Growth and Yield of Strawberry Influenced by the Application of Phosphate Solubilizing Biofertilizer

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ABSTRACT

Phosphorus availability in soil is one of the main limiting factors in the cultivation of horticultural crops, including strawberries. Although the total phosphorus content in the soil is relatively high, most of it is in a form that is not available to plants. Phosphate solubilizing microbes (PSM) play an important role in increasing the availability of phosphorus through the mechanism of dissolving insoluble phosphate compounds into forms that can be absorbed by plants. This study investigates the effect of phosphate solubilizing biofertilizer on the growth and yield of strawberry. Biofertilizer used phosphate solubilizing bacteria (Bacillus velezensis, Burkholderia mallei) and phosphate solubilizing fungi (Pseudallescheria boydii; Talaromyces islandicus; Penicillium janthinellum; Trichoderma harzianum). The experimental design is randomized block design five treatments, with seven replications. Treatments are control, bio-encapsule of P-solubilizing bacteria, bioencapsule of P-solubilizing fungi, phosphate solubilizing bacteria in carrier base on peat, and phosphate solubilizing fungi in carrier base on peat. The results of the experiment showed that the application of phosphate solubilizing fungi with compost and peat carriers significantly improved vegetative growth parameters, including plant height, leaf number, and crown diameter. Although no significant differences were observed in fruit yield, PSB in microcapsule form showed promising results in enhancing fruit weight and size.

Keywords: biofertilizer, phosphorus availability, organic carrier

1. INTRODUCTION

Phosphate is an essential nutrient for plant growth, playing a crucial role in various physiological processes that are vital for healthy and productivity crops. Strawberry production, like many other agricultural endeavors, relies on a steady supply of phosphate to ensure robust and abundant yields. However, phosphate availability in the soil can be limited due to its low solubility, making it challenging for plants to access this vital nutrient. The general problem with P nutrients in soil is that not all soil P is immediately available to plants (Johan et al., 2021). In this case, it really depends on the nature and characteristics of the land and the management of the land itself by humans.

One of the efforts made to increase soil P availability is by providing inorganic fertilizer. However, continuous use of inorganic fertilizers can reduce soil quality and pollute the environment. Research results prove that soil that is continuously fertilized with inorganic fertilizer will reduce the soil's C-organic content (Ozlu et al., 2019) and damage soil aggregates so that they are unable to support plants (Ghosh et al., 2019).

To increase plant growth strawberry and fertilization efficiency and soil quality, it is necessary to develop the use of potential biological resources to facilitate the availability of soil nutrients. One example is the use of soil microbes which play a role in the transformation of the nutrient P which can be used as biofertilizer, which is known as phosphate solubilizing microbes (Kalayu, 2019). Phosphate solubilizing microbes (PSM) are a group of soil microbes that have the ability to extract P from bonds with Al, Fe, Ca, and Mg, so that they can dissolve P that was not originally available to plants to become available to plants (Klaic et al., 2017). Phosphate solubilizing microbe increase the availability of soil P through the activity of phosphatase enzymes which convert P-organic to P-inorganic so that it is available to plants through P mineralization and secretion of organic acids which convert insoluble P to soluble P in the soil (Fitriatin et al., 2020; Rawat et al., 2021).

Innovations in carrier materials for biofertilizers can be developed to produce high/good quality biofertilizer as indicated by the viability of the microbes in the biofertilizer remaining high during the storage period. Therefore, research is needed that study phosphate solubilizing biofertilizers in different carrier materials to increase strawberry production.

2. MATERIALS AND METHODS

The experiment was carried out in the Bale Tatanen green house, Agriculture Faculty, Jatinangor, Sumedang District, West Java. Strawberry seedlings use Nanatsuboshi variety provided by JPV Project with Agriculture Faculty-UNPAD. The planting medium used is a mixed composition cocopeat, charcoal rice husk, and peat with the same composition with substrates in the ichigo greenhouse (1,6 kg). Biofertilizer used phosphate solubilizing bacteria (*Bacillus velezensis, Burkholderia mallei*) and phosphate solubilizing fungi (*Pseudallescheria boydii; Talaromyces islandicus; Penicillium janthinellum; Trichoderma harzianum)* which are a collection of isolates from the Soil Biology Laboratory, Faculty of Agriculture, Universitas Padjadjaran.

Experimental design is Randomized Block Design 5 treatments, with 7 replications. Treatments are:

a. Control
b. Bioencapsule of P-solubilizing bacteria
c. Bioencapsule of P-solubilizing fungi
d. Phosphate solubilizing bacteria in carrier base on peat
e. Phosphate solubilizing fungi in carrier base on peat

The dosage of biofertilizer is 50 kg/ha. The parameters that will be observed are strawberry growth (plant height, number of leaves) periodically every week until eight weeks after planting, and yield quality by measuring the sweetness value (Brix).

3. RESULTS AND DISCUSSION

3.1 Plant Height

The results revealed that applying PSB (phosphate solubilizing bacteria) and PSF (phosphate solubilizing fungi) to both carrier materials improved strawberry plant height compared to the control treatment (Table 1 and Fig.1). Bioencapsule of P-solubilizing fungi consistently achieved the greatest plant heights, peaking at 23.93 cm in week 8. This corroborates previous research demonstrating that PSF, when combined with organic carriers, significantly improved phosphorus availability and plant development (Klaic et al., 2017; Fitriatin et al., 2020). The increased plant height was most likely due to enhanced phosphorus solubilization by fungal mechanisms, such as the production of organic acids (e.g., oxalic, citric, lactic, and acetic acids) and enzymatic activity, which help release phosphate ions from insoluble complexes bound with calcium, iron, and aluminum (Arias et al., 2023). These organic acids, especially oxalic and citric acids, are known to increase the bioavailability of phosphorus in soil, especially under slightly acidic to neutral pH conditions (Johan et al., 2021).

The use of compost and peat as carriers played a critical role in maintaining microbial viability and supporting continuous fungal activity during the experiment. Organic carriers provide a favorable physical environment and additional nutrients, allowing PSF to remain active in the root zone for longer periods. Research has shown that co-composting with phosphate rock and organic matter enhances phosphorus solubilization, with PSF and their associated enzymes (like alkaline phosphatase) being key drivers of this process (Sarr et al., 2020). Additionally, compost and peat are known to improve soil structure, water retention, and aeration, which in turn stimulate root growth and nutrient absorption.

The presence of PSF in this organic-rich environment likely supported a synergistic interaction within the rhizosphere microbiome. According to Wang et al. (2024), such synergisms between beneficial microbes and organic matter can lead to enhanced root development and increased nutrient mobilezation. Furthermore, the fungal hyphae themselves may have contributed to an extended soil exploration capacity for the roots, thereby increasing the effective nutrient uptake area (Sharma et al., 2020).

Table 1 Effect of Phosphate Solubilizing Biofertilizer Application on Strawberry Plant Height

Treatments	Plant Height (cm)							
	Week							
	1	2	3	4	5	6	7	8
A (Control)	17.57 a	19.14 b	19.90 b	20.20 a	20.69 a	20.9 a	21.13 a	21.64 a
B (PSB - Compost + peat)	18.01 a	19.31 b	20.07 b	20.33 a	20.71 a	20.93 a	21.23 a	21.76 a
C (PSF - Compost + peat)	**20.11 c**	20.70 c	**21.60 c**	**22.16 c**	**22.73 c**	**23.07 b**	**23.51 d**	**23.93 c**
D (PSB - Microcapsules)	19.67 b	**21.14 c**	21.47 c	21.60 b	21.77 b	22.06 b	22.20 b	22.97 b
E (PSF - Microcapsules)	17.59 a	18.13 a	19.31 a	20.34 a	20.83 a	21.13 a	22.79 c	23.11 b

Note: Means followed by the same letter are not significantly different according to Duncan's multiple range test at the 0.05 significance level. (PSB: Phosphate-Solubilizing Bacteria; PSF: Phosphate-Solubilizing Fungi)

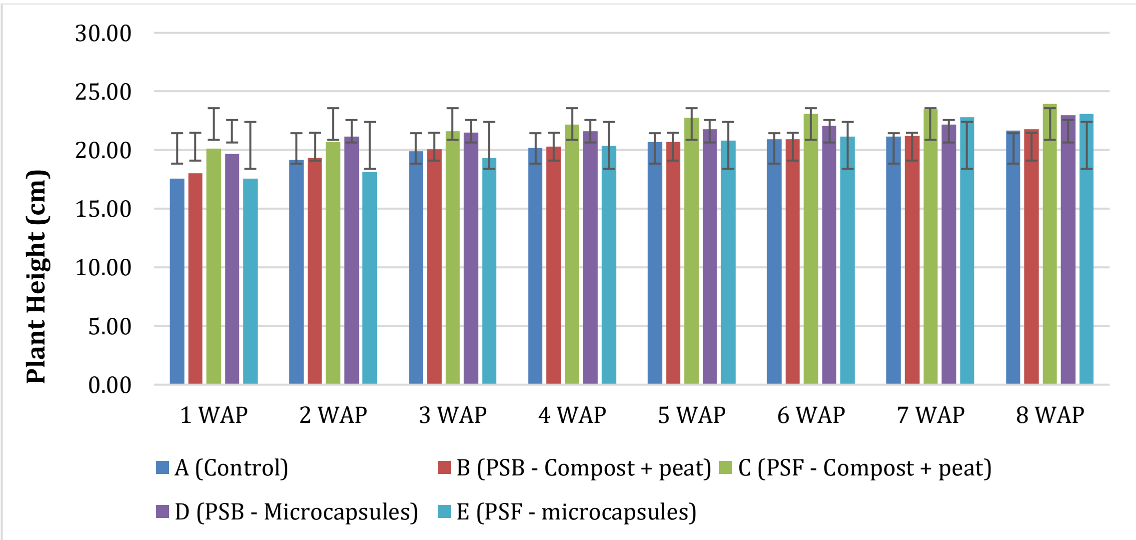

Figure 1. Plant Height of Strawberry Plants (1-8 weeks after planting)

Application PSB in microcapsules form (treatment D) showed a significant increase in plant height compared to the control treatment. This shows the efficacy of PSB, especially when encapsulated, in promoting plant growth by dissolving phosphorus compounds. This finding aligned with studies such as Bakki *et al.* (2024), which reported that encapsulated PSB promoted sustained nutrient release and plant growth (e.g. in tomato) through improved microbial viability. But their effects were less pronounced than those observed with compost and peat carriers. By week 8, the PSB-microcapsule treatment (D) achieved a plant height of 22.91 cm, while the PSF-microcapsule treatment (E) reached 23.11 cm. The slightly lower performance of micro-capsule treatments compared to organic carriers could be attributed to differences in microbial release rates and nutrient availa-bility in the rhizosphere. Previous research suggested that organic carriers such as compost and peat not only support microbial viability but also improve soil structure, water retention, and nutrient cycling, leading to better plant growth outcomes (Zhu et al., 2020; Khan et al., 2021).

3.2 Number of Leaves

The number of leaves on strawberry plants is vital for photosynthesis, nutrient absorption, water regulation, temperature control, defense against pests and diseases, and ultimately, for maximizing fruit yield and quality. Treatments B and C, which applied PSB and PSF to a mixed compost and peat carrier material, respectively, demonstrated similar leaf production trends (Table 2).

Table 2 Effect of Phosphate Solubilizing Biofertilizer Application on Strawberry Number of Leaves

Treatments	Number of Leaves							
	Week							
	1	2	3	4	5	6	7	8
A (Control)	8	10	11	12	12	13	14	15
B (PSB - Compost + peat)	9	10	11	12	13	14	16	16
C (PSF - Compost + peat)	9	11	12	12	13	15	16	16
D (PSB - Microcapsules)	9	11	12	13	13	14	15	14
E (PSF - Microcapsules)	8	10	11	12	13	13	15	15

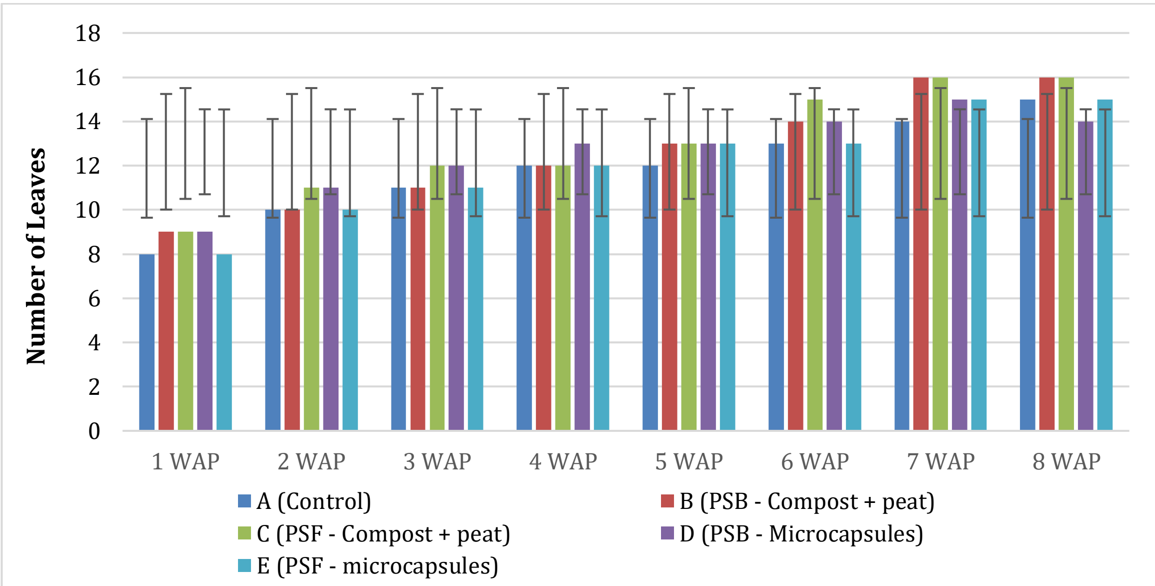

Figure 2 Number of Strawberry Leaves (1-8 weeks after planting)

Both treatments increased the number of leaves compared to the control group, indicating that PSB and PSF had a positive effect on strawberry leaf development when applied to organic substrates. Treatments D and E which PSB and PSF in microcapsules form, also demonstrated high leaf production compared with control treatment (Fig 2). However, the effect is less apparent than compost and peat carrier material. The dec-rease in the quantity of leaves is presumably caused by the leaves drying out and dying.

Treatments B and C both consistently produced a higher number of leaves than other treatments across the experimental period, although statistical analysis indicated no significant difference between them (Table 2). The elevated leaf counts were likely attributed to enhanced phosphorus solubilization facilitated by microbial action. In treatment B, phosphate-solubilizing bacteria (PSB) released organic acids and increased photosynthetic pigment concentration through mechanisms involving chlorophyll biosynthesis and auxin production, which promotes leaf expansion and branching (Wu et al., 2022). Meanwhile, treatment C's superior performance was due to phosphate-solubilizing fungi (PSF) functioning within an organic-rich carrier environment. Compost and peat in this treatment sustained fungal viability and stimulated microbial activity in the rhizosphere, thereby improving phosphorus availability for leaf formation (Ahmed et al., 2023).

Although both B and C outperform treatments D and E, where viability was maintained through microencapsulation, organic carrier-based treatments provided additional nutrient substrates and improved soil physical properties conducive to leaf development (higher moisture retention, aeration, and nutrient buffering). However, because both B and C employed nearly identical carrier systems and microbial P-solubilization capabilities, their leaf counts converged statistically. This suggests that while each microbial group contributed similarly to nutrient mobilization, the presence of compost and peat created a leveling effect, resulting in no significant difference between them. The overall outcome is consistent with recent findings that microbial inoculants delivered via organic carriers enhance vegetative growth metrics comparably when their mechanisms of P-solubilization overlap (Ahmad et al., 2022).

In addition to the biological solubilization of phosphorus, the increased number of leaves observed in Treatments B and C can also be linked to the synergistic interactions between microbial inoculants and the organic carrier materials, compost and peat. These carriers not only served as substrates that prolonged microbial viability but also contributed essential macro and micro nutrients, thereby enhancing the nutritional environment for plant vegetative growth (Rodríguez et al., 2020). Compost, in particular, is rich in humic substances, which stimulate root elongation and increase the expression of nutrient transporter genes, including those for phosphorus and nitrogen uptake, ultimately promoting leaf proliferation (Shah et al., 2016; Wu et al., 2022).

The presence of beneficial microbes in these treatments likely led to improved root development and nutrient absorption. This supports a feedback mechanism where improved nutrient uptake increases photosynthetic efficiency, which in turn supports further leaf production. Phosphate solubilizing bacteria and fungi are known to stimulate the biosynthesis of plant growth hormones, such as indole-3-acetic acid (IAA), gibberellins, and cytokinins (Rawat et al., 2021).

These hor-mones play a key role in cell division and ex-pansion in meristematic tissues, including those responsible for leaf initiation and expan-sion (Wu et al., 2021).

Interestingly, Treatment D (PSB-microcap-sules) and E (PSF-microcap-sules) also showed relatively high leaf num-bers, although slightly lower than B and C. This suggests that while microencapsulation effect-tively preserves microbial viability and con-trolled release, it may delay peak microbial activity compared to direct application with compost or peat (Balla et al., 2022). The slower release of P from microcapsules might be more beneficial over a longer cropping period rather than during short-term vegetative assessments.

3.3 Diameter crown

Strawberry crown diameter is an impor-tant factor in affecting the total productivity, yield, and health of the plant (Ismail & Ganzour, 2021). Larger crown diameters may arise through the introduction of beneficial mic-robes like PSB and PSF, which have been demonstrated to improve nutrient intake, root development, and overall plant vigor. By developing symbiotic interactions with the plants, these microbes help the plants absorb vital nutrients and hormones, which support healthy growth (Pii et al., 2015).

The data presents the crown diameters (in millimeters) of strawberry plants over an eight-week period under different treatments. By the end of the eighth week, the diameter of the control group (Treatment A) had risen from 10.43 mm at the beginning to 19.29 mm (Table 3). Treatment B, which applied PSB along with a compost and peat carrier, started out with a slightly larger diameter of 11.66 mm and grew steadily over the span of the weeks, reaching 22.03 mm by week eight (Fig 3).

Table 3 Effect of Phosphate Solubilizing Biofertilizer Application on Strawberry Diameter Crown

Treatments	Crown Diameters (mm)							
	Week							
	1	2	3	4	5	6	7	8
A (Control)	10.43 a	11.98 a	14.09 a	15.31 a	16.73 a	18.04 a	19.06 a	19.29 a
B (PSB – Compost + peat)	11.66 b	13.90 c	16.56 b	19.28 c	20.64 c	21.5 c	21.57 b	22.03 b
C (PSF – Compost + peat)	13.28 d	15.65 d	17.30 c	19.93 c	21.11 c	22.48 d	23.41 d	23.71 d
D (PSB – Microcapsules)	12.27 c	14.10 c	16.41 b	18.60 b	20.79 c	21.67 c	22.14 c	22.59 c
E (PSF – Microcapsules)	10.22 a	12.90 b	16.71b	18.14 b	19.43 b	20.97 b	21.54 b	21.81 b

Note: Means followed by the same letter are not significantly different according to Duncan's multiple range test at the 0.05 significance level. (PSB: Phosphate-Solubilizing Bacteria; PSF: Phosphate-Solubilizing Fungi)

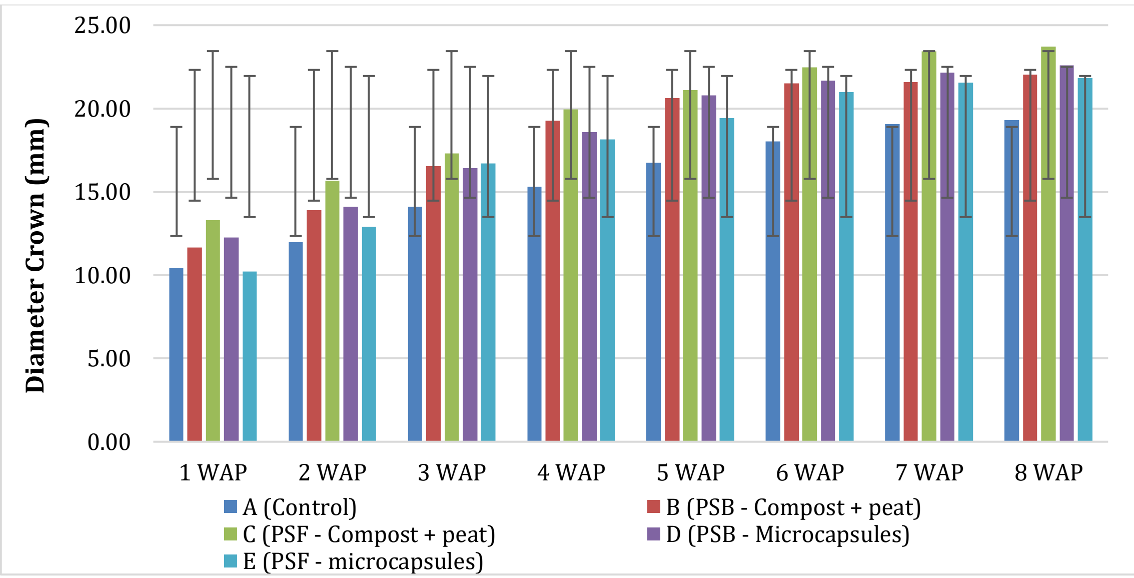

Figure 3 Diameter Crown of Strawberry Plants (1-10 weeks after planting)

Using PSF with compost and peat, treatment C began with an even larger diameter of 13.28 mm and grew steadily, reaching a diameter of 23.71 mm by the eighth week. Treatments D and E, which used PSB and PSF with microcapsules, respectively, showed larger crown diameters compared to the control group, with treatment E exhibiting a significant first growth crown diameters from week one to week two. Overall, the results show the positive effects of using PSB and PSF, especially in combination with peat and compost carrier material.

Treatment C, which combined phosphate-solubilizing fungi (PSF) with compost and peat, consistently produced the largest crown diameter throughout the observation period, reaching approximately 23.93 mm at week 8. This superior performance was likely due to the synergistic effects between PSF activity and the nutrient-rich, organic carrier materials. PSF are well-known for their ability to produce organic acids such as gluconic, citric, and oxalic acid, as well as phosphatase enzymes, which enhance phosphorus (P) solubilization from insoluble forms in the soil (Rawat et al., 2021; Kalayu, 2019). When applied together with compost and peat, the fungi were provided with a favorable microhabitat that supported their survival and sustained activity throughout the growth period (Rodríguez et al., 2020).

The organic carriers, especially compost, also contributed humic substances and improved soil structure, which enhanced root aeration, water retention, and nutrient exchange (Wu et al., 2022). These physical and chemical improvements likely facilitated better root expansion and nutrient uptake, which in turn stimulated shoot growth and crown development. Furthermore, PSF have been shown to produce plant growth-promoting hormones such as indole-3-acetic acid (IAA), which stimulate meristematic activity and contribute to the enlargement of structural tissues including the crown (Rawat et al., 2021). The treatment also likely benefited from the mycelial network formed by the fungi, which extended the rhizosphere and improved access to less mobile nutrients such as phosphorus and micronutrients. In contrast, treatments involving microcapsules (D and E) may have delayed microbial activity due to the controlled release mechanism, resulting in slightly lower crown diameter during the limited 8-week observation period.

3.4 Fruit Yields

There was no significant difference in the yield components of strawberry plants following biological fertilizer application toward the control treatment (Table 4). However, the data shows that biofertilizer treatments have the potential to improve strawberry output and quality. Fruit weight, length, and diameter improved spesifically with treatments using PSB in microcapsules form (Fig 4). In order to maximize strawberry cultivation's production and quality, more study is necessary to clarify the underlying mechanisms causing these effects and to optimize biofertilizer application tactics.

Table 4 Effect of Phosphate Solubilizing Biofertilizer on Fruit Yields

Treatments	Number of fruits	Fruit Weight (g)	Fruit Length (mm)	Fruit Diameters (mm)	Brix (%)
A (Control)	4	3.62	18.68	16.50	9.12
B (PSB - Compost + peat)	4	4.70	20.24	19.23	9.80

C (PSF - Compost + peat)	3	4.67	19.53	18.64	9.51
D (PSB - Microcapsules)	3	5.45	20.17	20.57	9.54
E (PSF - Microcapsules)	4	3.91	18.44	17.36	9.02

Notes: PSB: Phosphate-Solubilizing Bacteria; PSF: Phosphate-Solubilizing Fungi.

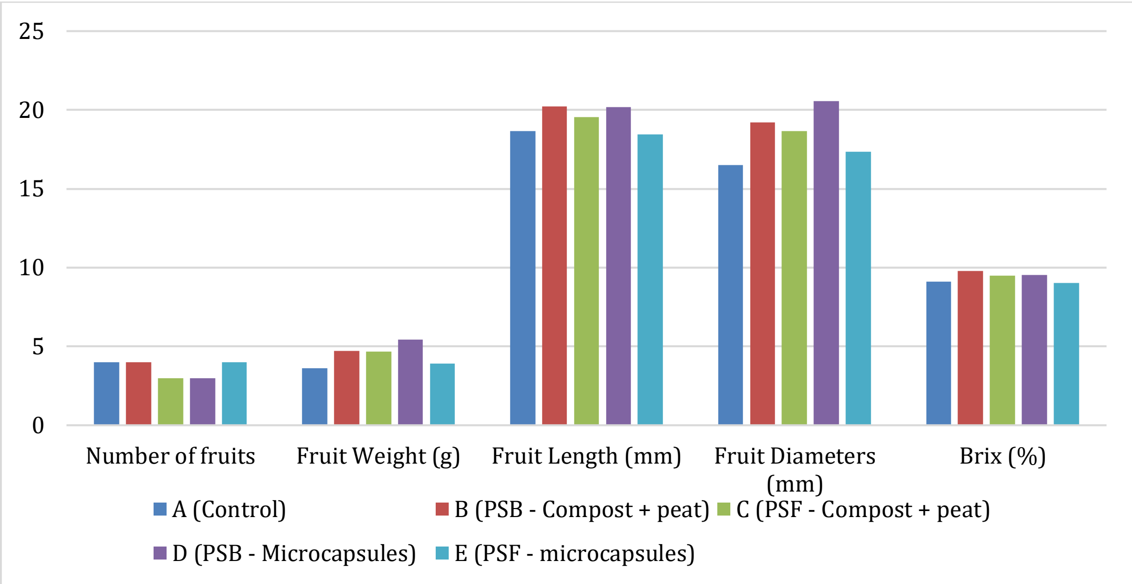

Figure 4 Strawberry Plant Fruit Yields

Strawberry cultivation requires a balance between ideal growing conditions and various environmental challenges that can inhibit plant growth and yield. Temperature, humidity and pest attacks play an important role in determining the strawberry plants growth (Adrian et al., 2025). High temperatures during which tests may be conducted can affect flowering, fruit production, and general plant health, resulting in lower yields. Aside from that, the presence of pests such as aphids and thrips throughout the experiment can harm strawberry plants, resulting in dried fruit. These factors are expected to influence strawberry plant growth and yield during the trial. Therefore, more attention is needed to optimize the area for strawberry cultivation

4. CONCLUSION

The application of phosphate solubilizing biofertilizers, particularly phosphate solubilizing fungi (PSF) combined with compost and peat (Treatment C), significantly improved strawberry vegetative growth parameters such as plant height, leaf number, and crown diameter. These enhancements were attributed to the synergistic effects between microbial activity and organic carrier materials that promoted phosphorus availability, root development, and overall plant vigor. Although no significant differences were observed in fruit yield components, PSB microcapsules (Treatment D) showed promising trends in improving fruit weight and size. These results highlight the potential of biofertilizer formulations, especially those using organic carriers, in enhancing strawberry growth and suggest that further optimization could improve fruit yield outcomes under greenhouse conditions.

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