting pathogen growth through the release of antibiotics. Their advantageous effects have been related to plant development and defence against dangerous microorganisms. *Fusarium wilts* in a range of plants have been successfully treated with *Pseudomonads* (Chandra *et al.*, 2007). The next section describes several vital abilities that endophytes have that aid in biocontrol.

1) Siderophore Production

Plant iron availability may be increased while also being protected against pathogenic bacteria through the development of low molecular weight ferric-chelating chemical siderophores. Siderophores are essential for the iron feeding of plants. Pseudomonas fluorescens C7's Fe-pyoverdine combination was well assimilated. This enhanced growth in *Arabidopsis thaliana* and raised the amount of iron in plant tissue. By reducing the harmful effects of heavy metals, siderophores also assist bacteria in the production of IAA. Metals can be removed from the body through chelation (Dimkpa *et al.*, 2008).

2) Hydrogen Cyanide Production

Gram-negative bacteria create cyanide as a secondary metabolite. HCN catalyzes by glycine synthase enzyme. Cyanide is a phytotoxic chemical that inhibits enzymes involved in plant metabolism. It is one of the characteristic aspects of deleterious substances in important metabolic processes and is regarded as one of the typical features of deleterious substances. According to Ahmad *et al.*, 2008, HCN production is observed to be a common feature in the rhizospheric soil, where *Pseudomonas* (88.89%) and *Bacillus* (50%) have a common feature. The root-colonizing and plant-beneficial *P. fluorescent* strain CHA0, which protects numerous plants from bacterial cyanogenesis, has been found.

Various secondary metabolites secreted by Pseudomonas sp., including HCN and siderophores, are inhibitory against different phytopathogens. Volatile compounds such as ammonia and hydrogen cyanide produced by several rhizobacteria were reported to play an important role in biocontrol. HCN expression and production by Pseudomonas are strongly dependent on iron availability. Moreover, the antifungal activity of Pseudomonas and others (Bacillus and Azotobacter) may be due to the production of HCN and siderophores or synergistic interaction of these two or with other metabolites (Ahmad *et al.*, 2008).

3) Ammonia Production

Rhizobacteria are the most frequent organisms to produce ammonia, which is linked to nitrogen fixation. The primary metabolic processes involved in biological nitrogen fixation include: a symbiotic connection between nitrogen-fixing bacteria and legumes that results in the conversion of atmospheric nitrogen (N_2) into ammonia (NH_3). Rice, wheat, maize, sugarcane, cotton, Jatropha, and interactions with C3 and C4 plants are all produced by rhizobacteria (e.g., rice, wheat, maize, sugarcane, Jatropha, and cotton). They considerably increase their vegetative growth and grain output (Kennedy *et al.*, 2004).

Plant development is indirectly influenced by ammonia production. The synthesis of ammonia by B. subtilis strain MA-2 and Pseudomonas fluorescens strain MA-4 was effective, and these strains also considerably boosted the biomass of aromatic and medicinal plants like geranium (Mishra *et al.*, 2010). ninety-five percent of the isolates from rice, mangrove, and soil infected with effluent that encourages plant growth produced ammonia (joseph *et al.*, 2007).

C. BIOACTIVE molecules of endophytes

Figure V displays a number of bioactive substances of endophyte that can be used to accomplish various advantageous strategies.

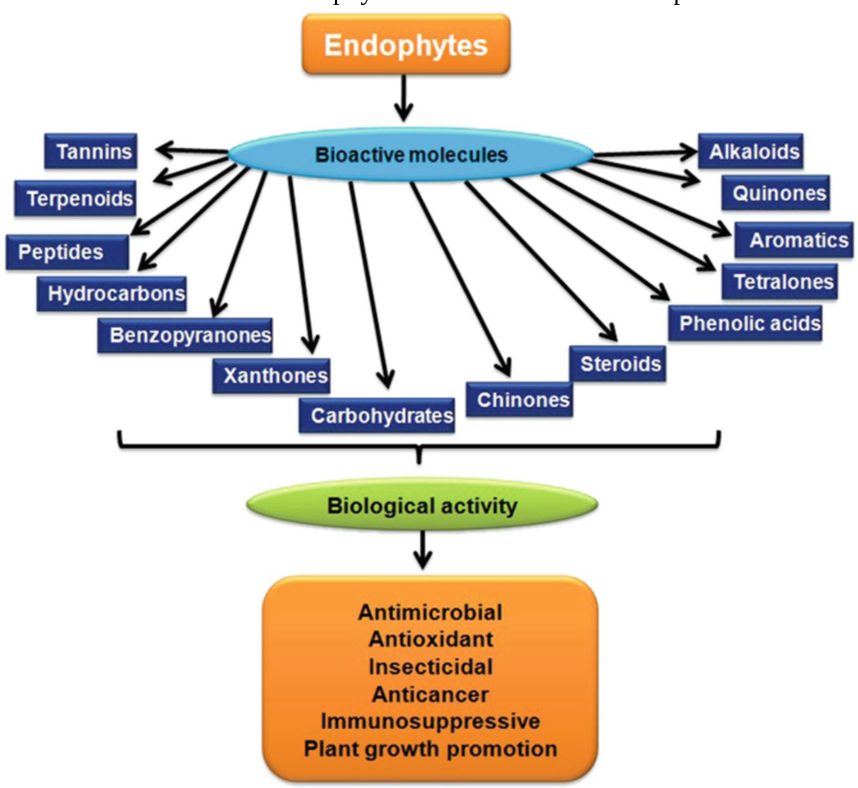

Fig. V Endophyte's bioactive molecules and their biological activity (Sarethy *et al.*, 2019)

Several synthetic drugs have been developed in response of the frequent utilisation of natural chemicals as sources for lead molecules. Paclitaxel (Taxol), the first anti-cancer drug ever developed and worth $1 billion, is a prime example of a natural product generated from the yew tree (Wani *et al*., 2007). Taxol can also be produced by the *Pestalotiopsis Microspora*, an endophytic fungus that lives on Yew trees (Strobel *et al*.,2004). A well-known immunosuppressant is cyclosporine is also best example. The efficiency was further enhanced by the extract made from the endophytic fungus *Tolypocladium inflatum*. There is also a great deal of opportunity for innovation among endophytic bacteria and fungi. Ingredients from nature: Leucomycins, pseudotyping, munumbicins, and kanamycin are a few examples. Numerous novel antibiotics are produced by endophytic microorganisms (Strobel *et al*., 2004).

IV. CONCLUSIONS

Here, the process of cultivating medicinal plants necessitates interdisciplinary research on the biology, microbiology, ecology, and agricultural technology of endophytic organisms in order to generate efficient means of biomass production and obtain high-quality material rich in phytochemicals. The unintentional demise of medicinal plants can be stopped by preserving the green cover if phytochemicals are discovered and generated by microbes. Additionally, the goods can be produced on a huge scale and at a low cost. Different medicinal plant endophytes that have not yet been thoroughly explored will undoubtedly have a growth-promoting impact.

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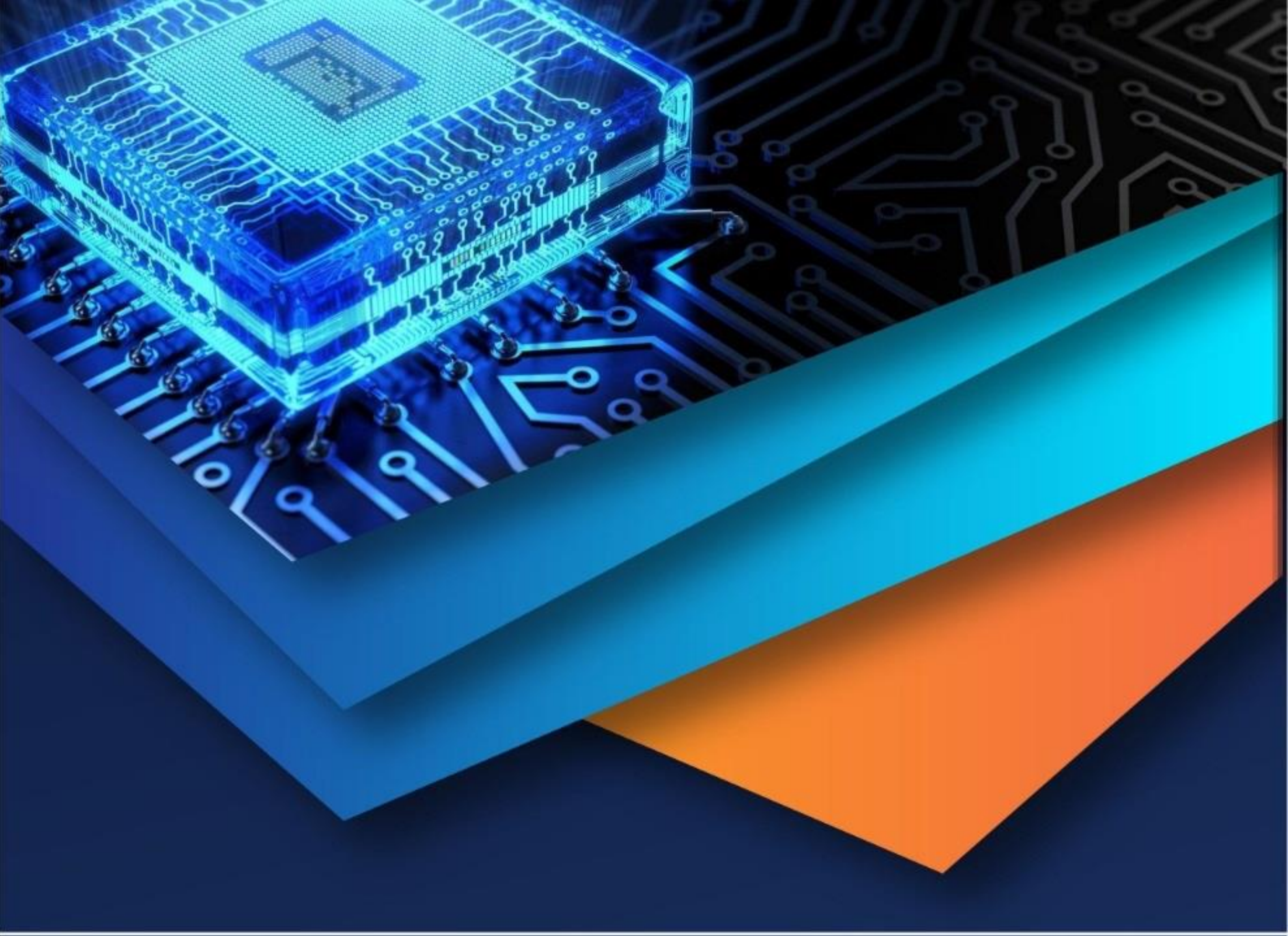

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