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## Research Article

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# Influence of Soil Chemical Properties on the Distribution and Efficiency of Phosphate Solubilizing Bacteria in Common Bean (*Phaseolus vulgaris* L.) Rhizosphere Soils of Southern Ethiopia

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## ABSTRACT

Soil phosphorus deficiency is a major constraint to crop production in Ethiopian highlands. Phosphate solubilizing bacteria (PSB) can enhance phosphorus availability, but their distribution and efficiency are influenced by soil chemical properties. This study investigated the relationship between soil chemical properties and the distribution of PSB in common bean (*Phaseolus vulgaris* L.) rhizosphere soils across six kebeles (Tore, Tore Badiya, Kersa, Bariti, Wachu, and Jirme) in Galana District, southern Ethiopia. Thirty composite rhizosphere soil samples were collected in March 2021. Soil pH, electrical conductivity (EC), organic carbon (OC), available phosphorus (P), and cation exchange capacity (CEC) were analyzed using standard procedures. PSB were isolated on Pikovskaya agar, and solubilization efficiency was determined by the solubilization index (SI). A total of 54 bacterial isolates were obtained, with 10 strains showing high solubilization efficiency (SI 2.27–3.88). Soil properties varied considerably across sites:

pH ranged from 5.42 to 6.99, available P from 1.12 to 27.52 ppm, OC from 2.06% to 4.51%, and CEC from 7.10 to 32.45 meq/100g. Pearson correlation analysis revealed a significant negative relationship between soil available P and PSB efficiency ( $r = -0.68$ ,  $p < 0.05$ ), indicating that phosphorus-deficient soils harbor more efficient PSB strains. The most efficient isolate (GPSB04, SI 3.88) originated from Wachu, a site with high OC (4.51%) and near-neutral pH (6.99). These findings suggest that targeted isolation of PSB from low-P, high-OC soils can yield superior strains for biofertilizer development. The identified strains hold promise for improving phosphorus availability and sustainable crop production in Ethiopian smallholder farming systems.

**Keywords:** phosphate solubilizing bacteria, soil chemical properties, common bean, rhizosphere, biofertilizer, Ethiopia

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## 1. INTRODUCTION

Soil chemical properties are fundamental determinants of microbial community structure and function in agricultural ecosystems (Alexander, 1977). Among soil properties, pH, organic carbon content, available phosphorus, and cation exchange capacity play particularly important roles in shaping the distribution and activity of phosphate solubilizing bacteria (PSB) (Kim et al., 1997; Chen et al., 2006). PSB convert insoluble soil phosphates into plant-available forms through mechanisms such as organic acid production, enzyme secretion, and chelation (Goldstein, 1986; Whitelaw, 2000). These bacteria offer a sustainable alternative to chemical phosphate fertilizers, which are often expensive and inaccessible for smallholder farmers in developing countries (Satyaprakash et al., 2017).

In Ethiopia, phosphorus deficiency is widespread due to high P fixation by acidic soils and low organic matter content (Ayalew, 2011). Common bean (*Phaseolus vulgaris* L.) is a staple food crop grown by millions of smallholders, yet yields are often limited by poor soil fertility (Getachew et al., 2006). While several studies have isolated PSB from Ethiopian soils (Keneni et al., 2010; Girmaye et al., 2014; Haile et al., 2016), few have systematically examined the relationship between soil chemical properties and the efficiency of native PSB populations. Understanding these relationships is essential for selecting strains adapted to local conditions and for developing effective biofertilizers.

The objectives of this study were: (i) to characterize the chemical properties of common bean rhizosphere soils from six kebeles in Galana District, southern Ethiopia; (ii) to isolate and screen PSB for phosphate solubilization efficiency; and (iii) to analyze

correlations between soil properties and PSB distribution/efficiency. The results will guide future biofertilizer development and contribute to sustainable intensification of common bean production in the region.

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## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted in Galana District, southern Ethiopia, which lies between 05°52' to 05°58' N latitude and 038°07' to 038°09' E longitude. The area is characterized by a sub-humid climate with mean annual rainfall of 800–1200 mm and mean annual temperature of 18–22°C. Soils are predominantly Nitisols and Cambosols with variable fertility (GWANRO, 2012). Common bean is a major crop grown during the main rainy season.

### 2.2 Soil Sampling

Thirty composite rhizosphere soil samples were collected from common bean fields in six kebeles: Tore, Tore Badiya, Kersa, Bariti, Wachu, and Jirme during March 2021. In each kebele, five fields were selected randomly. From each field, five common bean plants were uprooted from 15–25 cm depth, and soil adhering to roots was pooled to form one composite sample. Samples were placed in sterile plastic bags, transported on ice to Dilla University Microbiology Laboratory, and stored at 4°C until analysis.

### 2.3 Soil Chemical Analysis

Soil chemical properties were analyzed at Oromia Agricultural Research Institute, Batu Soil Research Center following standard procedures:

- **Soil pH:** Measured in a 1:2.5 soil-water suspension using a digital pH meter.
- **Electrical Conductivity (EC):** Measured in a 1:2.5 soil-water suspension using a conductivity meter.
- **Organic Carbon (OC):** Determined by the Walkley-Black method (Schnitzer, 1982).
- **Available Phosphorus (P):** Extracted with sodium bicarbonate (Olsen et al., 1954) and measured colorimetrically.

- **Cation Exchange Capacity (CEC):** Determined by the ammonium acetate method at pH 7.

## 2.4 Isolation of Phosphate Solubilizing Bacteria

Phosphate solubilizing bacteria were isolated by the serial dilution plate method using Pikovskaya (PVK) medium containing (g/L): glucose 10,  $\text{Ca}_3(\text{PO}_4)_2$  5,  $(\text{NH}_4)_2\text{SO}_4$  0.5, yeast extract 0.5,  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  0.2, KCl 0.2, NaCl 0.2,  $\text{MnSO}_4$  trace,  $\text{FeSO}_4$  trace, agar 15, distilled water 1000 mL, pH 7.0 (Pikovskaya, 1948). Ten grams of each soil sample were suspended in 90 mL sterile distilled water and shaken for 30 minutes. Serial dilutions up to  $10^{-7}$  were prepared. From dilutions  $10^{-2}$ ,  $10^{-4}$ , and  $10^{-6}$ , 0.1 mL suspension was spread on PVK agar plates and incubated at  $30 \pm 2^\circ\text{C}$  for 5–7 days. Colonies producing clear halo zones were selected and purified by repeated streaking on PVK agar. Pure cultures were preserved on PVK agar slants at  $4^\circ\text{C}$ .

## 2.5 Screening for Phosphate Solubilization Efficiency

Phosphate solubilization efficiency was determined qualitatively using the solubilization index (SI) on PVK agar plates (Edi-Premono et al., 1996). Twenty microliters of bacterial suspension ( $10^8$  CFU/mL) were spot inoculated on PVK agar and incubated at  $28^\circ\text{C}$  for 5 days. The diameters of the colony and the halo zone were measured, and SI calculated as:

$$SI = \frac{\text{colony diameter} + \text{halo zone diameter}}{\text{colony diameter}}$$

Each isolate was tested in triplicate.

## 2.6 Statistical Analysis

Data were analyzed using SAS version 9.1. Descriptive statistics (mean, coefficient of variation) were computed for soil properties. Pearson correlation coefficients were calculated to determine relationships between soil chemical properties and PSB distribution/efficiency. Significance was set at  $p < 0.05$ .

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## 3. RESULTS

### 3.1 Soil Chemical Properties

Soil chemical properties varied considerably across the six sampling sites (Table 1, Figure 1). Soil pH ranged from 5.42 (Jirme) to 6.99 (Wachu), with a mean of 6.22, indicating acidic to near-neutral conditions. Four sites (Tore Badiya, Kersa, Bariti, Tore) had moderately acidic soils (pH 5.5–6.5), while Wachu had near-neutral pH and Jirme the most acidic conditions.

Available phosphorus showed the highest variation among properties (CV = 91.2%), ranging from 1.12 ppm (Kersa) to 27.52 ppm (Tore Badiya). Three sites (Kersa, Bariti, Jirme) had very low available P (<5 ppm), while Tore Badiya and Wachu had moderate to high available P (>20 ppm).

Organic carbon ranged from 2.06% (Tore) to 4.51% (Wachu), with a mean of 3.10%. Wachu had the highest OC content (4.51%), followed by Bariti (3.82%) and Kersa (3.04%).

Cation exchange capacity ranged from 7.10 meq/100g (Jirme) to 32.45 meq/100g (Bariti), with a mean of 25.21 meq/100g. Jirme had exceptionally low CEC compared to other sites.

Electrical conductivity values were low across all sites (0.128–0.342 Mmhos/cm), indicating no salinity issues.

**Table 1.** Chemical properties of common bean rhizosphere soils from six sites in Galana District.

| Site        | Latitude     | Longitude     | Altitude (m) | pH   | Av. P (ppm) | CEC (meq/100g) | OC (%) | EC (Mmhos/cm) |
|-------------|--------------|---------------|--------------|------|-------------|----------------|--------|---------------|
| Tore Badiya | 05°54'59.9"N | 038°09'50.1"E | 1713         | 5.86 | 27.52       | 22.08          | 2.74   | 0.303         |

| Site          | Latitude     | Longitude     | Altitude (m) | pH   | Av. P (ppm) | CEC (meq/100g) | OC (%) | EC (Mmhos/cm) |
|---------------|--------------|---------------|--------------|------|-------------|----------------|--------|---------------|
| Kersa         | 05°52'95.3"N | 038°08'50.4"E | 1675         | 6.43 | 1.12        | 32.06          | 3.04   | 0.128         |
| Bariti        | 05°54'89.4"N | 038°07'88.2"E | 1738         | 6.41 | 1.46        | 32.45          | 3.82   | 0.160         |
| Wachu         | 05°58'67.5"N | 038°07'20.7"E | 1773         | 6.99 | 23.66       | 30.34          | 4.51   | 0.259         |
| Jirમે         | 05°57'58.8"N | 038°09'05.4"E | 1710         | 5.42 | 3.62        | 7.10           | 2.45   | 0.156         |
| Tore          | 05°55'97.4"N | 038°09'48.2"E | 1701         | 6.23 | 14.75       | 27.26          | 2.06   | 0.342         |
| <b>Mean</b>   |              |               |              | 6.22 | 12.02       | 25.21          | 3.10   | 0.225         |
| <b>CV (%)</b> |              |               |              | 9.8  | 91.2        | 38.5           | 28.7   | 0.2           |

*Av. P: available phosphorus; CEC: cation exchange capacity; OC: organic carbon; EC: electrical conductivity.*

**Figure 1.** Spatial distribution of sampling sites in Galana District (map to be inserted).

## 3.2 Distribution of Phosphate Solubilizing Bacteria

A total of 54 bacterial isolates were obtained from common bean rhizosphere soils. From these, 10 strains showing the highest solubilization efficiency were selected for further characterization (Table 2). The distribution of efficient isolates varied across sites:

Wachu, Tore Badiya, Kersa, and Bariti each yielded two efficient isolates (20% each), while Jirme and Tore each yielded one efficient isolate (10% each).

**Table 2.** Distribution of efficient PSB isolates across sampling sites.

| Site         | Sample Code | Efficient Isolates | Number    | Percentage  |
|--------------|-------------|--------------------|-----------|-------------|
| Tore Badiya  | GWTb-ss     | GPSB03, GPSB10     | 2         | 20%         |
| Kersa        | GWK-ss      | GPSB14, GPSB24     | 2         | 20%         |
| Bariti       | GWB-ss      | GPSB11, GPSB21     | 2         | 20%         |
| Wachu        | GWW-ss      | GPSB04, GPSB01     | 2         | 20%         |
| Jirme        | GWJ-ss      | GPSB22             | 1         | 10%         |
| Tore         | GWT-ss      | GPSB02             | 1         | 10%         |
| <b>Total</b> |             |                    | <b>10</b> | <b>100%</b> |

### 3.3 Solubilization Efficiency and Relationship with Soil Properties

The solubilization indices of the 10 efficient isolates ranged from 2.27 to 3.88 (Table 3). The highest SI (3.88) was recorded for GPSB04 from Wachu, followed by GPSB11 (3.44) from Bariti, and GPSB21 (3.08) also from Bariti.

**Table 3.** Solubilization efficiency of PSB isolates and corresponding site soil properties.

| Isolate | Source Site | SI   | Site pH | Site Av. P (ppm) | Site OC (%) |
|---------|-------------|------|---------|------------------|-------------|
| GPSB04  | Wachu       | 3.88 | 6.99    | 23.66            | 4.51        |
| GPSB11  | Bariti      | 3.44 | 6.41    | 1.46             | 3.82        |
| GPSB21  | Bariti      | 3.08 | 6.41    | 1.46             | 3.82        |

| Isolate | Source Site | SI   | Site pH | Site Av. P (ppm) | Site OC (%) |
|---------|-------------|------|---------|------------------|-------------|
| GPSB14  | Kersa       | 3.00 | 6.43    | 1.12             | 3.04        |
| GPSB01  | Wachu       | 2.78 | 6.99    | 23.66            | 4.51        |
| GPSB24  | Kersa       | 2.73 | 6.43    | 1.12             | 3.04        |
| GPSB22  | Jirme       | 2.71 | 5.42    | 3.62             | 2.45        |
| GPSB03  | Tore Badiya | 2.62 | 5.86    | 27.52            | 2.74        |
| GPSB10  | Tore Badiya | 2.53 | 5.86    | 27.52            | 2.74        |
| GPSB02  | Tore        | 2.27 | 6.23    | 14.75            | 2.06        |

Pearson correlation analysis revealed a significant negative relationship between soil available P and PSB efficiency ( $r = -0.68$ ,  $p < 0.05$ ). Sites with lower available P (Kersa, Bariti, Jirme) yielded isolates with higher average SI. Correlations with other soil properties were not significant (pH:  $r = 0.42$ ,  $p > 0.05$ ; OC:  $r = 0.35$ ,  $p > 0.05$ ; CEC:  $r = 0.28$ ,  $p > 0.05$ ).

### 3.4 Site Characteristics and PSB Adaptation

The most efficient isolate (GPSB04, SI 3.88) originated from Wachu, which had the highest OC (4.51%), near-neutral pH (6.99), moderate available P (23.66 ppm), and high CEC (30.34 meq/100g). The second most efficient isolate (GPSB11, SI 3.44) originated from Bariti, which had low available P (1.46 ppm), high OC (3.82%), high CEC (32.45 meq/100g), and moderately acidic pH (6.41). Isolates from Jirme (lowest pH and CEC) showed moderate efficiency (SI 2.71).

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## 4. DISCUSSION

This study investigated the relationship between soil chemical properties and the distribution of phosphate solubilizing bacteria in common bean rhizosphere soils of

Galana District, southern Ethiopia. The results demonstrate significant variation in soil properties across sites and a clear relationship between soil available phosphorus and PSB efficiency.

## **4.1 Soil Chemical Properties**

The wide variation in soil properties across the six kebeles reflects the diverse agro-ecological conditions in Galana District. Soil pH ranged from acidic (5.42 in Jirme) to near-neutral (6.99 in Wachu), consistent with previous reports on Ethiopian highland soils (Ayalew, 2011). The acidic conditions in Jirme may limit phosphorus availability due to fixation by aluminum and iron oxides (Satyaprakash et al., 2017).

The extremely low available P in Kersa (1.12 ppm) and Bariti (1.46 ppm) indicates severe phosphorus deficiency, well below the critical level of 10–15 ppm recommended for optimal crop growth (Olsen et al., 1954). These sites represent priority areas for phosphorus management interventions, including biofertilizer application.

Organic carbon content ranged from 2.06% to 4.51%, with Wachu showing the highest OC (4.51%). Soil organic matter is known to influence microbial activity and nutrient cycling (Alexander, 1977), and the high OC in Wachu may contribute to the exceptional PSB efficiency observed there.

Cation exchange capacity varied dramatically, with Jirme showing exceptionally low CEC (7.10 meq/100g) compared to other sites (22.08–32.45 meq/100g). Low CEC indicates poor nutrient retention capacity and may explain the limited PSB diversity and efficiency at this site (Kim et al., 1997).

## **4.2 PSB Distribution and Soil Properties**

The distribution of efficient PSB isolates across sites (20% from four sites, 10% from two sites) suggests that soil properties influence PSB community composition. Sites with higher organic carbon and moderate pH (Wachu, Bariti, Kersa) yielded more efficient isolates, consistent with findings of Chen et al. (2006) who reported that PSB abundance correlates positively with soil organic matter.

The negative correlation between soil available P and PSB efficiency ( $r = -0.68$ ,  $p < 0.05$ ) is a key finding. Sites with lower available P (Kersa, Bariti, Jirme) produced isolates with higher solubilization indices. This supports the "stress-adapted mutualism" hypothesis proposed by Goldstein (1994), which suggests that phosphorus deficiency stimulates the

proliferation and activity of PSB. Similar findings were reported by Keneni et al. (2010) for Ethiopian faba bean rhizosphere isolates.

The most efficient isolate (GPSB04, SI 3.88) came from Wachu, which had moderate available P (23.66 ppm) but the highest organic carbon (4.51%). This suggests that while phosphorus deficiency stimulates PSB activity, high organic matter provides the energy sources necessary for sustained microbial activity and organic acid production (Illmer and Schinner, 1995). Isolates from high-OC soils may therefore be particularly robust candidates for biofertilizer development.

### 4.3 Implications for Biofertilizer Development

The relationship between soil properties and PSB efficiency has important implications for biofertilizer development:

1. **Site-specific selection:** Isolates should be selected from environments similar to target application areas. The superior performance of GPSB04 from Wachu and GPSB11 from Bariti suggests these isolates may be best suited for soils with moderate to high organic carbon and near-neutral pH.
2. **Phosphorus-deficient soils as sources:** Soils with low available P are likely to harbor highly efficient PSB strains, making them valuable sources for biofertilizer prospecting.
3. **Soil management integration:** Biofertilizer effectiveness will depend on soil conditions, particularly organic matter content. Application of organic amendments may enhance PSB survival and activity (Bashan et al., 1995).
4. **Acid tolerance:** Isolates from Jirme (pH 5.42) and other acidic sites may possess acid tolerance mechanisms valuable for biofertilizer development in acidic soils common in Ethiopian highlands.

### 4.4 Comparison with Previous Ethiopian Studies

The negative correlation between soil available P and PSB efficiency observed in this study is consistent with findings of Keneni et al. (2010) for faba bean rhizosphere isolates from central Ethiopia. Girmaye et al. (2014) also reported that the most efficient PSB from Wollega originated from phosphorus-deficient soils.

The range of solubilization indices (2.27–3.88) observed in this study compares favorably with previous reports: Keneni et al. (2010) reported SI of 1.9–3.2, while Haile et al. (2016) reported SI of 1.8–3.4 for white lupin isolates. The higher SI values in this study (3.88 for

GPSB04) may reflect the unique soil conditions in Galana District and highlight the potential of these native strains.

## **4.5 Limitations and Future Research**

This study was based on a single sampling season and a limited geographic area. Seasonal variation and long-term stability of PSB populations should be investigated. Molecular identification of the most efficient isolates is needed to determine their taxonomic positions and genetic determinants of phosphorus solubilization. Greenhouse and field trials are required to validate plant growth promotion under realistic conditions. Additionally, formulation studies are needed to develop practical biofertilizer products.

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## **5. CONCLUSION AND RECOMMENDATIONS**

This study demonstrates that soil chemical properties significantly influence the distribution and efficiency of phosphate solubilizing bacteria in common bean rhizosphere soils of Galana District, southern Ethiopia. Key conclusions include:

1. Soil properties vary considerably across the six kebeles, with available phosphorus showing the highest variation (1.12–27.52 ppm) and organic carbon ranging from 2.06% to 4.51%.
2. A significant negative correlation ( $r = -0.68$ ,  $p < 0.05$ ) exists between soil available phosphorus and PSB solubilization efficiency, indicating that phosphorus-deficient soils harbor more efficient PSB strains.
3. Sites with higher organic carbon (Wachu 4.51%, Bariti 3.82%) produced the most efficient isolates (SI 3.88 and 3.44), suggesting organic matter supports PSB activity.
4. The distribution of efficient PSB isolates varied across sites, with Wachu, Tore Badiya, Kersa, and Bariti each yielding 20% of efficient isolates, while Jirme and Tore yielded 10% each.
5. The most efficient isolate (GPSB04, SI 3.88) originated from Wachu, characterized by high organic carbon (4.51%), near-neutral pH (6.99), and moderate available phosphorus.

Based on these findings, the following recommendations are made:

1. **Biofertilizer prospecting:** Future efforts to isolate efficient PSB should target phosphorus-deficient soils with adequate organic matter content.
2. **Site-specific recommendations:** Isolates GPSB04 (Wachu) and GPSB11 (Bariti) are recommended for biofertilizer development in soils with similar characteristics to their sites of origin.
3. **Soil management:** Integration of organic amendments with PSB inoculation may enhance biofertilizer effectiveness, particularly in low-organic-matter soils.
4. **Further research:** Molecular characterization of the most efficient isolates is needed to identify their taxonomic position and genetic determinants of phosphorus solubilization.
5. **Broader application:** The relationship between soil properties and PSB efficiency should be investigated across wider geographic areas and cropping systems in Ethiopia.

This study contributes to understanding the ecological determinants of PSB distribution in Ethiopian agricultural soils and provides a scientific basis for targeted biofertilizer development.

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## 7. DECLARATIONS

- **Conflict of Interest:** The author declares no competing interests.
- **Funding:** This work was supported by Dilla University (internal research grant, grant number not specified). The funder had no role in study design, data collection, analysis, or manuscript preparation.
- **Author Contributions:** Y.M.T. conceived and designed the study, performed fieldwork and laboratory analyses, analyzed the data, and wrote the manuscript.
- **Data Availability:** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

- **Ethics Approval and Consent to Participate:** Not applicable (no human or animal subjects involved).
  - **Consent for Publication:** Not applicable.
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