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# Phosphate-Solubilizing Bacteria with Solid Carrier Material in The Cultivation of Sweet Corn

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**Abstract**

**The limited availability of fertile land is a strong reason to utilize marginal land. Marginal land has potential for agricultural development because it has relatively high total phosphorus, but this phosphorus is in a form that is not available to plants. The use of phosphate-solubilizing bacteria (PSB) can be an alternative to change this form. The effectiveness of PSB activity in altering this form can be enhanced through carriers that are able to maintain their viability and activity in the soil. This study investigates the use of marginal land treated with phosphate solubilizing bacteria (PSB) incorporated with carrier materials to addressing the demand for sweet corn. PSB application followed a Randomized Block Design (RBD) involving the treatments as follows: control (T0), 150 kg Super Phosphate-36 (SP-36) per hectare (T1), PSB $B_{5(6)}$ + shrimp shells + 75 kg SP-36 per hectare (T2), PSB $B_{1(17)}$ + shrimp shells + 75 kg SP-36 per hectare (T3), PSB $B_{5(6)}$ + husk charcoal + 75 kg SP-36 per hectare (T4) and PSB $B_{1(17)}$ + husk charcoal + 75 kg SP-36 per hectare (T5). The results yield the optimum outcome associated with T2 by plant height (±70.25 cm), number of leaves (±8.97 pieces) and roots (±41 cm), root length (±31.10 cm) and volume (±14.05 ml), plant fresh (±53.72 gr) and dry weight (±28.01 gr), cob weight with husk (± 23.68) and without husk (±14.67 gr), cob length with husk (±12.88 cm) and without husk (±7.38 cm), cob diameter with husk (±22.76 cm) and without husk (±16.67 cm). T2 can reduce the use of inorganic phosphorus fertilizer up to 50% and increase production by approximately 7 times better than control.**

**Keywords: Husk charcoal, phosphate solubilizing bacteria, shrimp shells, sweet corn**

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## Introduction

Sweet corn, a member of Gramineae family, is distinguished by its highest glucose content compared to other types of corn, rendering it a decent option for consumption. Along with population growth and changes in consumption patterns, demand for sweet corn continues to increase. Despite the increasing annual demand for sweet corn, the expansion of planting areas remains stagnant. This highlights the need for measures to increase sweet corn production, one of which is by utilizing marginal land.

Using marginal land, however, may require the measures to address poor soil quality due to low fertility, poor soil texture, poor drainage, and unfavorable climatic conditions. In contrast, marginal land affords potential advantages that can render it a decent alternative replacement to common fertile land. In addition, utilizing marginal land can elevate agricultural sustainability and reduce potential environmental damage to productive land. Notwithstanding, addressing the shortage of marginal land requires greater investment in processing and improvement, such as adding fertilizer, irrigation, and special agricultural technology. Another issue is the potential lower yields compared to fertile land and the higher risk of crop failure due to unfavorable soil and climate conditions.

Low soil fertility is not always triggered by insufficient nutrients; it may also result from a plant’s inability to absorb existing nutrients (Karthika *et al*., 2018). Although the soil may have adequate nutrients, various

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factors can hinder their absorption. Poor soil pH can bind nutrients, making them unavailable to plants (Barrow & Hartemink, 2023). In addition, poor soil structure, such as excessive density or a high amount of sand, can prevent plant roots from absorbing nutrients properly (Karthika *et al*., 2018). Unbalanced humidity and low microbial activity can also determine nutrient absorption (Zhang *et al*., 2019). Therefore, increasing soil fertility needs to focus beyond merely adding fertilizer. One of the potential measures is improving the physical, chemical, and biological conditions of the soil for optimum absorption of nutrients.

Phosphate (P) comes from organic materials such as manure, plant residues, chemical fertilizers, and soil minerals (Billah *et al*., 2019). Phosphate is divided into organic P and inorganic P. Plants absorb phosphate in inorganic forms such as $H_2PO_4^-$, $HPO_4^{2-}$, dan $PO_4^3$ (Anjum *et al*., 2024). The availability of inorganic phosphate is influenced by the level of soil acidity (Kahura *et al*., 2018), the presence of dissolved iron (Fe), aluminium (Al), and calcium (Ca) compounds (Azam *et al*., 2019), the level of decomposition of organic matter (Xu *et al*., 2018), and microorganism activities (Rawat *et al*., 2021). Phosphate fixation in the soil results in inefficient use of phosphate fertilizer (Etesami, 2020), leading to the need for greater amounts of fertilizer. One way to increase the efficiency of phosphate fertilization and improve phosphate availability is to utilize phosphate solubilizing microbes (PSM). Wang *et al*. (2022) research shows that the yield of wheat (*Triticum aestivum)* under PSM especially bacteria inoculation significantly increased up to 14.42% ($P < 0.05$) compared with the control treatment. Besides promoting wheat growth, the labile P fraction in soil was significantly increased by over 122.04% ($P < 0.05$) under PSB inoculation compared with it in soils without.

PSM are soil microorganisms that can dissolve phosphate ions (P) bound to soil cations such as Al, Fe, Ca, and Mg, which can make them available for absorption by plants (Zhu *et al*., 2024). Using PSM at the onset of planting can increase phosphate availability in the soil (Elhaissoufi *et al*., 2022), leading to higher corn growth and yield. However, it requires a carrier material to provide nutrients for the microbes to maintain inoculum viability for a certain period (Sahu & Brahmaprakash, 2016). Therefore, the carrier material must be able to activate microbial activity, allowing plants to grow and develop. Some potential carrier materials include charcoal husks and shrimp shells.

Shrimp shells can be an effective medium because they are rich in the nutrients essential for microorganisms. Shrimp shells contain chitosan and chitin, which can be broken down by bacteria into essential carbon and nitrogen sources for microbial growth (Pal *et al*., 2021). Pal *et al*. (2021) also emphasized that the use of fermented hydrolysate (FH) containing 85.42 U/ml of chitin derived from crab and shrimp shells increased the growth of phosphate-solubilizing bacteria in the soil by 5.57 times. In addition, shrimp shells provide a supportive physical environment, with a porous structure that allows bacteria to attach and reproduce (Rahman & Maniruzzaman, 2023). In addition, shrimp shells have antimicrobial properties that can reduce the growth of harmful pathogens (Vilar Junior *et al*., 2016) thereby providing a supportive environment for desirable bacteria. Using shrimp shells as a carrier media supports the survival and activity of bacteria over a longer period, making it a decent choice in agricultural and biotechnological applications.

Another alternative material is husk charcoal. Husk charcoal made from burning rice husks has a porous structure with a large surface area, providing plenty of space for bacteria to stick and reproduce. These pores allow microorganisms to obtain enough oxygen necessary for their respiration and growth (Thunshirn *et al*., 2022). In addition, husk charcoal can absorb and store water (Aditama *et al*., 2024), creating a moist environment ideal for bacterial growth. Husk charcoal also contains small amounts of minerals that can be utilized by bacteria as additional nutrients (Singh *et al*., 2018). Husk charcoal has relatively inert and stable properties so that it will not adversely react to bacteria or the surrounding environment while making it a safe and stable medium for bacterial inoculation. This is in line with the results of Akhadi *et al*. (2024) research which stated that the growth of bacterial colonies in rice husk charcoal petri dishes was stable at $10^6$.

Previous research focused on a single series: crustacean waste or charcoal as a bacterial carrier. This study directly compared charcoal husk and shrimp shells to corn plants in the same location. Furthermore, this study was conducted on marginal land. Building on this line of inquiry, this research aims to examine the use of carrier materials for the presence of PSB in increasing the growth and production of corn plants in marginal land.

## Methods

### Research time and site

This research started from january to june 2025 and took place in Mamburungan Village of Tarakan City, Plant Protection Laboratory and Soil Science Laboratory, Faculty of Agriculture, Universitas Borneo Tarakan, North Kalimantan, Indonesia.

### The Collection of phosphate solubilizing bacteria

This study used the bacteria PSB $B_{5(6)}$ and $B_{1(17)}$. These were isolated from the rhizosphere of the forest in Tarakan, Pantai Amal Village, East Tarakan District, Tarakan City, North Kalimantan Province. These bacteria had been tested for their ability to dissolve phosphate, as indicated by the formation of clear zones on Pikovskayas Agar media (Pudjiwati *et al*., 2019).

### The Preparation of bacterial carrier material

The carrier material was ground and filtered using a 150-mesh sieve, and then the formulation was prepared by inoculating one colony of bacterial isolates from the Pikosvkaya medium into an Erlenmeyer flask containing 200 mL of Nutrient Broth (NB). The incubation took place for ± 48 hours using a shaker speed of 150 rpm with a temperature of 28ºC. A total of 10 ml of PSB inoculant was put into a container holding 100 g of carrier material and then incubated for ± 72 hours at room temperature.

### Field test

This research used a one-factor Randomized Block Design (RBD) by combining carrier materials and types of bacteria including control (T0), 150 kg Super Phosphate-36 (SP-36) per hectare (T1), PSB $B_{5(6)}$ + shrimp shells + 75 kg SP-36 per hectare (T2), PSB $B_{1(17)}$ + shrimp shells + 75 kg SP-36 per hectare (T3), PSB $B_{5(6)}$ + husk charcoal + 75 kg SP-36 per hectare (T4), PSB $B_{1(17)}$ + husk charcoal + 75 kg SP-36 per hectare (T5). Each treatment was repeated 4 times, resulting in 24 experimental units with 8 plants per unit. The bacterial carrier material was applied in the planting pit at a dose of 2.5 grams per plant, 2 days before planting and 6 weeks after planting. Other chemical fertilizers were given gradually at 2, 4, and 6 weeks after planting at a dose of 350 kg/ha for urea and 150 kg/ha for KCL.

### Data analysis

Soil chemical properties analysis was presented descriptively, while growth and corn production parameters were analyzed for variance using SPSS 26. When a difference was identified, the Duncan Multiple Range Test with a 95% confidence interval would be performed.

## Results and Discussion

### Chemical properties

The analysis of shrimp waste and husk charcoal had been performed before the two media were used. The media satisfied the requirements as carrier materials for PSB isolates due to the ideal pH. The results of soil analysis (T0) show that soil pH is highly acidic with very low C-Organic values, which implies the unavailability of most nutrients (Nitrogen, Phosphorus, and Potassium) (Table 1). The analysis of the chemical properties of the planting media for each treatment after the harvest season showed that the application of PSB increased the pH level, thus indicating the mineralization of PSM in the soil. Bacteria secrete enzymes and organic acids that interact with phosphate in the soil (Rodríguez & Fraga, 1999). Organic acids form complexes with cations such as $Ca^{2+}$, $Fe^{3+}$, and $Al^{3+}$ bound to phosphate, subsequently releasing phosphate from its bonds (Beauchamp *et al*., 2012). The release of organic acids also lowers the soil pH and aids in the dissolution of bound phosphate minerals (Lazo *et al*., 2017). The higher microorganism activity promotes the release of phosphate and increases soil pH. By extension, this promulgates the population of microorganisms and multiplies the soil organic matter

**Table 1.** The Chemical Analysis of Carrier Media and Treatments

| Description | | Analysis | | | |
|---|---|---|---|---|---|
| | | pH | C-Organic | Total P | Available P |
| Carrier media | Shrimp shells | 8.30 sa | 4.12 h | 15.84 l | 12.39 h |
| | Husk charcoal | 7.90 sa | 5.04 h | 11.28 vl | 9.64 m |
| Treatments | T0 | 4.76 ha | 0.32 vl | 29.29 vl | 5.58 l |
| | T1 | 4.16 ha | 0.92 vl | 27.85 m | 7.82 l |
| | T2 | 5.02 m | 1.15 l | 24.38 m | 5.92 l |
| | T3 | 4.77 m | 0.93 vl | 26.34 m | 9.21 l |
| | T4 | 4.86 m | 1.13 l | 23.04 m | 6.93 l |
| | T5 | 5.24 m | 1.99 l | 36.75 m | 8.91 l |

* Slightly alkaline (sa); acidic (a); highly acidic (ha); high (h); medium(m); low (l); very low (vl) (Soil Research Institute, 2009).

Administering PSB-laden media is proven to increase total phosphorus (P) and available phosphorus (P), despite only 50% Super Phosphate-36 (SP-36) fertilizer administered in T1. PSB can increase total phosphorus (P) and available phosphorus (P) in the soil because these bacteria can dissolve phosphate in complex compounds that otherwise cannot be directly absorbed by plants. PSB produces organic acids such as citric acid, gluconic acid, and lactic acid to dissolve phosphate compounds bound to cations such as aluminum (Al), iron (Fe), and calcium (Ca) (Arif *et al*., 2017), converting them into inorganic phosphate forms that can be absorbed by plants, namely $H_2PO_0^-$, $HPO_4^{2-}$, and $PO_4^{3-}$. Bacteria also produce phosphatase enzymes which can break down organic phosphate into inorganic phosphate. This enzyme aids in the mineralization of organic phosphate, making it readily available to plants. PSB possesses solubilization capabilities that enable the release of phosphate from soil minerals, such as apatite, tricalcium phosphate, and other phosphate compounds (Arif *et al*., 2017). This process increases the amount of inorganic phosphate accessible to plants. PSB also synergizes with other soil microbiology, thereby increasing organic matter decomposition and the release of nutrients, including phosphate.

## Corn growth

In terms of growth in the sixth week after planting, giving PSB yielded better results than the control treatment (T0) or giving 150 kg SP-36 per hectare (T1), despite no noteworthy difference compared to the other treatments. The table indicates that PSB can increase phosphorus (P) availability through the mechanism of dissolving bound P in the soil by producing organic acids and phosphatase enzymes, where P plays a crucial role in cell division, meristem tissue formation, and leaf development, thus directly increasing vegetative growth. Chen *et al*. (2016) reported that PSB produces various organic acids such as gluconic acid, citric acid, oxalic acid, malic acid, or acetic acid. These acids can lower the local pH around the rhizosphere, so that previously insoluble phosphate compounds become soluble (Kaur *et al*., 2016). PSB also produces acid and alkaline phosphatase enzymes that function to hydrolyze organic phosphorus (e.g., phytate, phospholipids, nucleotides) and then convert it into inorganic phosphate (Pi), which is available to plants (Iftikhar *et al*., 2023). Conversely, rice husk charcoal is more dominant in improving soil physical properties (porosity and aeration), so its effect on vegetative growth is not as strong as that of shrimp shells. Table 2 demonstrates that providing PSB with a solid carrier material reduces the use of SP-36 fertilizer by up to 50%. In addition, the shrimp waste (T2 and T3) produced better results than rice husk charcoal (T4 and T5). This happens because shrimp shell can improve soil properties and increase nutrient availability in the soil. This resonates with Abirami *et al*. (2022) which shows that the addition of shrimp shell improves the chemical, physical, and biological properties of the soil. Mansyur *et al*. (2021) further explained that shrimp waste has more complex functional groups as well as a greater effect in increasing pH and cation exchange capacity.

The observation of root parameters was taken after the harvest. The result affirmed the potential of PSB in significantly increasing the number of roots, compared to plants in control

(Table 3). This is because the bacteria provide phosphate easily absorbed by plants, thereby stimulating the formation of more roots. Treatments T2 and T3 were better because shrimp shells enriched the soil with organic matter that improved soil structure and stimulated lateral root growth. This is in accordance with the opinion Indriani *et al.* (2025) which states that organic matter can stimulate lateral root growth. Chitin in shrimp shells can stimulate rhizosphere microbial activity that contributes to the growth of a more extensive root system. This is in line with the opinion Safitri & Susilowati (2025) which states that rhizosphere microbial activity contributes to the growth of the root system. Apart from increasing the number of roots, root length also increases. Plants infected with phosphate-solubilizing endophytic bacteria show increased root length compared to those in control. Longer roots allow plants to reach more nutrients and water in the soil, therefore enhancing absorption efficiency and overall growth. Likewise, root volume also increases, indicating stronger and more developed root structures. Thicker roots and more branches allow plants to store more nutrient reserves, increase resistance to unfavorable environmental conditions, and support healthier and more productive plant.

The fresh weight encompasses all plant parts. The measurement indicates the congruence between optimal plant growth and optimal fresh weight. Meanwhile, dry weight is calculated to analyze plant metabolism, an indicator of actual growth. These two observations were made after the harvest period without including the cobs. According to Chen *et al.* (2013), phosphorus (P) collaborates with organic nitrogen (N) in supporting plant growth and development. The higher the dry weight of plant is, the better the plant will grow and develop. Of all the treatments, T2 (PSB + shrimp waste) shows the best average results (Table 4). This occurred because the nutrient requirements for sweet corn plants were satisfied, particularly due to the optimal amount of phosphorus (P) absorbed. Dry weight shows the amount of nutrients absorbed by plants. The greater the phosphorus (P) element absorbed, the higher the dry weight will be. The absorbed phosphorus (P) stimulates the growth of roots, stems, flowers, and cobs.

**Table 2.** Corn Growth in 6 Weeks After Planting (WAP)

| Treatments | Plant height (cm) | Number of leaves |
|---|---|---|
| T0 | 27.17 ± 5.68a | 5.95 ± 1.68a |
| T1 | 41.21 ± 5.80b | 6.80 ± 1.69ab |
| T2 | 70.25 ± 7.83d | 8.97 ± 1.06c |
| T3 | 64.11 ± 6.57d | 8.77 ± 0.78c |
| T4 | 45.50 ± 6.22bc | 7.80 ± 0.52bc |
| T5 | 52.50 ± 6.98c | 8.05 ± 0.95bc |

* Numbers followed by different superscript letters indicate significant differences from the control at $p \leq 0.05$

**Table 3.** The Root of Corn

| Treatments | Number of roots | Root length (cm) | Root volume (ml) |
|---|---|---|---|
| T0 | 13.50 ± 5.07a | 14.15 ± 5.42a | 3.12 ± 1.03a |
| T1 | 18.75 ± 6.08ab | 21.47 ± 2.24b | 5.90 ± 1.82ab |
| T2 | 41.00 ± 3.65c | 31.10 ± 6.69c | 14.05 ± 1.92d |
| T3 | 33.75 ± 6.95c | 23.85 ± 5.43b | 9.17 ± 1.48c |
| T4 | 15.75 ± 3.86a | 18.67 ± 5.41ab | 5.77 ± 2.46ab |
| T5 | 23.00 ± 4.08b | 24.30 ± 4.32b | 8.52 ± 2.48bc |

* Numbers followed by different superscript letters indicate significant differences from the control at $p \leq 0.05$

**Table 4.** Corn Weight

| Treatments | Fresh weight (g) | Dry weight (g) |
|---|---|---|
| T0 | 4.43 ± 4.26a | 1.80 ± 2.09a |
| T1 | 19.02 ± 10.07b | 7.73 ± 4.71b |
| T2 | 53.72 ± 19.35d | 28.01 ± 14.26c |
| T3 | 32.01 ± 12.08c | 11.25 ± 6.10b |
| T4 | 15.91 ± 6.79b | 5.56 ± 4.27ab |
| T5 | 23.16 ± 11.98bc | 7.91 ± 5.67b |

* Numbers followed by different superscript letters indicate significant differences from the control at $p \leq 0.05$

**Table 5.** Corn Production

| Treatments | Weight of Cob (g) | | Length of Cob (cm) | | Diameter of Cob (mm) | |
|---|---|---|---|---|---|---|
| | With Husks | Without Husk | With Husks | Without Husk | With Husks | Without Husk |
| T0 | 0a | 0a | 0a | 0a | 0a | 0a |
| T1 | 3.98 ± 2.33a | 2.16 ± 1.29ab | 2.94 ± 1.48a | 1.70 ± 0.53a | 5.92 ± 1.81ab | 4.92 ± 1.41b |
| T2 | 23.68 ± 9.06b | 14.67 ± 3.48c | 12.88 ± 4.59c | 7.38 ± 3.57b | 22.76 ± 7.15c | 16.67 ± 2.24c |
| T3 | 5.45 ± 3.33a | 3.59 ± 2.50b | 6.03 ± 5.45b | 2.89 ± 2.36a | 8.36 ± 5.53b | 7.59 ± 5.17b |
| T4 | 5.87 ± 3.06a | 2.88 ± 1.63ab | 4.83 ± 3.15ab | 2.26 ± 1.06a | 7.50 ± 3.22b | 6.34 ± 2.78b |
| T5 | 5.75 ± 2.55a | 3.33 ± 1.72b | 5.03 ± 3.81ab | 2.25 ± 1.30a | 10.62 ± 3.72b | 6.72 ± 2.63b |

* Numbers followed by different superscript letters indicate significant difference from the control at $p \leq 0.05$

### Corn production

Table 5 shows the absence of production in the corns with control (T0). This is due to the absence of additional nutrients and chemical properties, which would otherwise support production. Statistically, the production results of treatments T1 to T5 are not significantly different. This proves that providing PSB with a solid carrier material and a 50% dose of SP-36 can offset the production results of using a 100% dose of SP-36 (150 grams per hectare). Providing inorganic phosphorus (P) into the soil does not necessarily result in a positive effect on plants. The availability of inorganic phosphorus (P) is influenced by soil acidity, dissolved Fe, Al, and Ca compounds, the level of decomposition of organic matter, and the activity of microorganisms, each of which can hamper the intake of phosphorus (P). The fixation of phosphorus (P) in the soil renders inefficient use of phosphorus (P) fertilizer, which implies a higher need for fertilizer. Nevertheless, this does not guarantee higher growth and production.

Table 5 shows that the parameters of T0 do not demonstrate the production phase. This results from the absence of additional nutrients and soil chemical properties unsupportive to plant production and growth. Statistically, the production of T1 is not significantly different from those of T3, T4, and T5. The fact that production took place under suboptimal conditions confirms that administering bacterial carrier material can reduce the need for SP-36 fertilizer. Phosphorus (P) plays a critical role in photosynthesis, respiration, transfer, and energy storage (Khan *et al*., 2023). It helps speed up root development and germination, improves fruit quality, and aids in seed formation. Furthermore, phosphorus is crucial for cob formation, kernel filling, and seed maturation.

## Conclusion

The research results have acknowledged the affordances of PSB incorporated with a solid carrier to bring down the dependence on inorganic phosphorus (P) fertilizer by up to 50%. Furthermore, PSB T1(17), which was cultured on shrimp shell waste, can enhance plant production ± 7 times better than those receiving 100% inorganic phosphorus fertilizer.

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