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Potential of Rhizospheric Bacteria for Increasing Growth and Yield of Shallots (*Allium ascalonicum* L.) in Saline Soil

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Abstract. Shallots (*Allium ascalonicum* L.) are the primary agricultural commodity in Brebes Regency, Central Java, Indonesia. Due to the escalating demand for shallots, it is necessary to consider land expansion to accommodate this increased need, particularly extending to areas near coastal areas. However, shallot production near the coastal areas is still non-optimal compared to inland areas due to salinity with high osmotic pressure. Biological fertilizers containing saline-resistant microorganisms that can produce plant growth hormones and assist plants in absorbing nutrients are a promising solution to this issue. These microorganisms belong to the PGPR (Plant Growth Promoting Rhizobacteria) group. It was reported that PGPR bacteria can produce exopolysaccharides, which lead to the formation and production of osmoprotectant biofilms and antioxidant enzymes, significantly stimulating plant growth in saline soils. In addition, several properties of PGPR bacteria can stimulate plant growth by increasing nutrient availability and growth hormone production, which can simultaneously improve the quality of plant growth. Therefore, this review will highlight the survival mechanisms of saline-resistant bacteria, their influence on increasing plant growth in saline fields, and their bacterial identities.

1 Introduction

1.1 The importance of shallots as a horticultural commodity

Shallots (*Allium ascalonicum* L.) have a high value in horticultural trade, with an average retail price of IDR 31,900/kg in traditional markets and IDR 58,000/kg in modern markets as of July 2024 [1]. Brebes Regency is one of the main shallot-producing areas in Indonesia, with a planted area of around 20,000 hectares and an average production of 120,000 tonnes annually [2]. Demand for shallots from Brebes Regency continues to rise, with sales reaching an increase of 72,500 tonnes per three months in 2021 [3]. This trend is expected to continue

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as the population grows [4]. Therefore, shallots production in the Brebes Regency must be increased by expanding planting areas [5]. However, land conversion has resulted in the narrowing of agricultural land [6].

1.2 Constraints of shallot cultivation on saline land and the impact of salinity stress on shallot growth

Saline soils are defined by a high concentration of soluble salts, particularly sodium chloride (NaCl) and other ionic compounds, with an electrical conductivity (EC) greater than 4 dS/m. This condition occurs because salinity is mainly due to shallow saline groundwater combined with frequent flooding and seawater intrusion in low-lying areas. NaCl and Na_2SO_4 are the dominant salts in saline soils, with the abundance of soluble cations, in the order Na > Mg > Ca > K. Salt reaches the soil surface trough capillary upwelling during the dry season, making the soil have a high level of salinity and unproductive for agriculture activity. Salinities range from 0.5 dS/m in the rainy season to 50 dS/m in the dry season [7]. Saline soils also have an alkaline pH of 8.5-15, with high levels of chloride, sodium sulphate, calcium and magnesium [8].

Accumulation of dissolved salts, soil alkalinity, salt toxicity and soil nutrient deficiencies are the main limitations of using saline soils for agricultural purposes [7]. Excessive salt accumulation leads to salt accumulation in the root zone. This excess salt reduces plant growth and vigour by altering water uptake and causing toxicity or specific ion imbalances. High salt concentrations can cause osmotic stress in plants and lead to the accumulation of toxic ions such as Cl^- and Na^+ [9,10], particularly at the soil surface [11]. The presence of excess salt also inhibits the uptake of essential plant nutrients such as potassium (K^+), phosphorus (P) and calcium (Ca_2^+). This will result in stunted growth, chlorosis, a reduction in photosynthetic efficiency and poor crop yields. High salt levels also affect the closure of root vessels, disrupting the uptake of nutrients such as N, P and K. Nutrient deficiency causes plants to wilt, dry out or even die. Nutrient deficiencies also lead to a reduction in height, dry weight and number of tillers [12].

Saline soils present a multitude of challenges. Nevertheless, the extensive area of saline land in Indonesia represents a potential avenue for enhancing sustainable agricultural output. It is estimated that the area of saline land in Indonesia is 12,020,000 ha, which represents 6.20% of the country's total land area [13]. The expansion of agricultural land for shallots cultivation in Brebes Regency has included coastal areas, including Bulakamba and Wanasari Sub-districts, which have extensive areas of saline land [3]. The application of saline-tolerant rhizosphere bacteria, such as Plant Growth-Promoting Rhizobacteria (PGPR), has the potential to transform these soils into productive farmland. These microorganisms enhance nutrient solubilisation [14,15], mitigate salt stress through exopolysaccharide [16], improve production, and root structure [17]. Furthermore, saline soils in coastal regions often represent underutilised agricultural areas, offering opportunities for land expansion. By adopting sustainable management practices, including bio-fertilizer applications and soil improvements, saline soils can support the cultivation of salt-tolerant crops, thereby contributing to food security and sustainable agriculture [18].

1.3 The role of rhizospheric bacteria in enhancing plant growth

The growth of plants on saline land is adversely affected by the accumulation of salt around the root area, which impairs the absorption of nutrients from the soil. This condition results in deficiency of essential nutrients, which can lead to significant challenges in plant growth and development. In order to address this issue, farmers normally employ the use of inorganic fertilizers. This activity has an impact on soil fertility, nutrient availability and soil structure.

The utilization of root-microorganisms has the potential to enhance plant growth in saline soils. It has been demonstrated that bacterial communities in saline and non-saline soils are different. Actinobacteria (7.23%), Firmicutes (4.53%), and Chloroflexi (2.21%) are found in abundance in saline soils [19]. These microorganisms have the potential to be developed as biotechnological solutions to support plant productivity in saline soils. Some bacteria have the ability to produce exopolysaccharides containing functional groups such as carboxyl, carbonyl, hydroxyl, amino, and phosphate. These groups play a role in binding sodium ions (Na^+), which can indirectly reduce the negative effects of salinity stress on plants. This process helps to increase plant tolerance to saline soil conditions [20].

1.4 Objective

The objective of this review is to examine the mechanism of saline-tolerant rhizospheric bacteria to increase the growth and yield of shallots (*Allium ascalonicum* L.) in saline soil. The primary focus is on analysing the ability of bacteria to mitigate the impact of salinity stress, increase nutrient availability, stimulate the production of plant growth hormones, and increase shallot productivity.

2 Review and data collection method

This article is based on a narrative review. This review included multiple databases to support the explanation, including PubMed, Google Scholar, ResearchGate, Frontiers in Microbiology and Plants, and Science Direct. The searching procedure used keywords such as 'Shallots' or '*Allium ascalonicum* L.', 'Plant Growth Promoting Rhizobacteria (PGPR) bacteria', 'saline or sandy soils,' and 'PGPR activity'.

3 Discussion

3.1 Soil salinity and the effects of salinity on shallot crops

The United States Department of Agriculture (USDA) has established a classification system for saline soils, which is based on four categories (slightly saline, moderately saline, strongly saline, and extremely saline). Saline soils are typically characterized by an electrical conductivity (EC) of greater than 4 dS/m, an exchangeable sodium percentage (ESP) of less than 15%, and an acidity (pH) of less than 8.5. This classification serves as a crucial reference guide for understanding the level of soil salinity and its impact on land productivity [21].

High electrical conductivity (EC) values cause changes in osmotic pressure in soils around plants, so plants will find it challenging to grow [22]. Saline soil also causes a decrease in cation exchange capacity and pH, thereby inhibiting nutrient absorption [23]. High salinity causes water stress, ion toxicity, nutritional abnormalities, changes in metabolic processes, membrane disorganization, decreased cell division and expansion rates, and genotoxicity. High salinity also affects plant growth by lowering the osmotic potential of the roots, making it more difficult to absorb water around the roots (osmotic effect) and causing ion toxicity within the cells (ionic effect) [24].

The impact of saline soil stress causes stress conditions in plants. This stress condition increases the biosynthesis of the plant hormone ethylene, making it challenging for plants to grow optimally [25]. The application of Plant Growth-Promoting Rhizobacteria (PGPR) to shallot plants grown on saline soils demonstrated a notable enhancement in several growth and yield parameters, including bulb diameter (cm), bulb weight per plant (g), and the number of bulbs per plant. In particular, the application of PGPR was found to increase the number of bulbs by 33% compared to plants that were not treated with PGPR. This finding indicates that PGPR plays an important role in reducing the effects of salinity stress and increasing shallots productivity in saline soils [20]. Salinity stress causes shallots production in the coastal areas of Warnasari and Bulakamba Sub-district in Brebes Regency to average 88-94 Kw/Ha, lower than in non-coastal areas (non-saline) where the average shallot production reaches 110-126 Kw/Ha [26].

3.2 Effect of rhizospheric bacteria on shallot growth in saline soil

The application of rhizospheric bacteria to enhance plant growth and increase crop yields is becoming more widespread, encompassing a variety of plants, such as shallots. The use of PGPR bacteria, capable of nitrogen fixation and IAA (Indole Acetic Acid) hormone production in shallot plants, has been noted to enhance plant height, leaf count, leaf area, number of bulbs, and bulb diameter [27]. The availability of fulfilled nitrogen elements influenced the increase in growth parameters. Nitrogen can produce nucleic acids that play a role in the cell nucleus in cell division so that the layers of leaves can be appropriately formed, which then develop into shallot bulbs [28]. IAA Phytohormone can also increase the growth of shallots by increasing the number and area of leaves. This result will increase the photosynthesis rate, impacting shallot yields [29]. Another study also reported that bacteria capable of dissolving phosphate can be applied to shallot plants of several varieties in lowland land, such as Bima, Manjung, Ilokos, Mentes, and Rubaru. The application showed the results of the ability of phosphate-dissolving bacteria in increasing flowering, seed formation, and yield, especially in the Bima variety with a dry bulb yield per plot of 288.16 g, equivalent to 16 tonnes/ha and a large bulb percentage of 86.34% [30].

The potential of PGPR bacteria in increasing shallot growth and yield has been reported on marginal land, including saline soil. Saline-resistant bacteria were successfully isolated from saline land and the rhizosphere of plant growth in the north coastal area of Brondong District, Lamongan Regency, East Java, with the ability to produce IAA and nitrogen fixation [31]. The isolates were *Streptomyces* sp., *Bacillus* sp., and *Corynebacterium* sp. The selected bacteria were then applied to shallot plants in saline soils with the results that the bacteria-inoculated plants had significantly higher root dry weights (22.10-30%), the amount of chlorophyll (reaching 26.03%) was higher than without inoculation but had lower allicin in the bulbs. The use of saline-tolerant bacteria can improve plant growth under saline conditions through its ability to dissolve phosphate, fix nitrogen, dissolve potassium, produce IAA hormone, and produce ACC (1-aminocyclopropane-1-carboxylic acid) deaminase enzyme.

The impact of three distinct types of shallots (Bima Brebes, Batu Ijo, and SS Sakato) by treatments ie no inoculation, inoculation with actinobacteria, inoculation with actinobacteria + ameliorant, and inoculation with actinobacteria + ameliorant + dolomite has investigated. The findings indicate that the used of ameliorants + actinobacteria in shallots cultivation on tidal land with water-saturated cultivation represents an optimal approach for enhancing growth and yield, although not to the same extent as the single actinobacteria treatment. The Bima Brebes variety demonstrated considerably higher productivity in comparison to the Batu Ijo and SS Sakato [32].

PGPR (Plant Growth-Promoting Rhizobacteria) isolates used to treat shallot plants grown in sandy soil [33]. The isolates used were *Bacillus methylotrophic*, *Bacillus amyloliquofaciens*, *Bacillus subtilis*, *Burkholderia cepacia*, and *Burkholderia seminalis*. The result shows diverse on various shallot cultivars (Crok, Tiron, and Tuk-tuk). The results demonstrated that the Tiron cultivar shows an optimal performance in bulb number, fresh weight, and dry weight of shallots. The application of *Bacillus subtilis* isolates was observed to result in an increase in bulb diameter, fresh weight, and dry weight. However, no significant differences were noted in comparison to the treatments involving other isolates. Furthermore, The application of *Burkholderia cepacia* and *Burkholderia seminalis* isolates to Tiron cultivars resulted in significantly higher tuber weights compared to treatments using other isolates on Tiron cultivars [34]. Conversely, Crok and Tuk-tuk cultivars exhibited a comparatively lower response to PGPR treatment than Tiron.

3.3 Mechanism of rhizosphere bacteria in increasing shallot tolerance to salinity stress

3.3.1 Increase nutrient absorption (N, P, K)

Nutrient absorption in plants affected by salinity stress will undoubtedly decrease. Salinity stress is caused by high Na^+ content, which inhibits nutrient absorption, especially K ions. It is also due to the disruption of water homeostasis in plant tissues. The use of PGPR in some plants under salinity stress was reported to reduce Na^+ content because bacteria produce exopolysaccharides [14].

Exopolysaccharides function as immunomodulators that significantly increase soil porosity volume, soil aggregates, and retention of Na^+ ions [26]. Bacteria adapt to saline environments osmotically by intracellularly regulating ion concentration by pumping out Na^+/K^+ ions using antiporters or K^+/Na^+ ion transporters. After that, bacteria accumulate solutes by biosynthesizing and regulating the synthesis of essential amino acids, proteins, and enzymes [15].

Some rhizobacteria have the capability to fix nitrogen and are known as diazotroph bacteria. Diazotroph bacteria live freely, and some are symbiotic with plants by forming root nodules. The mechanism of N nutrient absorption by PGPR is by giving a signal to the nitrogenase enzyme in the bacteria, which then catalyses N_2 into NH_3 (ammonia). The catalysis results in the form of ammonia, which can then be absorbed by plants [35].

Azospirillum is a genus that is commonly found in the soil rhizosphere and has diverse PGPR abilities, Azospirillum isolates are able to help plants by providing N that plants can absorb. Azospirillum is also able to promote root growth, produce IAA, promote root growth in high oil environments, and increase the absorption of K^+ ions and produce phosphate [36–38].

Plants require phosphate as a vital nutrient for their growth. In nature, phosphate is available in organic and inorganic forms. PGPR also can dissolve phosphate in suboptimal soils, known as phosphate solubilizing bacteria. These bacteria work by converting bound P ($H_2PO_4^-$) into soluble P (HPO_4^{2-}) so that it can be absorbed by plants [39].

Potassium in stressed soil has a small content because minerals or other compounds bind it. The mechanism of bacteria dissolving potassium compounds is by producing organic acids such as citric acid, malic acid, oxalic acid, and gluconic acid, which can then weaken the potassium bonds so that they can be available [40].

3.3.2 Producing plant hormones (IAA, Gibberellins)

Saline conditions also affect the production of growth hormones in plants. In this case, PGPR has a role in producing plant growth regulators. Salinity stress stimulates the enzyme ACC deaminase in bacteria to reduce ethylene synthesis, which causes plant senescence and increases the content of IAA, cytokines, and gibberellins in plants [39]. The production of auxin by rhizosphere bacteria will be stimulated by the root exudate, especially by the precursor amino acid in the form of tryptophan, so that the bacteria are able to produce IAA for the host plant [41]. IAA biosynthesis can occur through three pathways that begin with tryptophan precursors, including the indole-3-acetamide (IAM) pathway, the indole-3-pyruvic acid (IPA) pathway, and the indole-3-acetonitrile (IAN) pathway [17].

Cytokinins play an essential role in the vascular system of plants in the embryogenesis phase through the formation of root nodules and response to environmental changes [42]. Gibberellin is a terpenoid derived from the precursor 20-carbon isoprenyl-geranylgeranyl diphosphate (GGPP). Gibberellin biosynthesis begins with two cyclical reactions, first with the formation of ent-copalyl diphosphate (CPP) from GGPP by ent-CPP synthase, and second through the formation of ent-kaurene from ent-kaurene synthase [43]. *Bacillus* sp. is known for its nitrogen-fixing ability, antifungal properties, production of anti-fouling substances, and synthesis of the gibberellin hormone [36,44]. Conversely, *Pseudomonas* sp. is reported to produce cytokines and can be utilized as a bioremediation agent.

3.3.3 Production of ACC deaminase enzyme

ACC Deaminase enzyme is a cytoplasmic enzyme produced by some rhizosphere bacteria to degrade ACC (precursor of ethylene hormone in plants) into ammonia and α-ketobutyrate which are sources of nitrogen and carbon for bacteria [45]. The mechanism of the ACC deaminase enzyme in increasing plant growth in saline land is by reducing ethylene, increasing nitrogen availability, reducing oxidative stress, increasing osmoregulation, and accumulation of plant resistance hormones [46].

Halotolerant bacteria isolated from wheat fields in saline soils from the genus Bacillus and Halomonas, which can produce the hormone IAA and the enzyme ACC deaminase, fix nitrogen, and dissolve phosphate [47]. An isolate from *Oxalis corniculate*, *Kocuria rhizophila*: KF875448 (14ASP), and *Cronobacter sakazakii*: KM042090 (OF115) have the ability to produce ACC deaminase enzyme and dissolve potassium [48]. The bacterial isolates were then applied to wheat plants in saline soil, which showed their ability to reduce ethylene stress salt poisoning and significantly increase production. Shallots grown on saline soils with the application of ACC deaminase-producing bacteria had a better effect on the growth and yield, such as root dry weight, leaf area, plant growth rate, total dry weight, plant height, bulbs oven dry weight, bulbs diameter, harvest index, bulbs fresh weight, bulbs weight loss, and sun-dried bulbs weight [25].

3.3.4 Exopolysaccharide and biofilm formulation

Exopolysaccharide (EPS) stands for ‘exopolymer saccharide’, a complex sugar polymer produced by microorganisms and secreted into their external environment. It is closely related to biofilm formation [49]. Exopolysaccharide production by bacteria is an important mechanism that contributes to the enhancement of shallot growth in saline soils.

Plant growth-promoting bacteria (PGPB) that produce exopolysaccharides can effectively increase shallot productivity in marginal lands [16]. Increased growth and productivity are achieved through several processes, one of which involves the formation of gels around plant roots to improve water and nutrient absorption. This process promotes better water retention and the uptake of important nutrients like nitrogen, phosphorus, and potassium. Such mechanisms are crucial because water and nutrients can easily dissolve, bound, or lost in high salt conditions [50].

Exopolysaccharides can function as plant protectors against environmental stress caused by high salt levels. They achieve this by reducing plants' uptake of excess salt ions. Excess salt ions can potentially harm plant cells and disrupt crucial physiological processes. This mechanism is elucidated in Figure 1, wherein bacteria can control the sodium level in the environment to ensure it does not reach harmful concentrations around the plant. Additionally, these bacteria can act as chelating agents [51]. The presence of exopolysaccharide-producing bacteria has been shown to enhance plant growth in saline soil by stimulating the production of growth hormones and enzymes, fostering more remarkable symbiosis with mycorhizal fungi, and generating antibacterial compounds that are effective against pathogens [16].

Research related to the application of EPS-producing bacteria informed that *Bacillus* sp. inoculated on lettuce plants showed higher N, P, and K concentrations under stress conditions increased by 5, 70, and 50%, respectively, compared to the control [52]. Streptococcus sp. is able to produce compounds that can kill pathogens around plants [53].

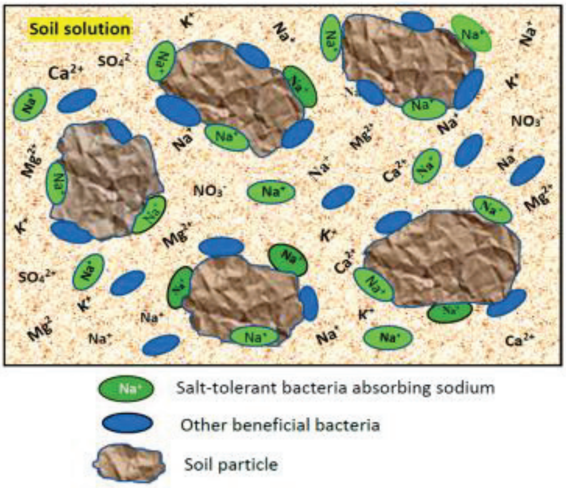

Fig. 1. Absorption of Na in saline soil [54].

3.3.5 Osmoprotectant

Osmoprotectants are compounds that help cells maintain their water balance in an environment that has high osmotic pressure. Saline soil has high osmotic pressure due to its high salt content [51]. This high osmotic pressure can pull water out of plant cells, leading to dehydration and cell damage. Cells use osmoprotectants to regulate their water balance by elevating the cell's internal osmotic pressure. This phenomenon helps prevent dehydration and cell damage and allows plants to grow and thrive in these saline soils [16].

These saline-resistant bacteria can help plants maintain cell water balance, protect enzymes and proteins, increase stress resistance, enhance photosynthesis, and increase mycorrhizal symbiosis [55]. One of the osmoprotectant-producing bacteria, *Serratia marcescens*, was reported to be able to increase shallot growth under stress conditions due to *Xanthomonas axonopodis* pv. allii. *S. marcescens* bacteria produce osmoprotectants that can increase shallot roots through a peroxide enzyme protection mechanism [55].

3.4 Examples of rhizospheric bacteria that can increase shallots growth in saline soils

Extensive research on plant-beneficial microorganisms has led to the development of various types of biofertilizers that can meet the nutritional needs of plants. In particular, successfully isolated rhizobial inocula are often applied to legumes. The application of these bacteria can increase the growth and production of legumes. Rhizobia is assumed to fulfil up to 90% of the N requirement of legume plants [56]. The use of growth-promoting microorganisms is increasingly being developed. Previous research showed that bacteria from the genus

Pseudomonas, Azotobacter, Bacillus, and Serratia were identified as PGPR phytohormone producers capable of increasing plant growth and yield [18].

Research on bacteria that can improve plant resistance in saline soil has been extensively documented in the publications. The bacteria that are able to live in saline condition are usually the genus Helianthus, Pseudomonas, Hallobacillus, and Bacillus. Bacillus, reported by [57], has genes that support living in salinity. The genus can also produce ACC diaminase and uses endospores in self-defense. Hallobacillus is reported to be able to produce IAA, grow in medium with KCl and 10% NaCl, produce HCN, and produce phosphate and ammonia.

The research has did to get bacteria from the genus Bacillus, Oceanobacillus, and Halomonas isolated from the rhizosphere of wheat plants. These bacteria are saline resistant, able to dissolve phosphate, produce IAA, and fix nitrogen [58]. Research also has did on a consortium of saline-resistant bacteria that can produce IAA hormone and ACC Deaminase enzyme. The isolate was applied to rice plants in saline soil, and the results showed that it increased plant growth [59]. The Halotolerant bacteria can increase rice growth in saline land by up to 20% [60]. The following table noted some studies related to the inoculation of PGPR bacteria that are reported to be able to increase the growth and yield of shallots on saline land.

Table 1. Examples of bacteria in the rhizosphere that have the potential to increase the growth of shallots in saline soils.

Isolate	Origin	Shallot's Varieties	PGPR Characteristic	Result	Reference
Steptomyces sp.	Tidal land	Bima Brebes, Batu Ijo, and SS Sakato	N-fixers, P, K, Fe, and Al solubilizers	Improved plant growth, shallot bulbs, and increased uptake of N, P, and K	[32]
Pseudomonas putida	N/A	Tiron, Biru	ACC deaminase producer	Root dry weight, leaf area, plant growth rate, total dry weight, plant height, bulb oven dry weight, bulb diameter, harvest index, bulb fresh weight, bulb weight loss, and sun-dried bulb weight	[25]
Bacillus methylotrophic, *Bacillus amyloliquofaciens*, *Bacillus subtilis*, *Burkholderia cepacia*, *Burkholderia seminalis*	Lamongan Beach sand	Tiron, Tuk-tuk, Crok	N-fixers	Germination, large number of bulbs, high fresh and dry weight of bulbs.	[34]

Streptomyces sp., *Bacillus* sp., and *Corynebacterium* sp.	Plant rhizosphere in saline soil located in the north coastal area of Brondong Sub-district, Lamongan Regency, East Java.	Bauji	IAA and N-fixers	Increased root weights and chlorophyll levels	[31]
Rhodobacter spp. and *Rhodopseudomonas* spp.	N /A	Crok Kuning	Phosphate Solubilizer and N- Fixer	Root length, chlorophyll content, nitrate reductase activity, fresh and dry weight of roots and shoots, number of bulbs per clump, fresh and dry weight of bulbs per clump, and overall productivity	[61]

3.5 The potential of rhizosphere bacteria to increase shallot productivity in saline soils

The use of rhizospheric bacteria in shallots cultivation has the potential to increase plant productivity and quality by producing plant hormones that function in plant growth and development. In controlling pests and plant diseases, rhizospheric bacteria carry out antagonistic reactions to pathogens and induce plant resistance to disease and environmental stress. Biofertilizers will undoubtedly be more environmentally friendly, so their use can reduce harmful chemical fertilizers and pesticide products that can affect environmental quality in the future. Reducing chemical fertilizers and pesticides can also reduce the production costs used to meet these needs, which is expected to increase profits for farmers. Environmental quality is improved by the presence of rhizosphere bacteria by improving soil structure and assisting in the process of bioremediation and decomposition of organic matter in the soil [62].

3.6 Challenges and opportunities in the utilization of rhizosphere bacteria

Microorganisms such as bacteria are able to survive, but they exhibit different levels of effectiveness under specific environmental conditions, particularly stressful ones. Environmental adaptation needs to be done by bacteria because, during laboratory testing, bacteria can live on well-nourished media. Therefore, conducting a test under field conditions is also necessary.

In developing these bacteria, a suitable formulation is needed to maintain the quality of the bacteria so that it remains alive even though it is stored for a long time and through a long process. Large-scale production of bacteria is also a challenge for producers in producing products that have good quality. Production costs to produce good products also need to be considered. It is essential to consider this not just during manufacturing but also during transportation and use to uphold the quality of the bacteria. The application process on plants needs to be considered to get optimal results. Effective use of bacteria is usually done by mixing with soil or applying it to the leaves of plants [63].

Using rhizosphere bacteria presents another obstacle, which is the acceptance of this biofertilizer product in the market and ensuring its safety. Market acceptance is an obstacle in the community because biofertilizer products are usually less attractive to the public because they have an insignificant effect and take a long time to show tangible results. This fact makes this product less desirable, leading to a preference for chemicals among farmers due to their quicker effect [62].

4 Conclusion

Rhizosphere bacteria can significantly enhance the growth of shallots in saline soil by acting as Plant Growth-Promoting Rhizobacteria (PGPR). These bacteria facilitate plant growth through various mechanisms, including increasing the availability of essential nutrients like nitrogen (N), phosphorus (P), and potassium (K). Additionally, they produce growth hormones, ACC Deaminase enzymes, exopolysaccharides, and osmoprotectants, all of which contribute to better plant health and growth. When applied to shallot plants, PGPR bacteria improve root length, leaf development, chlorophyll content, and yields, as evidenced by the increased bulb diameter and number of bulbs.

The bacteria identified as having the potential to enhance shallot growth in saline soils include *Azospirillum* sp., *Bacillus* sp., *Pseudomonas putida*, *Streptomyces* sp., *Bacillus methylotrophic*, *Bacillus amyloliquefaciens*, *Bacillus subtilis*, *Burkholderia cepacia*, and *Burkholderia seminalis*.

Future research and development should focus on improving the formulation of these rhizosphere bacteria to ensure their longevity and viability, even during extended storage and prolonged processing phases. This enhancement is crucial for maintaining the functional integrity of the bacteria, ensuring they remain biologically active and effective when applied to crops.

References

1. Pusat Informasi Harga Pangan Strategis Nasional, Inf. Harga Pangan Antar Drh. (2024)
2. Badan Pusat Statistik Brebes, Data Has. Panen Bawang Merah Di Wil. Brebes (2020)
3. Badan Pusat Statistik Brebes, Lahan Kadar Garam Tinggi Di Wil. Brebes (2022)
4. I. Annisa, R. W. Asmarantaka, and R. Nurmalina, Mix J. Ilm. Manaj. **8**, 254 (2018)
5. D. F. W. Permana, A. H. Mustofa, L. Nuryani, P. S. Krisputra, and Y. Alamudin, J. Bina Desa **3**, 125 (2021)
6. L. Rachma Septiana, M. Machfud, and I. Yuliasih, J. Teknol. Ind. Pertan. **27**, 125 (2017)
7. C. Arulmathi and G. Porkodi, Int. J. Curr. Microbiol. Appl. Sci. **9**, 1726 (2020)
8. A. C. A. L. Fall, Int. J. Biol. Chem. Sci. **11**, 1903 (2017)
9. P. M. Hasegawa, R. A. Bressan, J. K. Zhu, and H. J. Bohnert, Annu. Rev. Plant Biol. **51**, 463 (2000)
10. F. J. M. Maathuis, J. Exp. Bot. **57**, 1137 (2006)
11. V. Karolinoerita and W. Annisa, J. Sumberd. Lahan **14**, 91 (2020)

12. F. Krismiratsih, S. Winarso, and S. Slamerto, J. Ilmu Pertan. Indones. **25**, 349 (2020)
13. J. LUO, S. ZHANG, X. ZHU, L. LU, C. WANG, C. LI, J. CUI, and Z. ZHOU, J. Integr. Agric. **16**, 1624 (2017)
14. M. Shabaan, H. N. Asghar, Z. A. Zahir, X. Zhang, M. F. Sardar, and H. Li, Front. Microbiol. **13**, (2022)
15. F. H. Khumairah, M. R. Setiawati, B. N. Fitriatin, T. Simarmata, S. Alfaraj, M. J. Ansari, H. A. E. Enshasy, R. Z. Sayyed, and S. Najafi, Front. Microbiol. **13**, 1 (2022)
16. M. Kibret, K. Devkota, W. Benbakrim, A. Ezzariai, H. Terefe, F. Karouach, M. Sobeh, M. Hafidi, and L. Kouisni, CABI Rev. **19**, 1 (2024)
17. D. R. Duca and B. R. Glick, Appl. Microbiol. Biotechnol. **104**, 8607 (2020)
18. J. H. Purba, P. S. WAHYUNI, Z. ZULKARNAEN, N. SASMITA, I. G. A. D. YUNITI, and N. P. PANDAWANI, Nusant. Biosci. **12**, 127 (2020)
19. S. Mukhtar, B. S. Mirza, S. Mehnaz, M. S. Mirza, J. Mclean, and K. A. Malik, World J. Microbiol. Biotechnol. **34**, 136 (2018)
20. D. T. Rahmandhias, A. S. Karyawati, D. Hariyono, and M. D. Maghfoer, J. Degrad. Min. Lands Manag. **11**, 6461 (2024)
21. A. I. Ismayilov, A. I. Mamedov, H. Fujimaki, A. Tsunekawa, and G. J. Levy, Sustain. **13**, 1 (2021)
22. R. cahyaty, N. Aini, and T. Sumarni, Biotropika - J. Trop. Biol. **5**, 133 (2017)
23. R. Mukhopadhyay, B. Sarkar, H. S. Jat, P. C. Sharma, and N. S. Bolan, J. Environ. Manage. **280**, 111736 (2021)
24. G. Giannelli, S. Potestio, and G. Visioli, Plants **12**, (2023)
25. I. A. S. Akhwan, E. Sulistyaningsih, and J. Widada, Vegatilika **1**, 1 (2012)
26. Badan Pusat Statistik Brebes, Has. Panen Bawang Merah Di Brebes (2020)
27. C. Novatriana and D. Hariyono, PLANTROPICA J. Agric. Sci. **5**, 1 (2020)
28. N. Sumarni, J. Hortik. **22**, 14 (2012)
29. M. N. Haq, J. Repos. Univ. Muhammadiyah Jember **1**, 1 (2015)
30. E. Triharyanto, J. Syamsiyah, S. Nyoto, and E. A. L. Wardyani, IOP Conf. Ser. Earth Environ. Sci. **423**, 4 (2020)
31. N. Aini, W. Yamika, L. Qurata Aini, N. Azizah, and E. Sukmarani, J. Hortik. Indones. **10**, 182 (2019)
32. A. Haitami, M. Ghulamahdi, D. Sopandie, A. D. Susila, and Y. Lestari, IOP Conf. Ser. Earth Environ. Sci. **1359**, 4 (2024)
33. S. Tuhuteru, E. Sulistyaningsih, and A. Wibowo, Ilmu Pertan. (Agricultural Sci. **1**, 105 (2017)
34. S. Tuhuteru, E. Sulistyaningsih, and D. A. Wibowo, J. Agron. Indones. (Indonesian J. Agron. **47**, 53 (2019)
35. C. Santi, D. Bogusz, and C. Franche, Ann. Bot. **111**, 743 (2013)
36. T. T. Alawiye and O. O. Babalola, Diversity **11**, (2019)
37. A. Belimov, A. M. Kunakova, V. Safronova, V. V Stepanok, L. Y. Yudkin, Y. V. Alekseev, and K. A.P., Microbiology **73**, 99 (2004)
38. V. Orlandini, G. Emiliani, M. Fondi, I. Maida, E. Perrin, and R. Fani, Int. J. Evol. Biol. **2014**, 951035 (2014)
39. A. Kumar, S. Singh, A. K. Gaurav, S. Srivastava, and J. P. Verma, Front. Microbiol.

11, 1 (2020)

40. L. Mutmainnah, I. Anas, B. Nugroho, P. Studi Ilmu Tanah, and U. Jember, J. Agric. Sci. **21**, 2023 (2023)
41. Suliasih and S. Widawati, IOP Conf. Ser. Earth Environ. Sci. **572**, (2020)
42. M. Vocciante, M. Grifoni, D. Fusini, G. Petruzzelli, and E. Franchi, Appl. Sci. **12**, (2022)
43. R. S. Nett, H. Nguyen, R. Nagel, A. Marcassa, T. C. Charles, I. Friedberg, and R. J. Peters, MSphere **5**, (2020)
44. A. K. Shukla, in *PGPR Amelior. Sustain. Agric.*, edited by A. K. Singh, A. Kumar, and P. K. Singh (Woodhead Publishing, 2019), pp. 1–15
45. C. B. Jacobson, J. J. Pasternak, and B. R. Glick, Can. J. Microbiol. **40**, 1019 (1994)
46. M. D. C. Orozco-Mosqueda, B. R. Glick, and G. Santoyo, Microbiol. Res. **235**, 126439 (2020)
47. D. Ramadoss, V. K. Lakkineni, P. Bose, S. Ali, and K. Annapurna, Springerplus **2**, 1 (2013)
48. M. S. Afridi, Amna, Sumaira, T. Mahmood, A. Salam, T. Mukhtar, S. Mehmood, J. Ali, Z. Khatoon, M. Bibi, M. T. Javed, T. Sultan, and H. J. Chaudhary, Plant Physiol. Biochem. **139**, 569 (2019)
49. Aisha Waheed Qurashi, African J. Microbiol. Res. **5**, 3546 (2011)
50. A. A. H. A. Latef, A. M. Omer, A. A. Badawy, M. S. Osman, and M. M. Ragaey, Plants **10**, 1 (2021)
51. S. Sultana, S. Alam, and M. M. Karim, J. Agric. Food Res. **4**, 100150 (2021)
52. A. Vivas, A. Marulanda, J. M. Ruiz-Lozano, J. M. Barea, and R. Azcón, Mycorrhiza **13**, 249 (2003)
53. Y.-K. Park, S.-W. Nho, G.-W. Shin, S.-B. Park, H.-B. Jang, I.-S. Cha, M.-A. Ha, Y.-R. Kim, R. S. Dalvi, B.-J. Kang, and T.-S. Jung, Vet. Microbiol. **136**, 76 (2009)
54. R. Shultana, A. T. K. Zuan, U. A. Naher, A. K. M. M. Islam, M. M. Rana, M. H. Rashid, I. J. Irin, S. S. Islam, A. A. Rim, and A. K. Hasan, Agronomy **12**, (2022)
55. Z. Resti, T. Habazar, D. P. Putra, and Nasrun, J. Trop. Plant Pests Dis. **16**, 131 (2016)
56. C. Franche, K. Lindstrom, and C. Elmerich, (2009)
57. A. Sharma, K. Dev, A. Sourirajan, and M. Choudhary, J. Genet. Eng. Biotechnol. **19**, 99 (2021)
58. R. N. Albdaiwi, H. Khyami-Horani, J. Y. Ayad, K. M. Alananbeh, and R. Al-Sayaydeh, Oxid. Med. Cell. Longev. **10**, 1 (2020)
59. L. Rajput, A. Imran, F. Mubeen, and F. Hafeez, 178 (2018)
60. M. Wang, L. Ai, M. Zhang, F. Wang, and C. Wang, 3 Biotech **10**, 430 (2020)
61. Y. Avianto and W. Susila, J. Agron. Tanam. Trop. **6**, 185 (2024)
62. Jumin H. B., M. Nur, W. Warnita, H. Hapsoh, S. Ulpah, Mardaleni, T. Maharani, S. E., U. Paman, S. Elida, Fahrial, S. Vaulina, I. S. Dewi, S. Bahri, J. Setiaji, and H. Hermansah, *Pertanian Berkelanjutan* (UIR Press, Pekanbaru, 2024)
63. A. Efthimiadou, N. Katsenios, S. Chanioti, M. Giannoglou, N. Djordjevic, and G. Katsaros, Sci. Rep. **10**, 1 (2020)