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# Plant-Growth Promoting Rhizobacteria and Medicinal Plants

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**ABSTRACT**

*There is currently much interest in cultivating medicinal and aromatic plants (MAPs) in order to meet the great demand of biologically active compounds used by food, pharmaceutical industries and health care. Plant growth-promoting rhizobacteria (PGPR) have been used as inoculants in practical production, playing an important role as a supplement to improve the growth and yield of several MAPs. PGPR are able to improve plant growth by increasing the rate of seed germination and seedling emergence, minimizing the adverse effects of external stress factors and protecting plants from soil-borne pests and diseases. This chapter covers the scope of studies published to date focusing on the improvement of growth and biologically active compound production of select MAPs by PGPR.*

***Key words*:** Plant growth-promoting rhizobacteria (PGPR), Plant growth, Stress management

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## INTRODUCTION

Most of the world's population in developing countries still relies on herbal medicines to meet their health needs, because antibiotics are too expensive for low-income countries (Abu-Irmaileh & Afifi, 2000).

Medicinal and aromatic plants (MAPs) contain a wide range of essential oils rich in phenolic compounds and a wide array of other biological active compounds that are traditionally used as remedies to treat various diseases (Palombo & Semple 2001; Van Wyk & Wink, 2004). Many MAPs are typically consumed without further processing after harvest. Therefore, it is important that chemicals not be present in or on any part of the plant (Banchio *et al.*, 2008). It is essential to identify non-chemical growth measurements of MAPs avoiding chemical fertilizers and pesticides and achieving organic yields.

An intensive practice to obtain high yield from cultivated plants requires the extensive use of chemical fertilizers, fungicides and pesticides, which may create environmental problems. Nowadays, the use of biofertilizers in production plays an important role as a supplement to improve the growth and yield of several agricultural, horticultural and medicinal plants (Murthy *et al.,* 1998; Lugtenberg & Kamilova, 2009).

Plant growth-promoting rhizobacteria (PGPR) are able to improve plant growth by increasing the rate of seed germination and seedling emergence, minimizing the adverse effects of external stress factors, and protecting plants from soil-borne pests and diseases.

There are several reports that PGPRs have promoted the growth of cereals, ornamentals, vegetables, and MAPs (Vessey, 2003; Lugtenberg & Kamilova, 2009; Mahalakshmi & Reetha, 2009; Mishra *et al.*, 2010; Egamberdieva *et al*., 2011). However, a limited number of studies have been undertaken regarding rhizobacteria and medicinal plant interactions. The objectives of this chapter are to discuss recent developments and advances in our understanding of the beneficial microorganisms and their interactions with MAPs.

## BENEFICIAL RHIZOSPHERE BACTERIA AND FUNGI

Plant growth-promoting microbes found in the rhizosphere of various plants grown in different soils and climatic conditions can provide a wide spectrum of benefits to plants (Mayak *et al*., 2004). Arbuscular

mycorrhizal fungi (AMF) are also known to increase the growth of many plant species, including MAPs (Selvaraj *et al.*, 2008).

Beneficial rhizosphere bacteria are of two general types, those forming a symbiotic relationship with the plant and those that are free-living in the soil and root (Bianciotto *et al*., 2001; Barriuso *et al.*, 2005; Lugtenberg & Kamilova, 2009). Various PGPR strains have also proven to be able to increase nutrient availability in the rhizosphere (Cakmakci *et al.*, 2005). The occurrence of *Azospirillum*, *Azotobacter*, *Pseudomonas* and *Bacillus* in the rhizosphere of *Withania somnifera* has been reported by Attia and Saad (2001) and Thosar *et al.* (2005). Species such as *Azospirillum*, *Azotobacter* and *Pseudomonas* have been found in the rhizosphere of *Catharanthus roseus*, *Coleus forskohlii*, *Ocimum sanctum* and *Aloe vera* (Karthikeyan *et al.*, 2008). Turrini *et al.* (2010) reported the occurrence of AMF species such as *Glomus coronatum*, *G. mosseae*, *G. etunicatum*, *G. geosporum*, *G. viscosum*, and *G. rubiforme* in the rhizosphere of *Smilax aspera* and *Helichrysum litoreum.*

In the rhizosphere, a synergism between various bacterial genera such as *Bacillus*, *Pseudomonas*, *Arthrobacter* and *Rhizobium* has been shown to promote plant growth of various plants such as peanut (*Arachis hypogaea* L.) (Dey *et al*., 2004), corn (*Zea mays* L.) soybean (*Glycine max* L.) (Cassan *et al*., 2009), fodder galega (*Galega orientalis* L.) (Egamberdieva *et al.,* 2010) and sweet basil (*Ocimum basilicum* L.) (Hemavathi *et al*., 2006). Compared to single inoculation, co-inoculation has improved the absorption of nitrogen (N), phosphorus (P) and mineral nutrients by plants (Bashan & Holguin, 1997). Such PGPR activity has been reported in species belonging to *Azospirillum*, *Azotobacter*, *Pseudomonas*, *Bacillus*, *Burkholderia*, *Bradyrhizobium*, *Sinorhizobium* and *Trihoderma* (Sudhakar *et al.*, 2000; Hemavathi *et al*., 2006; Hossainzadah *et al.*, 2011; Rajasekar & Elango, 2011; Egamberdieva *et al.*, 2013) (Table 1).

## INTERACTIONS FOR IMPROVING PLANT GROWTH

The synergistic effects of combined inoculation of PGPRs and/or mycorrhiza have also been reported in various MAPs, for example in *Ocimum basilicum* (Hemavathi *et al*., 2006), *Silybum marianum* (Egamberdieva *et al.*, 2013), *Calendula officinalis* (Hosseinzadah *et al.* 2011), *Phyllanthus amarus* (Earanna & Bagyaraj, 2004), *Alpinia galanga* and *Coleus amboinicus* (Mani, 2004), *Saraca asoca* (Lakshmipathy *et al*., 2001) and *Azadirachta indica* (Sumana, 1998) (Table 2).

**Table 1:** List of plant growth promoting microorganisms for medicinal and aromatic plants

| ***Microorganisms*** | ***Plants*** | ***Reference(s)*** |
|---|---|---|
| *Azotobacter chrooccocum* | *Adathoda vasica* | Sudhakar *et al*., 2000 |
| | *Catharanthus roseus* | Karthikeyan *et al*., 2010 |
| | *Calendula officinalis* L. | Hosseinzadah *et al*., 2011 |
| | *Morus alba* | Vinutha, 2005 |
| | *Stevia rebaudiana* | Anantha Naik, 2006 |
| | *Ocimum* spp. | Earanna, 2007 |
| | *Ocimum basilicum* | Ordookhani *et al*., 2011 |
| | *Withania somnifera* | Rajasekar & Elango, 2011 |
| *Azosprillum lipoferum* | *Morus alba* | Sudhakar *et al*., 2000 |
| | *Ocimum basilicum* | Ordookhani *et al*., 2011 |
| *Bacillus coagulans* | *Begonia malabarica* L. | Selvaraj *et al.,* 2008 |
| | *Solanum viarum* | Hemashenpagam & Selvaraj, 2011 |
| *Bacillus lentus* | *Ocimum basilicum* | Golpayegani & Tilebeni, 2011 Heidari *et al*., 2011 |
| *Bacillus megaterium* | *Catharanthus roseus* | Karthikeyan *et al*., 2010 |
| | *Ocimum basilicum* | Hemavathi *et al*., 2006 |
| | *Withania somnifera* | Rajasekar & Elango, 2011 |
| *Bacillus subtilis* | *Chrysanthemum cineraefolium Origanum majorana* L. | Banchio *et al*., 2008 Mishra *et al*., 2010 |
| *Burkholderia* sp | *Cajanus cajan* | Pandey & Maheshwari, 2007 |
| *Bradyrhizobium* sp. | *Origanum majorana* L. | Banchio *et al.,* 2008 |
| *Glomus aggregatum* | *Solanum viarum* | Hemashenpagam & Selvaraj, 2011 |
| *Glomus fasciculatum* | *Ocimum basilicum* L. | Sadaghiani *et al*., 2010 |
| | *Ocimum* spp. | Vinutha, 2005 |
| | *O.basilicum* | Hemavathi *et al*., 2006 |
| | *Phyllanthus amarus* | Earanna, 2007 |
| | *Stevia rebaudiana* | Earanna & Bagyaraj, 2004 |
| *Glomus mosseae* | *Begonia malabarica* L. | Selvaraj *et al.,* 2008 |
| *P. extremorientalis* | *Sylebum marianum* | Egamberdieva *et al*., 2012 |
| *Psudomonas fluorescens* | *Calendula officinalis* L. | Jaleel *et al*., 2007 |
| | *Catharanthus roseus* | Karthikeyan *et al.,* 2010 |
| | *Chrysanthemum cineraefolium* | Banchio *et al.,* 2008 Hosseinzadah *et al*., 2011 |
| | *Origanum majorana* L. | Earanna, 2007 |
| | *Ocimum basilicum* | Hemavathi *et al*., 2006 |
| | *Stevia rebaudiana* | Mishra *et al*., 2010 |
| | *Withania somnifera* | Rajasekar & Elango, 2011 |
| *Pseudomonas* sp. | *Ocimum basilicum* | Golpayegani & Tilebeni, 2011 Heidari *et al*., 2011 |
| *Pseudomonas putida* | *Ocimum basilicum* | Ordookhani *et al.,* 2011 |
| *Sinorhizobium meliloti* | *Origanum majorana* L. | Banchio *et al*., 2008 |
| *Trichoderma harzianum* | *Solanum viarum* | Hemashenpagam & Selvaraj, 2011 |
| *Trichoderma viride* | *Begonia malabarica* L. | Selvaraj *et al*., 2008 |

**Table 2:** The list of scientific and common names of medicinal plants used in this review

| ***The scientific names of medicinal plants*** | ***Common names (English, where available)*** |
|---|---|
| *Aloe vera* | Aloe |
| *Alpinia galanga* | Greater galanga |
| *Ammolei majus* | Bishop's weed |
| *Azadirachta indica* | Neem |
| *Begonia malabarica* | Begonia |
| *Calamus thwaitesii* | Palm tree |
| *Calendula officinalis* | Pot marigold |
| *Cajanus cajan* | Pigeon pea |
| *Catharanthus roseus* | Madagascar periwinkle |
| *Chrysanthemum cinerariifolium* | Dalmatian chrysanthemum |
| *Coleus forskohlii* | Indian coleus |
| *Coleus amboinicus* | Indian mint |
| *Dendrobium moschatum* | Dendrobium orchid |
| *Eragrostis curvula* | Weeping lovegrass |
| *Galega orientalis* | Fodder galega |
| *Helichrysum litoreum* | Perpetuini delle spiagge |
| *Hyoscyamus niger* | Stinking nightshade |
| *Mentha arvensis* | Field mint |
| *Matricaria chamomilla* | Camomile |
| *Ocimum basilicum* | Sweet basil |
| *Ocimum sanctum* | Tulsii |
| *Phyllanthus amarus* | Stonebreaker |
| *Saraca asoca* | Ashoka tree |
| *Satureja hortensis* | Summer savory |
| *Silybum marianum* | Milk thistle |
| *Smilax aspera* | Rough bindweed |
| *Origanum majorana* | Marjoram |
| *Withania somnifera* | Ashwagandha |
| *Zingiber officinale* | Ginger |

Vinutha (2005) observed increased shoot and root growth weight, biomass and essential oil content of *Ocimum* spp. When inoculated with *Glomus fasciculatum*, *Azotobacter chroococcum* and *A. awamori*. Hemavathi *et al*. (2006) made similar observations in *Ocimum basilicum*, where plant growth increased after inoculation with *G. fasciculatum*, *Pseudomonas fluorescens* and *Bacillus megaterium*. In another study, Ordookhani *et al*. (2011) found an increase in shoot, root dry weight, N, P and potassium (K) content and essential oils in *Ocimum basilicum* inoculated with PGPR *Pseudomonas putida* and *Azotobacter chroococcum*. An *A. chroococcum* strain inoculated to *Adathoda vasica* also enhanced the root, shoot, growth and dry weight (Anantha Naik, 2006).

A significant increase in N content of root and shoot of *Galega orientalis* was also observed after co-inoculation of *Pseudomonas trivialis* strain 3Re27 with *Rhizobium galegae* HAMBI 540 which significantly increased the N content of the roots by 20% and of the shoots by 52% compared to *R. galegae* HAMBI 540 alone. Shoot and root growth were also increased by co-inoculation of both strains (Egamberdieva *et al.*, 2010). Improved mineral nutrition would explain the promotion of root and shoot growth. This rationale is consistent with the observation that plants inoculated with PGPR take up N, P, K and microelements more efficiently from the soil (Cakmakci *et al.*, 2005).

Two isolates of PGPR, *Bacillus subtilis* and *Pseudomonas fluorescens*, increased the yield of *Chrysanthemum cinerariifolium* up to 27% (Mishra *et al*., 2010). Earanna and Bagyaraj (2004) reported a better response of *Phyllanthus amarus* inoculated with *G. fasciculatum* and *A. chroococcum*, *P. fluorescens*. Karthikeyan *et al*. (2010) reported that PGPR strains *P. fluorescens* and *B. megaterium* significantly increased plant height, root length, root girth, alkaloid content and N, P, K, Ca and Mg uptake in *Catharanthus roseus* in comparison to the uninoculated control. Sharma *et al*. (1997) reported that *Zingiber officinale* plants inoculated with ***Glomus*** *mosseae* significantly increased plant growth and yield. Such a response resulting in improved plant growth was also obtained by Sivakumar *et al*. (2002) for *Pelargonium graveolens* inoculated with *Glomus fasciculatum* and *Azotobacter chroococcum* and *Pseudomonas* spp. and for *Withania somnifera* (Attia & Saad, 2001).

Earanna (2007) also found that plant growth, as well as NPK uptake of *Stevia rebaudiana* increased after inoculation with *A. chroococcum*, *P. fluorescens* and *G. fasciculatum*. In other studies, combined inoculation of *Begonia malabarica* and *Calamus thwaitesii* with ***Glomus*** *mosseae*, *Bacillus coagulans* and *Trichoderma viride* enhanced the growth, biomass, nutrients, and production of secondary metabolites such as phenols, ortho-dihydroxy phenols, tannins, flavonoids and alkaloids (Lakshmipathy *et al.*, 2002; Selvaraj *et al.*, 2008). Improved plant growth of *Solanum viarum* plants was possible with AMF and PGPRs (*G. aggregatum*, *B. coagulans* and *Trichoderma harzianum*) (Hemashenpagam & Selvaraj, 2011). In their study P, K, zinc, copper, manganese and iron content of leaf samples increased after treatment with PGPR strains. Moreover, production of secondary metabolites such as total phenols, orthodihydroxy phenols, flavanoids, alkaloids, saponins and tannins in plants were also stimulated after treatment with PGPR. The increase in secondary metabolites in the roots or shoots of MAPs

can be explained by the mycorrhizal and PGPR inoculation and nutrient status of plants (Elango, 2004; Mani, 2004). Such positive effects were observed by Hosseinzadah *et al.* (2011) when *Azospirillum lypoferum*, *A. chroococcum* and *P. fluorescens* increased the growth dry weights of shoot and root, NPK content of leaves and roots of *Calendula officinalis*.

Rajasekar and Elango (2011) observed that a combination of PGPR strains *Azospirillum*, *Azotobacter*, *Pseudomonas* and *Bacillus* significantly increased plant height, root length, and alkaloid content in *Withania somnifera* compared to the uninoculated control. In another study, combinations of *Sinorhizobium meliloti*, *Rhizobium leguminosarum* and *Bacillus* sp. resulted in an increase in plant growth and development of *Cajanus cajan* (Pandey & Macheshwari, 2007).

Banchio *et al*. (2008) observed significant increases in shoot length, shoot weight, number of leaves and nodes, root dry weight and essential oil yield of *Origanum majorana* inoculated with *P. fluorescens* and *Bradyrhizobium sp*. Similar results when observed by others when *Mentha arvensis* (Gupta et al., 2002), *Origanum* sp. (Khaosaad *et al*., 2006), and *Ocimum basilicum* (Copetta *et al.*, 2006) were inoculated with *Glomus fasciculatum* (AM), increasing plant growth and oil content.

## PGPRS FOR BIOTIC STRESS MANAGEMENT

In MAPs, growth, production of essential oil and biologically active compounds is influenced by various environmental factors, such as salinity, drought, and water stress (Hasegawa *et al.*, 2000; Parida & Das, 2005). Salt affects plant growth mainly through toxicity caused by the excessive uptake of salts, especially NaCl, reduced water uptake and reduction in uptake of essential nutrients (Munns 2003). Soil salinity significantly reduced the yield of MAPs *Satureja hortensis* and *Eragrostis curvula* (Baher *et al.*, 2002; Colom & Vazzana, 2002), *Citronella* (Kumar & Gill, 1995). Ashraf *et al.* (2004) found that high salt concentrations caused a significant reduction in the shoot and root growth and as well as seed yield of *Ammolei majus* and *Hyoscyamus niger*. Similar results were observed by Razmjoo *et al.* (2008), in which increased salinity and drought stress caused a reduction in the fresh and dry flower weight and essential oil content of *Matricaria chamomilla.*

The ameliorative effects of PGPR on plant growth under saline conditions have been shown on various plant species (non MAPs), such as bean, canola, eggplant, lettuce, maize, pepper and ,tomato (Hasnain

& Sabri, 1996; Mayak *et al.*, 2004; Yildirim & Taylor, 2005; Barassi *et al.*, 2006; Fu *et al*., 2010; Egamberdieva, 2011; Rojas-Tapias *et al.*, 2012). These PGPR (*e.g., Rhizobium*, *Azospirillum*, *Pseudomonas*, *Flavobacterium*, *Arthrobacter* and *Bacillus*) utilize osmoregulation, oligotrophic, endogenous metabolism, resistance to starvation, and efficient metabolic processes to adapt under dry and saline environments (Lugtenberg *et al*., 2001; Egamberdieva & Islam, 2008). These bacteria, with a physiological adaptation and genetic potential for increased tolerance to drought, increasing salt concentration, and high temperatures, could improve plant production in degraded sites.

*Galega officinalis* L., which is used for medicinal purposes (Atanasov, 1994; Atanasov & Spasov, 2000; Pundarikakshudu *et al*., 2001), is salt sensitive. Co-inoculation of salt-stressed goat's rue with *Rhizobium galegae* and *Pseudomonas extremorientalis* significantly improved root and shoot growth, nodulation and N content of plant roots grown in potting soils (Egambardieva *et al*., unpublished data). These results were somewhat similar to those obtained by Golpayegani and Tilebeni (2011) in which salinity decreased plant growth, photosynthesis, stomatal conductance, chlorophyll content and mineral uptake of basil (*Ocimum basilicum*) compared to soil without salinity. Inoculation of basil with *Pseudomonas* sp. and *Bacillus lentus* alleviated the effects of salinity on growth, photosynthesis, mineral content and antioxidant enzymes. Heidari *et al*. (2011) also reported that plant growth, auxin and protein contents of *Ociumum basilicm* inoculated by *Pseudomonas* sp. under drought stress conditions increased compared to the control. In a recent study, inoculation of salt-stressed milk thistle *Silybum marianum* with *P. extremorientalis* TSAU20 significantly improved root, shoot length (66%) and fresh weight (64%) at 100 mM NaCl compared to control plants. *P. extremorientalis* TSAU20 also increased the root and shoot length and dry weight of milk thistle in non-saline, weakly saline and saline soils (Figures 1, 2) (Egamberdieva *et al.*, 2013).

Similar to our findings, inoculation with PGPR *Pseudomonas* strains stimulated the shoot, root growth and yield of *Catharanthus roseus* under drought stress (Jaleel *et al*., 2007).

## BIOMECHANISMS TO ENHANCE PLANT GROWTH

Mechanisms by which PGPR are able to alleviate salt stress in plants and promote plant growth include mobilization of nutrients (Lugtenberg *et al*., 2001; Lifshitz *et al*., 2004), production of ACC deaminase enzyme, which can lower the level of the plant stress hormone ethylene (Glick *et*

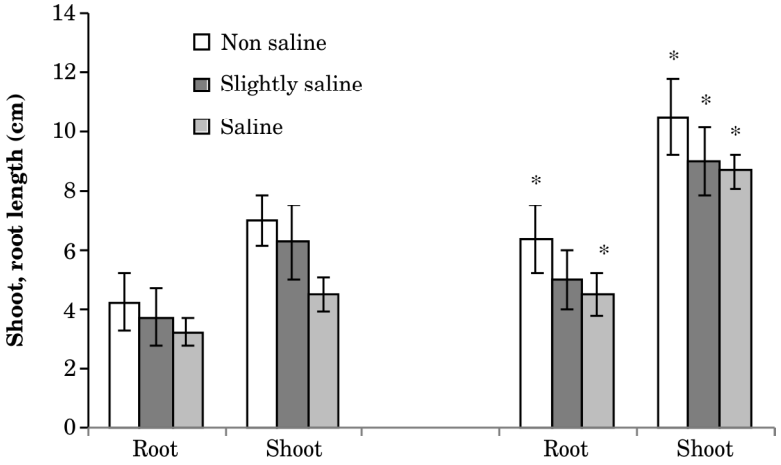


**Fig. 1:** The length of roots/ shoots of milk thistle grown under non saline, weak and saline soil and inoculated with *P. extremorientalis* strain TSAU20. Plants were grown in the greenhouse for six weeks. Values represent means for ten plants (n = 10), with error bars showing standard deviation. Columns marked with an asterisk differed significantly from control plants not inoculated with bacteria at $P < 0.05$. Source: Egamberdieva D, Jabborova D, Mamadalieva N (2013) Salt-tolerant *Pseudomonas extremorientalis* able to stimulate growth of *Silybum marianum* under salt stress condition. *Medicinal and Aromatic Plant Science and Biotechnology* 7 (Special Issue), in press, ©2013, with kind permission from Global Science Books, Ikenobe, Japan.

*al*., 1998; 2007; Belimov *et al*., 2009) and production of phytohormones such as auxins, cytokinins, and gibberellins (Costacurta & Vanderleyden, 1995; Vikram *et al*., 2007; Spaepen *et al*., 2009).

Auxin is a class of plant hormones: the most common and well characterised is indole-3-acetic acid (IAA), which is known to stimulate both rapid (*e.g.,* increases in cell elongation) and long-term responses in plants (Cleland, 1990). The exogenous application of auxins to *Vigna radiata* (Hayat *et al.*, 2008) promoted root growth, nodulation and nitrogenase activity. Barea *et al*. (1976) found that 90% of rhizosphere bacteria isolated from various plants were able to produce IAA. Other studies also reported that most *Pseudomonas* strains produced auxin-like compounds (Ataei, 2005; Zadeh, 2006; Khakipaour *et al.*, 2008). Tsavkelova and others (2007) studied the interactions of PGPR with *Dendrobium moschatum* via IAA. They found that bacterial strains which belong to genera such as *Rhizobium*, *Microbacterium*, and *Mycobacterium* were among the most active IAA producers. PGPR

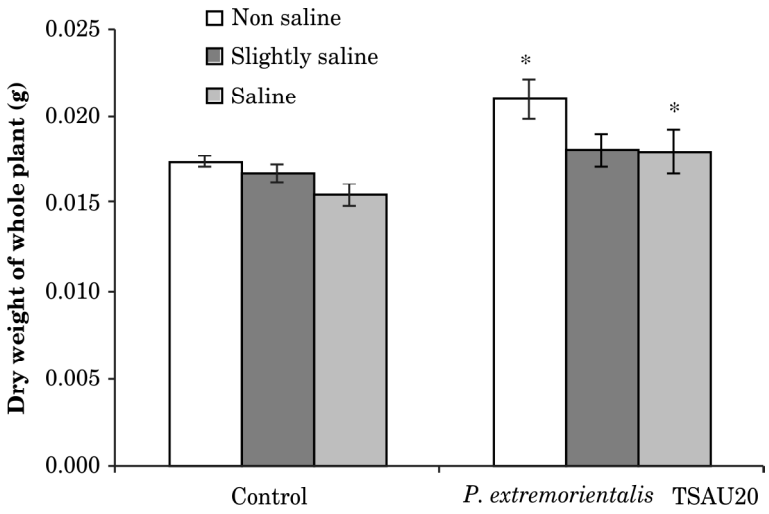


**Fig. 2:** The dry weight of whole plant grown under non saline, weak and saline soil and inoculated with *P. extremorientalis* strain TSAU20. Plants were grown in the greenhouse for six weeks. Values represent means for ten plants (n = 10), with error bars showing standard deviation. Columns marked with an asterisk differed significantly from control plants not inoculated with bacteria at $P < 0.05$. Source: Egamberdieva, D., Jabborova, D. and Mamadalieva, N. (2013). Salt-tolerant *Pseudomonas extremorientalis* able to stimulate growth of *Silybum marianum* under salt stress condition. *Medicinal and Aromatic Plant Science and Biotechnology* 7 (Special Issue), in press, ©2013, with kind permission from Global Science Books, Ikenobe, Japan.

supply additional IAA into the rhizosphere and plant cells can take up some of the IAA and, together with the endogenous plant IAA, can stimulate plant cell proliferation (Glick *et al.*, 2007).

Desbrosses *et al.* (2009) also reported that auxin mutants were found to retain the capacity to elongate root hairs when inoculated by PGPR. PGPR supply additional IAA into the rhizosphere and stimulate root development and alter the root architecture which increases root surface area and may lead to greater rates of nutrient absorption through which plant growth will increase significantly (Tanimoto, 2005; Tilak *et al.*, 2006; Yang *et al.*, 2008). According to Bouwmeester *et al.* (2007), AMF increase plant growth and oil content by stimulating the root system which would allow the plant to exploit a greater volume of soil. Another explanation by Sangwan *et al.* (2001) is that essential oils of MAPs have antimicrobial properties. The inoculation of plants results in higher colonization rate in the rhizosphere by PGPR and as a result of a plant's defense response, the essential oil content increases.

It is thought that the depressive effect of salinity on plant growth could be related to a decline in levels of endogenous plant hormones, including auxins and gibberellins (Zholkevich & Pustovoytova, 1993; Jackson, 1997; Debez *et al.*, 2001). Incorporation of plant growth regulators during the pre-sowing treatments in plants can alleviate salt stress (Gul *et al.*, 2000; Khan *et al.*, 2001, 2004; Afzal *et al.*, 2005). It is also suggested that PGPR, which produce phytohormones, can prevent the deleterious effects of stresses from the environment (Frankenberger & Arshad, 1995). The salt-tolerant *P. extremorientalis* TSAU20 strain which produces IAA was able to alleviate salt stress in *Sylebum marianum* grown under saline conditions (Egamberdieva *et al.*, 2013) (Fig. 3).

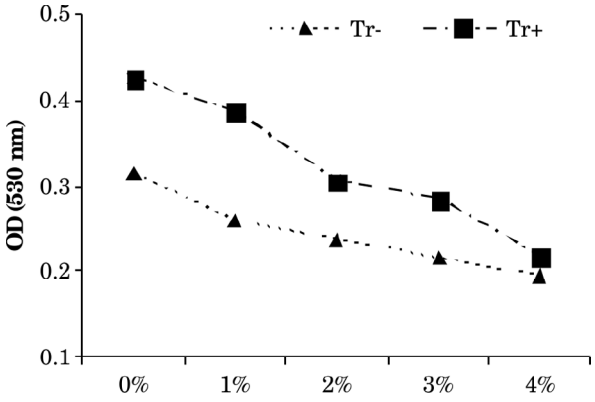


**Fig. 3:** The effect of salinity (NaCl) on IAA production ability of *P. extremorientalis TSAU20* (bacteria were grown 7 days in KB medium at 28°C with the absence and presence of 100 µg/ml of the auxin precursor tryptophan (Tr)). Tr- = without tryptophan; Tr+ = with tryptophan. X-axis, NaCl concentration (%). Unpublished data.

PGPR also improve solubilization of fixed soil P and help improve P uptake by plants (Nautiyal 1999). Wu *et al*. (2005) reported that microbial inoculum *Bacillus megaterium* and *Bacillus mucilaginous* improved nutritional assimilation of plant total NPK. PGPR have the ability to convert nutritionally important elements from unavailable to available form through biological processes (Vessey, 2003).

In another of our studies, we observed that PGPR strain *P. putida* TSAU1 was able to produce ACC deaminase and alleviate salt stress in MAP *Corhorus olitorius* L. (Egambardieva *et al*. unpublished data). Bacterial strains contain ACC deaminase, which can cleave the plant

ethylene precursor ACC, and thereby lower the level of ethylene in a developing or stressed plant. For many plants, a burst of ethylene is required to break seed dormancy but, following germination, a sustained high level of ethylene may inhibit root elongation (Penrose *et al.*, 2001). Thus, PGPR contain the enzyme ACC deaminase, and their colonization of the seed coat of a developing seedling may decrease the ethylene level thus preventing the inhibition of the root growth by ethylene (Glick *et al*., 2007).

## CONCLUSIONS

The plant growth promoting microorganisms were found to have a great potential for use as bioinoculants to increase production in medicinal and aromatic plants. Such strategies will be useful in reducing the chemical loads into plant production and a move towards chemical free herbals. Future studies will elucidate the mechanisms involved in stimulation of biological active compounds, potential competition between PGPR strains and indigenous soil microflora in the rhizosphere of medicinal plants.

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