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Optimization of Growth and Yield of Several Varieties of Green Beans (Vigna Radiata L) Using Solid Oil Palm Waste on Red Yellow Podzolic Soil in Bengkulu

Rita Hayati[1*], Jafrizal[1], Yukiman Armadi[1], Neti Kesumawati[1], Usman[1]

[1] Agrotechnology Study Program, Faculty of Agriculture and Animal Husbandry, Universitas Muhammadiyah Bengkulu, Indonesia.

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Corresponding Author:
Rita Hayati
ritahayati@umb.ac.id

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Abstract: This study aimed to evaluate the effects of solid oil palm waste application and mung bean (Vigna radiata L.) varietal differences on growth and yield performance in red-yellow podzolic soils in Bengkulu, Indonesia. A factorial experiment was conducted using a Randomized Block Design (RBD) with three replications. The two factors tested were four levels of solid waste application (0, 10, 15, and 20 tons/ha) and three mung bean varieties (Vima 2, Vima 4, and Vima 5). Data were analyzed using Analysis of Variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level. The results showed that solid waste application significantly improved plant height, number of pods per plant, pod weight, and seed weight per plant. Variety also had a significant effect on plant height at 56 days after planting. No significant interaction was observed between the two factors. Overall, the application of 20 tons/ha of solid waste resulted in the highest improvements in agronomic parameters. Among the tested varieties, Vima 5 demonstrated the best overall performance. These findings suggest that using solid oil palm waste at an optimal dose can enhance mung bean productivity in red-yellow podzolic soils, supporting sustainable agricultural practices.

Keywords: Green bean; Organic fertilizer; Podzolic soil; Solid oil palm waste; Vigna radiata; Yield optimization

Introduction

Green beans (Vigna radiata L.) play a strategic role in Indonesian agriculture as a source of vegetable protein, animal feed, and as a crop that supports agricultural diversification and soil improvement (Ebrahimi et al., 2022; Ramamoorthy et al., 2020). Although Indonesia is the second-largest green bean producer after China, its productivity remains low. According to the Center for Agricultural Data and Information, the national average yield of green beans is approximately 0.75 tons per hectare, significantly lower than China's productivity which reaches around 1.3–1.5 tons per hectare (Pusdatin May 2024 edition, volume 21 number 05). This discrepancy highlights the urgent need for agronomic innovations to increase mung bean productivity in Indonesia.

Despite its economic potential—evidenced by a total export volume of 16.54 thousand tons valued at IDR 314.90 billion in 2022—Indonesia still imports green beans in large quantities, with import volumes reaching 99.33 thousand tons in the same year (BPS, 2023). This imbalance indicates a domestic productivity challenge that needs to be addressed, particularly in underutilized yet potentially productive regions such as Bengkulu (Nurmegawati et al., 2021).

One of the main constraints in Bengkulu is the dominance of red-yellow podzolic (PMK) soil, which is

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characterized by high acidity (pH < 5), low organic matter, poor nutrient retention (low Cation Exchange Capacity), and high concentrations of aluminum and iron—conditions that are generally unfavorable for crop growth (Farhain et al., 2022; Karimaei et al., 2022; Krettek et al., 2020). Improving the fertility of PMK soil is therefore essential for enhancing green bean cultivation in the region (Khairuddin et al., 2016; Naz et al., 2022; Patria et al., 2022).

One promising and sustainable strategy is the use of solid waste (hereafter consistently referred to as solid palm oil waste) from palm oil mills as organic fertilizer (Darmawan et al., 2021; Dayok et al., 2020). This material—often referred to as solid in the palm oil industry—is rich in nutrients such as nitrogen (10.3 kg/ton), phosphorus (3.3 kg/ton), potassium (6.1 kg/ton), magnesium (4.5 kg/ton), calcium, and organic matter (Banjarnahor et al., 2020); (Martínez-Caro et al., 2020), and is known to improve the physical, chemical, and biological properties of acid soils (Banamtuan et al., 2020; Kooleshwarsingh et al., 2018).

Bengkulu Province, with its 319,027 hectares of oil palm plantations and 42 active palm oil mills, generates significant volumes of solid palm oil waste (Martínez-Mena et al., 2020). Each mill processes between 35–60 tons of fresh fruit bunches per hour, with approximately 4% of that weight becoming solid waste (January et al., 2020). If left unmanaged, this waste poses environmental risks. However, when utilized appropriately, it can serve as a low-cost and eco-friendly soil amendment, particularly in PMK soils (Januari et al., 2020; Rupani et al., 2022).

Although prior studies have shown the positive effects of solid palm oil waste on soil properties, few investigations have examined the interactive effects of different green bean cultivars and solid waste application in PMK soil conditions, particularly in Bengkulu. Cultivar selection is critical because different varieties may vary significantly in their response to organic amendments, especially under stress conditions like those found in PMK soils (Gharsallah et al., 2021; Lege et al., 2020; Yakubenko et al., 2023).

Thus, the novelty of this research lies in combining site-specific soil constraints (PMK soils in Bengkulu), local solid palm oil waste as an organic input, and the performance evaluation of different mung bean cultivars (Elsalam et al., 2021; Kazydub et al., 2020; Lyu et al., 2022). This integrated approach is relatively unexplored and can generate context-specific recommendations for improving green bean productivity using locally available resources.

Therefore, this study aims to analyze the effectiveness of solid palm oil waste application in enhancing PMK soil fertility and its interaction with different mung bean cultivars to identify optimal combinations that maximize growth and yield. This research is expected to contribute to the development of sustainable agricultural practices in marginal soils and to support local food security efforts.

Method

This research was conducted in Tebeng Village, Ratu Agung District, Bengkulu City, at an elevation of 30.00 meters above sea level with an average temperature ranging between 26–30°C and relative humidity of 70–90%. The study was carried out from October 2023 to January 2024. The planting media were collected from Tanjung Terdana Village, Pondok Kubang District, Central Bengkulu Regency, which is characterized by red-yellow podzolic soils (PMK). These soils typically exhibit low pH (4.9) due to base leaching and the accumulation of decomposed organic matter, resulting in low organic content, limited cation exchange capacity (CEC), and reduced nutrient and water retention. Additionally, the clayey and dense alluvial soil structure has slow to moderate permeability and poor drainage. While such details are vital for site characterization, they were only considered to ensure consistency in the planting medium.

The research employed a Randomized Block Design (RBD) with a factorial pattern, consisting of two factors. The first factor was solid waste application rates:
L0 = 0 tons/ha
L1 = 10 tons/ha
L2 = 15 tons/ha
L3 = 20 tons/ha
The second factor was mung bean variety, namely:
V1 = Vima 2
V2 = Vima 4
V3 = Vima 5

This design resulted in 12 treatment combinations, replicated three times, totaling 36 experimental units, with each unit consisting of five mung bean plants, for a total of 180 plants.

Solid waste used in this study was sourced from a palm oil processing plant located in North Bengkulu. The solid waste was air-dried using a dryer machine until the moisture content was reduced to below 15%, following the standard recommended by Yuniza (2015). This threshold was maintained to ensure material consistency in nutrient release and soil structure improvement during application. While the initial nutrient composition of the solid waste was not analyzed in this experiment, future studies are encouraged to conduct a comprehensive nutrient profile to better interpret the effects observed.

Main materials included mung bean seeds of three selected varieties (Vima 2, Vima 4, and Vima 5), solid

waste, and NPK compound fertilizer. Seeds were selected based on their national release status and relevance to dryland cultivation areas in Indonesia (Anyaoha et al., 2018). Although performance characteristics of each variety—such as yield potential, seed size, and pest resistance—are well-documented by the breeders, those data are not repeated here as they fall outside the experimental results of this study.

Key equipment used included a pH meter, digital scale, thermo-hygrometer, and basic planting tools. Common gardening tools such as hoes, buckets, shovels, and labeling materials were also utilized but are not detailed here for brevity.

A simplified workflow diagram (not included here) is recommended for inclusion in the full article version to visually present the experimental sequence: soil and solid waste preparation, planting, maintenance, and data collection phases.

Result and Discussion

Based on the results of the Analysis of Variance (ANOVA), the application of solid oil palm waste significantly influenced the vegetative growth parameters of mung beans (Vigna radiata L.), particularly plant height observed at 14, 42, and 56 Days After Planting (DAP). The statistical analysis also revealed that the varietal differences among the three mung bean cultivars (Vima 2, Vima 4, and Vima 5) contributed significantly to variations in plant height and leaf number. Notably, the interaction between the levels of solid waste and the specific variety treatments showed synergistic effects on early growth performance, indicating that certain combinations are more effective in optimizing plant development on marginal soils. These findings underscore the potential of utilizing solid oil palm waste as an organic soil amendment to enhance plant growth in Red-Yellow Podzolic soils, which are typically characterized by low fertility, poor structure, and limited nutrient retention capacity. The incorporation of organic waste not only improves the physical and chemical properties of the soil but also aligns with sustainable agriculture practices by recycling agro-industrial byproducts (Elwi et al., 2019; Ragimov et al., 2021; Salley et al., 2018). Therefore, the use of solid oil palm waste represents a practical and environmentally responsible strategy to boost crop productivity, particularly in underutilized and degraded agricultural lands such as those found in the Bengkulu region (Alsina et al., 2022).

Plant Height

Figure 1 is a bar graph depicting the relationship between the dose of Solid waste applied with values 0, 10, 15, and 20 (in tons per hectare) and plant height (in cm). The x-axis represents the age of the plant from 14 hst to 56 hst, the Y-axis shows the highest plant height of 48.48 cm resulting from the use of 20 tons/ha of Solid when compared to without the use of Solid, the plant height produced was 33.11 cm, there was an increase in plant height of 15.37 cm or 18.83%.

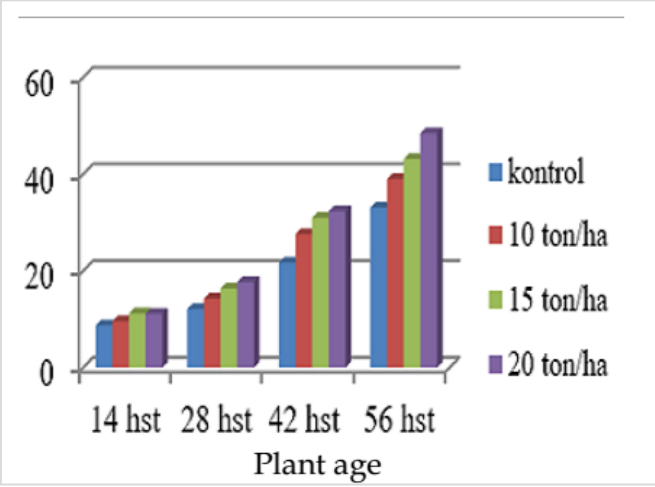

Figure 1. Bar graph of green bean plant height at the age of 14 hst to 56 hst with solid 10, 15 and 20 treatment tons/ha

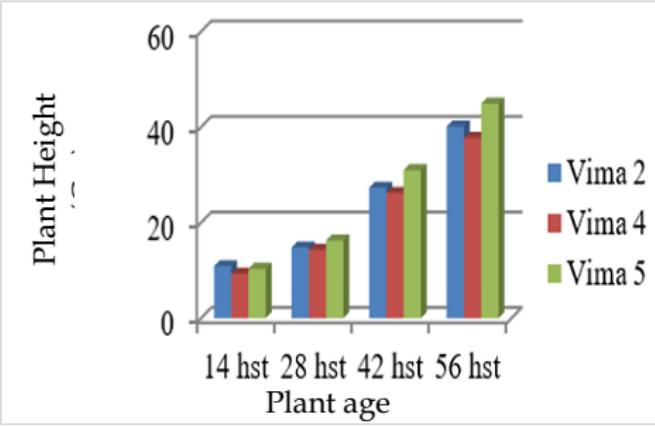

Figure 2. Bar graph of bean plant height green at the age of 14 hst to 56 hst in some varieties

Figure 2 is a bar graph depicting the relationship between mung bean varieties used such as Vima 2,4, and 5 with plant height (in cm). The X-axis represents the age of the plant from 14 hst to 56 hst. The y-axis shows the highest plant height of 44.91 cm produced by the Vima 5 variety, when compared to the Vima 2 variety the plant height produced was only 40.13 cm, there was an increase in plant height of 4.78 cm or 5.62%. The Solid Waste used comes from the palm oil extraction process, which contains essential nutrients including potassium, magnesium, and calcium, all of which are very beneficial to help the development of mung beans (Farid et al., 2019). Solid waste shows a dry matter content of 81.56%, which includes a crude protein fraction of 12.63%, crude

fiber of 9.6%, and lipid components of 4.1%, in addition to calcium of 0.03% and phosphorus of 0.003% (Ibrahim, 2017).

Utilization of Solid waste can be utilized to increase soil fertility and increase optimal growth and production of green beans in PMK soil (Rabinovich et al., 2020). The findings of the investigation revealed differences in the response of each variety to the treatments given, thus allowing the recommendation of the most resilient variety under these specific edaphic conditions. Furthermore, a comprehensive statistical analysis was conducted to ascertain the significance of the observed varieties among the treatments given. The optimal dosage of sludge waste that produces the most favorable results for each variety, especially Vima 2, 4, and 5, should be determined. The optimal dosage for each variety will be further analyzed to determine the most effective application rate in increasing mung bean yield in PMK soil (Nadezkin et al., 2021), the right dose can help in achieving maximum results and support the sustainability of agricultural practices in the Bengkulu region (Barchia et al., 2020). the right dose of Solid waste has the potential to significantly increase green bean yields, thus supporting the sustainability of agriculture in areas with challenging soil conditions in overcoming FMD soil problems (Grisulka, 2019) from this study shows that the application of Solid palm oil solid waste not only increases the growth of green beans, but also contributes to the improvement of overall soil quality. Palm oil sludge waste is rich in important nutrients such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca), which are very important for plant growth (Febriana et al., 2022). Research has shown that applying Solid Waste to PMK/ Ultisol soil significantly increases soil pH, organic carbon, and available phosphorus, which are essential for plant development (Pandapotan et al., 2017). The use of palm oil waste (POME) has been shown to increase the nutrient content of sandy soil, leading to increased palm oil production (Gunawan et al., 2024). The application of palm oil mill effluent (POME) and sludge can improve the physical properties of the soil, such as soil structure and water retention, which are important for plant growth.

Number of Pods per Plant

Figure 3 is a bar graph depicting the relationship between the dose of Solid waste applied with values 0, 10, 15, and 20 (in tons per hectare) and the number of pods per plant. The X-axis represents the dose of Solid waste and the Y-axis represents the number of pods per plant, it can be seen that the highest number of pods per plant is with the provision of Solid waste of 20 tons/ha with an average number of pods of 29.07 fruits, while when compared to without the provision of Solid waste, the number of pods produced is an average of 14.37 fruits, there is an increase in the number of pods per plant of 33.84%, there is an increase in the number of pods per plant by 14.70 fruits or 33.84%.

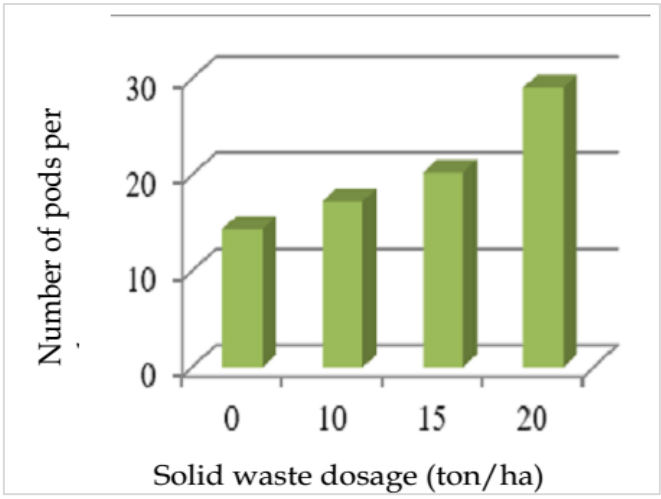

Figure 3. Bar graph of number of pods/plant Green beans with the provision of solid waste of 0, 10, 15 and 20 tons/ha

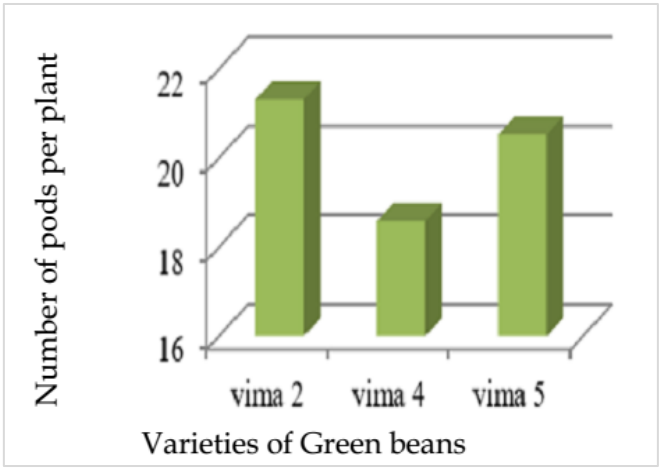

Figure 4. Number of pods/plant of mung beans in some green varieties Vima 2, 4 and 5

Figure 4 is a bar graph depicting the relationship between the green bean varieties used Vima 2, 4, and 5 with the number of pods per plant produced. The x-axis represents the green bean varieties used Vima 2, 4 and 5. The y-axis represents the number of pods per plant produced from the Vima 5 variety with an average of 20.83 fruits, Vima 4 with 18.58 fruits while Vima 1 produces the highest number of pods per plant 21.31 fruits, when compared to the Vima 4 variety with the highest number of pods while the smallest number of pods per plant is Vima 4, there is an increase in the number of pods per plant by an average of 2.73 fruits or 13.49%. The results of this study, the best dose of Solid waste, the highest number of plant pods is 20 tons per hectare and the most adaptive variety to the provision of

Solid waste is Vima 2 with the highest number of pods per plant on average 21.31 fruits on PMK soil, the increase in the number of green bean pods is due to nutrient enrichment and soil improvement. According to the opinion of Solid Waste in the form of mud from palm oil processing, it is rich in macro nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are important for plant growth and development (Febriana et al., 2022). The application of palm oil sludge can increase soil nutrient content and increase plant growth and productivity. The use of palm oil mill waste (POME) and its derivatives can increase plant productivity by 7.57% to 63.23% (Febriana et al., 2022). Composting palm oil sludge with other organic materials, such as kitchen waste, can further enhance its nutrient profile, making it a more effective soil amendment (Tweib et al., 2014).

Weight of Pods per Plant

Figure 5 is a bar graph depicting the relationship between the dose of Solid waste applied with values of 0, 10, 15, and 20 (in tons per hectare) and the weight of pods per plant. The X-axis represents the dose of Solid waste and the Y-axis represents the weight of pods per plant, it can be seen that the highest pod weight per plant was obtained by administering 20 tons/ha of Solid waste with an average pod weight of 31.37 grams, while when compared to without the administration of Solid waste, the average pod weight produced was 14.63 grams, there was an increase in pod weight per plant of 16.74 grams or 36.39%. The results of this study obtained the highest dose producing pod weight per plant was by administering 20 tons of Solid waste per hectare.

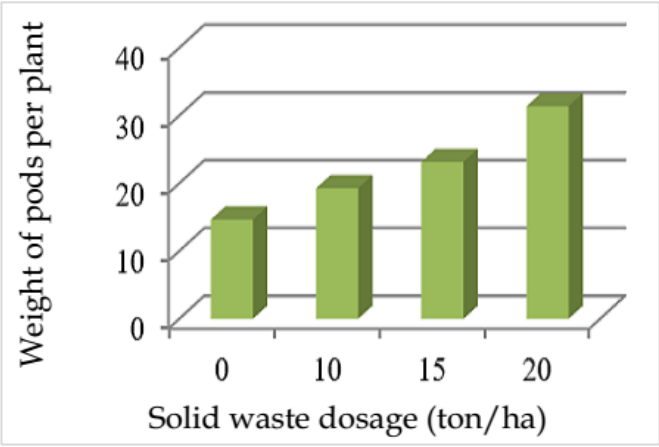

Figure 5. B close up of green bean pods per plants with the provision of Solid waste of 0, 10, 15 and 20 tons/ha

Figure 6 is a bar graph depicting the relationship between the green bean varieties used Vima 2.4, and 5 with the weight of pods per plant produced. The x-axis represents the green bean varieties used Vima 2, 4, and 5. The y-axis represents the weight of pods per plant produced from the Vima 5 variety with an average of 23.72 grams, Vima 4 with 21.02 grams is the highest while Vima 4 produces the highest pod weight per plant of 21.02 grams which is the lowest, when compared to the Vima 2 variety with an average pod weight of 21.56 grams. When compared to the pod weight per plant of Vima 5 and Vima 4, there was an increase in the weight of pods per plant by an average of 2.70 grams or 6.03%. The results of the study showed that the most adaptive variety with the provision of Solid waste on PMK soil was the Vima 5 variety. POME application has been shown to increase soil cation exchange capacity (CEC) and organic carbon content, which are indicators of increased soil fertility (Febriana et al., 2022; Gunawan et al., 2024).

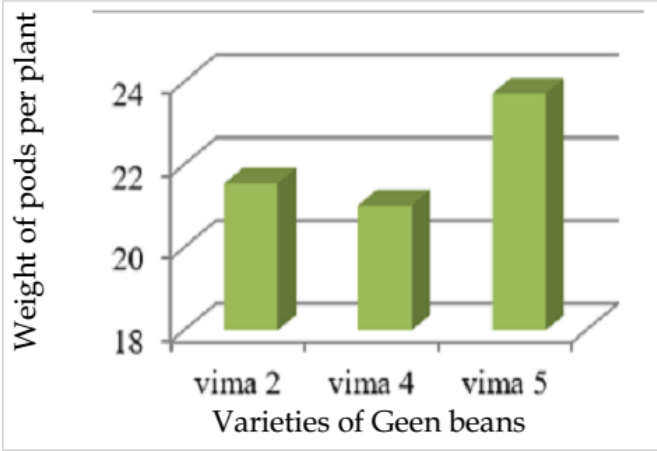

Figure 6. Pea plant pod weight green per plant on some green bean varieties

Utilization of waste sludge from oil palm production offers significant benefits for improving soil fertility (Fitria et al., 2021; Hani et al., 2022). This waste, which includes various by-products such as empty fruit bunches, palm oil mill effluent (POME), and sludge, can be converted into valuable fertilizers that improve soil properties and plant growth. Application of these materials not only recycles waste but also contributes to sustainable agricultural practices by improving soil chemical and physical properties, increasing nutrient availability, and supporting plant health. The following section details the specific benefits and applications of oil palm waste sludge in improving soil fertility. Application of POME has been associated with increased oil palm fresh fruit bunch production, indicating its potential to increase crop yields (Gunawan et al., 2024). Red-yellow podzolic soils are typically acidic and low in nutrients, making them challenging for plant growth. The addition of oil palm sludge can help neutralize soil acidity and increase its nutrient content (Rahmawan et al., 2015). A study on cocoa seedlings

showed that a 1:1 ratio of red-yellow podzolic soil to oil palm sludge produced the best growth results, suggesting potential benefits for other crops such as mung beans (Rahmawan et al., 2015). The organic matter content of the sludge can improve soil structure, water retention, and aeration, which are essential for healthy mung bean plant growth (Anyaoha et al., 2018). Utilizing palm oil sludge as a soil amendment can reduce environmental pollution by diverting waste from landfills and waterways (Tweib et al., 2014). Conversion of oil palm waste into valuable soil amendments can provide economic benefits by reducing the need for chemical fertilizers and increasing crop yields (Anyaoha et al., 2018). The process of composting palm oil sludge with other organic materials can be optimized to produce high-quality compost that meets agricultural standards.

Seed Weight per Plant

Figure 7 presents a bar graph illustrating the relationship between different application rates of solid oil palm waste—0, 10, 15, and 20 tons per hectare—and the resulting seed weight per plant. The X-axis denotes the dosage of solid waste applied, while the Y-axis indicates the average seed weight per plant. The highest seed weight was observed at the application rate of 20 tons/ha, producing an average of 29.56 grams per plant. In comparison, the control treatment (0 tons/ha) produced an average seed weight of 13.18 grams, resulting in an increase of 16.38 grams or approximately 124.28%. These findings clearly demonstrate that the application of solid oil palm waste significantly enhances the yield component of mung beans, particularly seed weight per plant, when cultivated in Red-Yellow Podzolic (PMK) soil.

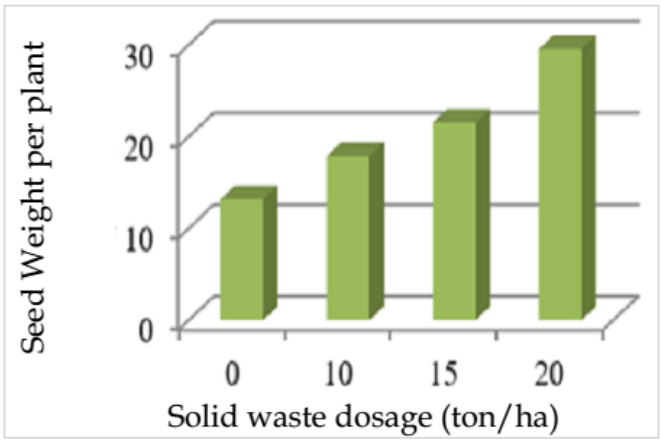

Figure 7. Close-up of green bean seeds/plants by providing 0, 10, 15 and 20 tons/ha of solid waste

Figure 8 displays the relationship between the green bean varieties used—Vima 2, Vima 4, and Vima 5—and the seed weight per plant. The X-axis lists the varieties, while the Y-axis shows the seed weight per plant in grams. Among the tested varieties, Vima 5 yielded the highest seed weight, averaging 21.99 grams per plant, followed by Vima 2 at 20.05 grams, and Vima 4 with the lowest at 19.55 grams. The difference in seed weight between Vima 5 and Vima 4 was 2.44 grams, corresponding to an increase of approximately 12.48%. Assuming a planting density of 50 plants per 10 m², which extrapolates to 500,000 plants per hectare, this difference would translate to an increase of roughly 1,220 kg/ha, emphasizing the practical significance of varietal selection in productivity outcomes. However, it is important to explicitly state the assumed planting density for accurate conversion from per-plant yield to per-hectare estimates.

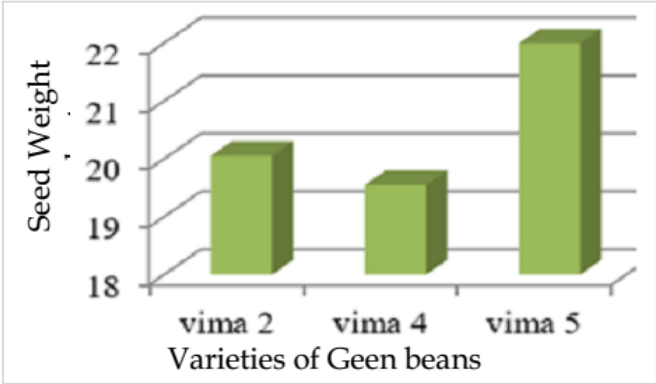

Figure 8. B close to green bean seeds/plants on some varieties of Vima 2, 4 and 5

These results confirm that both the application of solid oil palm waste and the selection of appropriate mung bean varieties play a critical role in optimizing crop yield. The positive effects observed are likely attributable to improvements in soil fertility and nutrient availability facilitated by the organic waste. Solid oil palm waste is known to enhance soil structure, increase organic matter, and improve nutrient retention, particularly in acidic soils like PMK (Pandapotan & Marbun, 2017; Ermadani et al., 2019). Prior studies have reported similar outcomes: the application of palm oil mill sludge improved the dry weight of corn seeds, where treatment with 400 cc/plant increased seed dry weight from 38 g to 43 g (Jumin et al., 2015). In soybean cultivation, Ermadani and Ar found that 75 mL of palm oil compost—equivalent to 2.82 t/ha—produced the highest seed weight, indicating the compost's potential to increase crop yields (E. Ermadani et al., 2013; H. Ermadani et al., 2019; Pandapotan et al., 2017).

By aligning with previous findings in corn and soybean research, the current study strengthens the evidence that organic waste from palm oil mills can substantially improve productivity across various crop types. The consistent improvement in seed weight

observed in mung beans, especially when treated with 20 tons/ha of solid waste and planted with the Vima 5 variety, demonstrates the synergistic benefits of integrating soil amendment strategies with varietal selection. This approach is particularly valuable for enhancing productivity on marginal lands such as PMK soil in Bengkulu.

Conclusion

This study demonstrates that the application of solid waste from palm oil processing significantly enhances mung bean growth and yield on Red Yellow Podzolic (PMK) soils in Bengkulu. The most effective dose was 20 tons per hectare, resulting in the highest seed weight per plant and indicating improved soil fertility and crop performance. Among the three varieties tested, Vima 5 consistently produced the greatest seed weight per plant, confirming its superior agronomic performance on marginal soils. These results highlight the strong varietal effect, rather than a significant interaction between variety and solid waste dose. The application of solid waste at the tested rates proved beneficial, with no evidence of adverse effects such as nutrient leaching. The findings support the use of palm oil solid waste as a sustainable soil amendment for improving legume productivity, particularly in suboptimal soils like PMK. Based on this study, the adoption of Vima 5 and solid waste at 20 t/ha is recommended for maximizing yield potential. These results provide practical insights for smallholder farmers and agricultural policymakers aiming to improve crop output through low-cost, organic soil management strategies. The study's implications are specific to the conditions tested and contribute to site-specific nutrient management in mung bean cultivation.

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Author Contributions
Conceptualization: RH, JF, YA, NK; Methodology: RH, JF; Validation: RH; Formal Analysis: RH; Investigation: RH, JF; Resources: RH, JF, Us, NK; Data Curation: RH, JF, Us; Writing – Original Draft: RH, NK; Writing – Review & Editing: JF; Visualization: RH, JF. All authors have read and approved the final version of the manuscript for publication.

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Conflicts of Interest
This research was conducted as part of the institution's commitment to enhance the competencies and capacities of its academic staff. The findings are expected to contribute positively to human resource development within the academic environment and support the advancement of innovation and educational progress.

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