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RESEARCH ARTICLE

Growth and yield of hydroponic Pak choy (*Brassica rapa* subsp. *chinensis* L) under organic-derived nutrient sources from vetiver biochar and liquid pineapple waste

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ABSTRACT

This study evaluated the potential of vetiver grass biochar and liquid pineapple waste as organic nutrient sources in the hydroponic cultivation of Pak choy (*Brassica rapa* subsp. *chinensis* L). Six treatments were tested: a synthetic AB fertilizer control (T1), and five organic alternatives, including 100% pineapple waste (T2), 100% biochar (T3), and various combinations of both (T4–T6). Growth parameters such as chlorophyll content, plant height, number of leaves per plant, and biomass were measured. The control (T1) consistently exhibited superior performance, with the highest chlorophyll content (40.87 ± 7.02), plant height (13.85 ± 1.57 cm), and yield (42.44 ± 6.05 g). Among the organic treatments, T5 (75% biochar + 25% pineapple waste) produced the best results, with elevated chlorophyll content (25.10 ± 2.19) and the highest yield (3.84 ± 0.47 g), indicating the effect of the nutrient-retentive properties of biochar combined with the nutrient-rich composition of pineapple waste. Pearson correlation analysis revealed strong positive relationships among all parameters, with yield highly correlated with the number of leaves per plant (r = 0.99), plant height (r = 0.99), and chlorophyll content (r = 0.94). These results highlight the relevance of vegetative traits as reliable indicators of crop productivity in hydroponic systems. While entirely replacing synthetic nutrients remains challenging, the T5 formulation presents a potential alternative for reducing chemical inputs. This study supports the advancement of sustainable nutrient management practices in soilless agriculture. Furthermore, although vetiver grass biochar combined with liquid pineapple waste shows promise, further research is needed to understand the long-term effects on optimizing organic nutrient sources ratios, pH buffering, comprehensive nutrient uptake, and the synergistic potential with other organic nutrient sources or fertilizer practices. Such understanding is crucial for guiding future research in sustainable farming practices.

1. INTRODUCTION

Hydroponics has emerged as a viable solution for sustainable agriculture, improving resource efficiency and crop productivity (Khan et al., 2024). It is a method of growing plants without soil, utilizing a nutrient-rich solution in a controlled environment, which enables the efficient use of water and nutrients (Thapa et al., 2024). However, the reliance on synthetic nutrient solutions raises concerns about the environmental sustainability due to nutrient runoff and the use of fossil-fuel-based inputs (Zhou et al., 2023). Incorporating organic nutrient sources, such as biochar and agro-industrial waste, offers an eco-friendly approach to enhancing nutrient availability and plant health.

Vetiver grass is native to South and Southeast Asia. In Malaysia, vetiver grass (*Chrysopogon zizanioides* L.) is widely cultivated and valued for its environmental benefits, particularly in stabilizing slopes and mitigating soil erosion. It grows quickly and thrives in tropical climates with ample water and sunlight. Malaysian agricultural agencies are actively planting vetiver along terraces, roadsides, and slopes to prevent landslides, reduce erosion, and conserve moisture for neighboring crops (Aleiadeh et al., 2024). Compared to bare soil, vetiver grass has also been used effectively in hydroponic or semi-hydroponic systems to reduce chemical oxygen demand (COD) and biological oxygen demand (BOD), as well as to remove heavy metals such as lead and cadmium from industrial wastewater. Because of this, vetiver grass is an affordable and sustainable solution for cleaning contaminated water in enclosed hydroponic systems (Davamani et al., 2021). Additionally, since vetiver grass grows well in hydroponic environments and efficiently accumulates pollutants, its biomass can be converted into biochar with minimal risk of pollutant leakage (Barcellos-Silva et al., 2025).

Biochar, derived from the pyrolysis of organic biomass, improves soil aeration, nutrient retention, and microbial activity in the root zone (Na Nagara et al., 2024; Ch'ng et al., 2013). Vetiver grass is particularly suitable for biochar production due to its dense root system and high biomass yield (Ch'ng et al., 2013). Vetiver grass biochar, produced through the pyrolysis of the vetiver biomass, can be applied to soils to improve quality, enhance plant growth, and increase nutrient uptake (Aleiadeh et al., 2024). Its high porosity and carbon-rich nature enhance microbial activity, water-holding capacity, and nutrient retention. Studies have shown that when applied with nutrients, vetiver biochar can increase nutrient availability and enable gradual nutrient release, thereby enhancing fertilizer use efficiency and promoting healthier plant growth. It also contributes to nutrient cycling and reduces environmental impacts, supporting more sustainable hydroponic practices. In hydroponic systems, it serves as an effective carrier or amendment for organic nutrients, enhancing their efficiency and stabilizing the growing environment (Barcellos-Silva et al., 2025; Na Nagara et al., 2024).

In Malaysia, pineapple waste production is substantial due to the country's large pineapple industry. An estimated 2 million tonnes of pineapple waste are produced annually. This waste includes leaves, stems, crowns, and peels from pineapple harvesting and processing (Matius et al., 2022). Current disposal practices include composting, animal feed use, replanting with crowns, and, unfortunately, open-field burning, which pollutes the environment (Harith et al., 2023). From the perspective of organic nutrient sources, pineapple waste is rich in essential nutrients–particularly phosphorus (P), potassium (K), and nitrogen (N)–which are critical for plant growth. This biomass can be converted into liquid organic nutrient solutions through anaerobic fermentation or composting. For example, pineapple waste has been used to produced liquid fertilizers with reported values of 1.7% nitrogen, 0.33% phosphorus, and 1.74% potassium. This makes it a valuable nutrient source for both soil-based or hydroponic farming systems (Wichitsathian et al., 2020).

These organic materials enhance plant growth, especially under soilless conditions (Chaosap et al., 2021; Rani & Nand, 2004). Fermentation is the primary method used to produced liquid fertilizer from pineapple leaf waste, converting organic matter into nutrient-rich solutions. Pineapple peel and leaf residues contain essential elements and organic matter suitable for plant growth. When properly diluted and balanced, the resulting nutrient levels can support hydroponic cultivations. By using natural nutrients and beneficial microbes rather than synthetic chemicals, these fertilizers can promote plant development in the hydroponic systems. However, liquid organic nutrient typically exhibit high electrical conductivity (EC) and slightly acidic pH (between 4.65 and 6.05), requiring regular monitoring and adjustments to maintain optimal plant health (Seman & Adam, 2023).

Despite their potential, research on the application of these organic materials in hydroponic systems remains limited. Therefore, this study aims to evaluate the viability of vetiver grass biochar and liquid pineapple waste as alternative organic nutrient sources and assess their effects on the growth and yield of Pak choy (*Brassica rapa* subsp. *chinensis*).

2. MATERIALS AND METHODS

2.1 Experimental site, experimental design, and treatment

The study was conducted at the Farm Unit, Universiti Teknologi MARA (UiTM) Sarawak Branch, Samarahan Campus, Sarawak, Malaysia (1°26'47.926" N 110°27'6.551" E (1.446646, 110.451820) under nursery glasshouse conditions for 42 days between September and November 2024. The plant materials consisted of pre-germinated seeds of commercially sourced *Brassica rapa* (cultivar DPC477), purchased from a local commercial supplier.

The experimental design followed a Completely Randomized Design (CRD), comprising six treatments with four replications, and seven plants per replication, resulting in a total of 168 Pak choy plants. The parameters studied included vegetative growth, chlorophyll content, number of leaves per plant, plant height, and the total dry biomass, which served as the yield indicator.

Table 1: Treatment composition and rate

Treatment	Rate of Fertilizer	Quantity (ml/L) / g
T1	100% Control AB fertilizer	10.0 ml
T2	100% Liquid Pineapple Waste	50.0 ml
T3	100% Vetiver Grass Biochar	100.0 g
T4	50% Vetiver Grass Biochar + 50% Liquid Pineapple Waste	50.0 g + 25.0 ml
T5	75% Vetiver Grass Biochar + 25% Liquid Pineapple Waste	75.0g+ 12.5ml
T6	25% Vetiver Grass Biochar + 75% Liquid Pineapple Waste	25.0 g + 37.5ml

AB fertilizer served as the standard control, while *Brassica rapa* seeds were used as plant indicators. Seed preparation followed the method described by Morgan (1999), where germination trays were filled with peat moss, leaving 1.3 cm from the top, and moistened before sowing. Seeds were evenly distributed and gently pressed into the medium. Seedlings were grown for five weeks under adequate sunlight and regular watering to maintain moist conditions. Once the seedlings developed a second set of true leaves and reached 4–6 cm, they were ready for transplanting.

Treatments applications began post-transplanting and continued until harvest, from 18 October to 8 November 2024 (six weeks). Vetiver grass, sourced locally, was processed into biochar via pyrolysis following the method of Pan et al. (2021). The biomass was placed in an appropriately sized ceramic crucible and carbonized at 350–400 °C for 2 hours in a large-chamber muffle furnace (Type 62700; Thermo Scientific Barnstead/Thermolyne, USA). The resulting biochar was cooled, collected and pulverized for characterization.

Pineapple waste–including stems and leaves–was collected from local smallholder farms in Samarahan, Sarawak. Liquid pineapple waste was produced via anaerobic fermentation, following the method described by Saif et al. (2021). The formulation included 50 kg of pineapple waste, 5 kg of brown sugar, and 50% water (based on the waste volume), maintaining a 1:10 ratio of sugar to plant waste. The materials were mixed in a drum, with water added to slightly exceed the waste level (Muri, 2022). After 14 days of fermentation, the liquid was stirred to prevent sedimentation and analyzed for nutrient content according to standard laboratory procedure (Mahdian et al., 2025). Before application, the stock was diluted at a ratio of 1:15–20 (v/v).

Several plant growth parameters were measured weekly beginning the third week after transplanting. Plant height was measured (in cm) from the base of the stem to the tallest point using a measuring tape. Leaf number per plant was determined manually. Chlorophyll content was recorded using a SPAD-502 chlorophyll meter (Minolta). Plant yield assessed by determining total dry biomass. After harvesting, the leaves, stems, and roots were gently washed and weighed using an analytical balance. The samples were oven-dried at 65 °C for 72 hours and reweighed to obtain total dry biomass. Routine pest and disease management was performed, and standard hydroponic nutrients adjustments were made in accordance with plan growth stages, as recommended by Khan et al. (Khan et al., 2024).

3. RESULTS AND DISCUSSION

The nutrient analysis used in this study, as presented in Table 2, was adequate and tolerable for the growth of Pak choy. This finding aligns with a previous study by Suharyatun et al. (2024). The nutrient profile indicates that vetiver grass biochar and liquid pineapple waste contain essential macro- and micronutrients required for optimal Pak choy developnment. The total nitrogen (N) content in biochar and pineapple waste highlights their potential as nitrogen source, which are critical for vegetative growth and chlorophyll synthesis in *Brassica* species (Sun et al., 2020).

The phosphorus (P_2O_5) levels–0.12% in biochar and 0.33% in pineapple waste–are moderate but may require supplementation to meet the high phosphorus demand of *Brassica* during rapid growth stages. Potassium (K_2O) is notably higher in pineapple waste (1.74%) than in biochar (0.91%), indicating a strong potential for improving water regulation and turgor pressure. In addition, magnesium (MgO) and calcium (CaO) levels in biochar can support cell wall stability and essential enzymatic functions.

Micronutrients such as copper (Cu), zinc (Zn), and iron (Fe) were detected at concentrations that could support key metabolic processes. However, their bioavailability in hydroponic media may vary depending on pH and ion interactions. Notably, the pH of vetiver grass biochar was relatively alkaline (8.7), which could influence nutrient availability and uptake unless corrected. In contrast, the lower pH of liquid pineapple waste (4.8) may help buffer the nutrient solution but could also result in nutrient imbalances if not properly managed.

Therefore, although the nutrient content–particularly nitrogen and potassium–is promising, the high alkalinity of biochar and potential micronutrient imbalances suggest that supplementation and pH adjustments are necessary to optimize the formulation for hydroponic *Brassica* cultivation.

Table 2: Nutrient content of Vetiver grass biochar and liquid pineapple waste

Source	Vetiver Grass Biochar	Liquid Pineapple Waste
pH	8.7	4.8
Total N (%)	0.44	1.70
Total P_2O_5 (%)	0.12	0.33
Total K_2O (%)	0.91	1.74
Total MgO (%)	0.15	0.24
Total CaO (%)	0.42	0.20
Total Cu (mg/Kg)	5.0	<1.0
Total Zn (mg/Kg)	29.0	5.0
Total Fe (mg/Kg)	65.0	14.0

3.1 Growth and yield performance

The experimental treatments significantly influenced the growth and yield performance of hydroponically grown Pak choy, as demonstrated by variations in plant height, number of leaves per plant, chlorophyll content, and total dry biomass (yield) (Table 3).

ANOVA followed by Duncan's Multiple Range Test (DMRT) revealed significant difference among all treatments at $p < 0.05$. The control treatment (T1), consisting of 100% AB synthetic fertilizer, consistently recorded the highest mean values across all measured parameters.

Table 3: Effect of different treatments on the growth and yield performance

Treatment	Plant Height (cm)	Leaf (per plant)	Chlorophyll Content (SPAD)	Dried Biomass (g)
T1	13.85 ±1.57^{a}	14.00 ±1.56^{a}	53.28 ± 3.04 ^{a}	3.49 ± 0.47 ^{a}
T2	6.08 ± 1.16 ^{d}	5.10 ± 0.74 ^{d}	22.24 ± 3.21 ^{d}	0.56 ± 0.20 ^{d}
T3	6.65 ± 1.36 ^{d}	4.80 ± 0.63 ^{d}	23.40 ± 4.95 ^{d}	0.60 ± 0.13 ^{d}
T4	6.84 ± 0.82 ^{d}	5.50 ± 1.08 ^{d}	29.28 ± 4.80 ^{c}	0.64 ± 0.24 ^{d}
T5	10.20 ± 0.74^{b}	9.40 ± 1.42 ^{b}	40.16 ±3.49 ^{ab}	2.35 ± 0.13 ^{b}
T6	8.02 ± 1.05 ^{c}	7.10 ± 1.44 ^{c}	35.90 ± 4.80 ^{b}	0.89 ± 0.23 ^{c}

Means sharing similar letters in a column for different levels of the same nutrient are statistically non-significant according to Duncan's Multiple Range Test (DMRT) at α=0.05; values are the means of twenty-eight replicates ± standard error.

Specifically, T1 achieved a plant height of 13.85 ± 1.57 cm, 14.00 ± 1.56 leaves per plant, chlorophyll content of 53.28 ± 3.04 SPAD unit, and a total dry biomass of 3.49 ± 0.47 g per plant. These results reaffirm the superior performance of conventional hydroponic nutrient solutions, attributed to their precise nutrient composition and immediate availability to plant roots (Khan et al., 2024; Zhou et al., 2024).

Among the organic treatments, T5 (75% vetiver grass biochar + 25% liquid pineapple waste) emerged as the most promising alternative. It achieved a mean plant height of 10.20 ± 0.74 cm, 9.40 ± 1.42 leaves per plant, chlorophyll content of 40.16 ± 3.49, and total dry biomass of 2.35 ± 0.13 g. Although this biomass was lower than that of the control, it was the highest among all organic treatments. The improved performance is likely due to the synergistic interaction between the nutrient-retentive properties of biochar and the nutrient-rich composition of pineapple waste–particularly its nitrogen (1.7%) and potassium (1.74%) content, which are vital for vegetative growth and yield formation (Sultana et al., 2022).

Treatment T4 (50% biochar + 50% pineapple waste) and T6 (25% biochar + 75% pineapple waste) produced moderate biomass values of 0.64 ± 0.24 g and 0.89 ± 0.23g, respectively. However, their lower chlorophyll levels (29.28 ± 4.80 and 35.90 ± 4.80) and reduced plant height suggest that excessive pineapple waste may have led to over-acidification (pH 4.8), negatively impacting nutrient availability and root activity. Acidic conditions in hydroponic media can impair nutrient uptake and trigger micronutrient imbalances.

The poorest performance was observed in T3 (100% biochar), with a dry biomass of 0.60 ± 0.13 g, and T2 (100% pineapple waste), with 0.56 ± 0.20 g. While biochar enhances structural properties and supports microbial colonization, its lack of soluble nutrients likely limited the productivity of T3. Conversely, the suboptimal performance of T2 may be attributed to high acidity and imbalanced nutrient composition, despite its relatively high nitrogen and potassium levels.

A strong relationship between chlorophyll content and yield was evident across treatments, reinforcing that photosynthetic efficiency closely correlates with biomass accumulation (Liu et al., 2011). Although none of the organic treatments matched the yield of the synthetic control, T5 showed considerable potential as a sustainable alternative with lower environmental impact when properly optimized.

As anticipated, the performance of T1 across all growth and yield parameters confirms that well-formulated mineral solutions continue to deliver the highest productivity in hydroponic *Brassica* cultivation. These findings are consistent with previous nutrient-solution optimization studies, where balanced N–P–K ratios and micronutrient availability supported vigorous vegetative growth (Park & Williams, 2024).

Among the organic treatments, T5 outperformed others in terms of plant height, chlorophyll content, and biomass, supporting the hypothesis that vetiver biochar's high surface area and porosity enhance nutrient retention and reduces leaching. Meanwhile, fermented pineapple waste provides readily available nitrogen and potassium, critical for leafy biomass production in *Brassica* crops. Similar benefits of biochar–organic nutrient blends have been reported in cocoa pod husk systems and bioorganic fertilizer studies on Pak choy, where improved nutrient holding and microbial-mediated mineralization enhanced plant performance compared to unamended organic (Wang et al., 2022).

In contrast, the poor performance of T2 and T3 highlights the risks of relying solely on single-source organic inputs in hydroponic systems. Despite high nutrient content, T2's low biomass and chlorophyll suggest that low pH (~4.8) and elevated EC may have induced root stress and nutrient imbalances–consistent with findings that food-waste–based hydroponic solutions often exhibit excessive salinity. Similarly, T3's low yield demonstrates that biochar's structural benefits are insufficient without accompanying soluble nutrients (Park & Williams, 2024; Wang et al., 2025).

Together with the intermediate responses in T4 and T6, these findings underscore the importance of balancing nutrient sources ratios and buffering capacity to avoid both nutrient dilution and over-acidification.

In summary, vetiver grass biochar contributes structural, microbial, and retention benefits, while fermented pineapple waste supplies essential nutrients. Their combination, particularly at a 3:1 ratio (T5), represents a viable alternative for growers seeking to reduce dependence on synthetic inputs without significantly compromising yield.

Future research should aim to optimize the biochar-to-pineapple waste ratio while maintaining a neutral pH favourable for nutrient uptake. The inclusion of natural or commercial buffering agents may further enhance nutrient availability. Additionally, investigating microbial community dynamics within organic-amended hydroponic nutrient solutions will provide insights into the roles of beneficial microbes in nutrient absorption, disease resistance, and plant growth. Tracking real-time uptake of macro- and micronutrients will also support the development of more targeted nutrient strategies tailored to crop requirements and growth stages (Park & Williams, 2024).

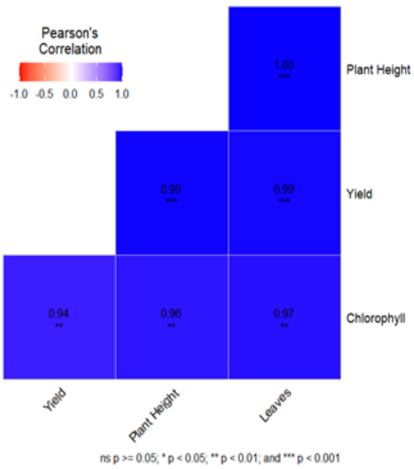

Figure 1: Pearson correlation heatmap showing the relationships among parameters in hydroponically grown Pak choy.

3.2 Correlation analysis among growth and yield parameters

The most notable correlation was observed between the number of leaves per plant and yield ($r = 0.99$, $p < 0.001$), indicating that leaf count is a highly reliable predictor of final biomass production in this hydroponic system. This strong association suggests that treatment T5, which promoted vigorous vegetative growth–particularly leaf development–directly contributed to yield accumulation. Biologically, this correlation is plausible because the number of leaves is directly linked to photosynthetic capacity. A greater number of leaves typically indicates a higher total photosynthetic surface area, resulting in increased biomass accumulation and yield (Cruz et al., 2022).

Similarly, plant height also showed a statistically significant and strong positive correlation with yield ($r = 0.99$, $p < 0.001$). This suggests that taller plants may benefit from more efficient nutrient uptake, enhanced photosynthetic area, and consequently greater yield potential. These findings align with previous research demonstrating positive relationships between vertical growth and productivity in leafy vegetables (Liu et al., 2011).

Chlorophyll content also exhibited a strong correlation with yield ($r = 0.94$, $p < 0.01$), confirming that chlorophyll concentration–a proxy for photosynthetic efficiency–is a central determinant of biomass production. Higher chlorophyll content typically reflects improved nitrogen assimilation and active photosynthetic metabolism, both of which are critical for yield formation (Sultana et al., 2022).

In addition, chlorophyll content was positively correlated with leaf number ($r = 0.97$) and plant height ($r = 0.96$), further reinforcing the physiological interconnections among photosynthetic efficiency, vegetative growth, and overall plant vigor (Moore et al., 2021).

The very strong positive correlations observed between yield and vegetative traits–namely, leaf number, plant height, and SPAD chlorophyll content–demonstrate that these parameters serve as reliable early indicators of productivity in hydroponic Pak choy systems, under both synthetic and organic nutrient conditions. Similar correlation patterns have been reported in hydroponically grown leafy vegetables, where canopy traits and chlorophyll levels closely reflect final biomass output. This suggest that routine monitoring of these easily measurable traits can inform timely nutrient and pH adjustments to optimize productivity.

From a practical perspective, these correlations provide a valuable tool for growers, especially those using organic nutrient sources. Non-destructive measurement measurements of leaf number, plant height, and SPAD values can serve as early predictors of system performance, allowing for intervention before yield losses become irreversible (Kwon et al., 2021). This predictive framework is particularly important in organic systems, where real-time estimation of nutrient sufficiency and productivity is more complex.

Moreover, the high degree of correlation among all parameters–especially the near perfect association between leaf number, height, yield–underscores the importance of vegetative traits as early performance indicators. Such insights can aid in maximizing yield potential by optimizing fertilizer management strategies in both synthetic and organic hydroponic systems (Srivani et al., 2021).

Overall, the findings of this study contribute to the expanding body of research on organic and food–waste–based hydroponic fertilization, which seeks to close the yield gap between organic and synthetic systems while promoting sustainable waste utilization. Recent high-impact reviews have emphasize that successful organic hydroponic must tightly regulate pH and EC, ensure adequate mineralization rates, and often incorporate biochar or microbial inoculants to stabilize nutrient availability. The performance of T5 in this study demonstrates that the combination of vetiver grass biochar and fermented pineapple waste can partially fulfill these criteria. This combination offers a promising approach to reducing synthetic fertilizer dependence while enabling the circular reuse of local agro-industrial by-products (Matius et al., 2022; Park & Williams, 2024; Wang et al., 2025). Nonetheless, further research is required to optimize nutrient ratios, refine buffering strategies, and conduct multi-crop validation trials before before these practices can be recommended for large-scale commercial adoption.

4. CONCLUSION

This study demonstrated that integrating vetiver grass biochar and liquid pineapple waste can influence the growth performance and yield of hydroponically grown Pak choy. Among the organic treatments, the combination of 75% biochar and 25% pineapple waste (T5) resulted in the highest mean values of chlorophyll content, moderate plant height, and improved yield compared to other organic combinations. These results highlight the potential of optimizing the balance between the nutrient-holding capacity of bio-char and the nutrient-rich composition of pineapple waste.

Although the synthetic AB fertilizer (T1) consistently outperformed all treatments across measured parameters-as expected-the performance of the 75% biochar and 25% pineapple waste treatment (T5) demonstrate the potential of sustainable organic input to serve as a partial alternatives to conventional fertilizers in hydroponic systems.

Moreover, correlation analysis revealed strong positive relationships among plant height, number of leaves per plant, chlorophyll content, and yield. These findings confirms that vegetative growth traits are reliable early indicators of productivity in hydroponically grown Pak choy and emphasize the importance of selecting nutrient sources that enhance photosynthetic efficiency and vegetative vigor.

For future research, comprehensive studies are recommended to assess the long-term effects of Vetiver grass biochar and liquid pineapple waste. Key areas of focus should include optimizing nutrient formulations, managing pH imbalances, and evaluating efficacy across a range of crops and hydroponic environments to support wider adoption of sustainable organic nutrient source.

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REFERENCES

Aleiadeh, H., Idris, ;, Juferi, Mohidin, ;, Hasmah, Omar, ;, Latifah, Man, ;, Sulaiman, Munir, ;, Siraj, Jong, ;, & Vivien. (2024). Effect of Co-application of Vetiver Grass Biochar and NPK Fertilizer on the Growth of Oil Palm (Elaeis guineensis Jacq.) Seedlings and Soil Chemical Properties. In Malaysian Journal of Soil Science Year (Vol. 28).

Barcellos-Silva, I. G. C., dos Santos, F. K. F., Kharkwal, H., Chander, S., Kharkwal, A. C., Awasthi, R., Dhiman, N., Sharma, B., Kulkarni, G. T., Larssen, H., Silva, J. M. L., Souza, M. A. de, Setzer, W. N., & Veiga-Junior, V. F. (2025). Vetiver, Vetiveria zizanioides (L.) Nash: Biotechnology, Biorefineries, and the Production of Volatile Phytochemicals. Plants, 14(10), 1435. https://doi.org/10.3390/plants14101435

Chaosap, C., Sahatsanon, K., Sitthigripong, R., Sawanon, S., & Setakul, J. (2021). The Effects of Using Pineapple Stem Starch as an Alternative Starch Source and Ageing Period on Meat Quality, Texture Profile, Ribonucleotide Content, and Fatty Acid Composition of Longissimus Thoracis of Fattening Dairy Steers. Foods, 10(10), 2319. https://doi.org/10.3390/foods10102319

Chatterjee, A., Ghosh, P., Winkler, B., V, V., Debnath, S., Cichocki, J., Trenkner, M., Vanicela, B., Riethmueller, C., Walz, M., Chandra, S., & Pal, H. (2025). Demystifying the integration of hydroponics cultivation system reinforcing bioeconomy and sustainable agricultural growth. Scientia Horticulturae, 341, 113973. https://doi.org/10.1016/j.scienta.2025.113973

Ch'ng, H. Y., Ahmed, O. H., Kassim, S., & Majid, N. M. A. (2013). Co-composting of pineapple leaves and chicken manure slurry. International Journal Of Recycling of Organic Waste in Agriculture, 2(1), 23. https://doi.org/10.1186/2251-7715-2-23

Cruz, A. L. D., P. Sinco, C., S. Cantor, Ma. L., T. Viña, M., Bolaños, J. R. G., & B. Bordios, R. Jr. (2022). Effects of Varying Nutrient Solution to Brassica Rapa "Bokchoy" Grow Under Hydroponic System. American Journal of Environment and Climate, 1(2), 31–37. https://doi.org/10.54536/ajec.v1i2.485

Davamani, V., Indhu Parameshwari, C., Arulmani, S., Ezra John, J., & Poornima, R. (2021). Hydroponic phytoremediation of paperboard mill wastewater by using vetiver (Chrysopogon zizanioides). Journal of Environmental Chemical Engineering, 9(4), 105528. https://doi.org/10.1016/j.jece.2021.105528

Harith, N. S., Rahman, N. A., Zamanhuri, N. A., & Hashib, S. A. (2023). Microwave-based antioxidant extraction from pineapple peel waste. Materials Today: Proceedings, 87, 126–131. https://doi.org/10.1016/j.matpr.2023.02.384

Khan, N., Sudhakar, K., & Mamat, R. (2024). Macroalgae farming for sustainable future: Navigating opportunities and driving innovation. Heliyon, 10(7), e28208. https://doi.org/10.1016/j.heliyon.2024.e28208

Kwon, M. J., Hwang, Y., Lee, J., Ham, B., Rahman, A., Azam, H., & Yang, J.-S. (2021). Waste nutrient solutions from full-scale open hydroponic cultivation: Dynamics of effluent quality and removal of nitrogen and phosphorus using a pilot-scale sequencing batch reactor. Journal of Environmental Management, 281, 111893. https://doi.org/10.1016/j.jenvman.2020.111893

Liu, W. J., Zeng, F. X., Jiang, H., & Zhang, X. S. (2011). Preparation of high adsorption capacity bio-chars from waste biomass. *Bioresource technology*, *102*(17), 8247-8252.

Mahdian, S., Mohidin, H., Khalid, K., Abdullah, R., Rosli, N., & Jos, S. (2025). Growth, Yield, and Nutrient Content of Habanero Chili (Capsicum chinense) in Response to Different Pineapple Leaf Biochar and Trichoderma Biofertilizer Ratios. Agrivita, 47(1), 1–10. https://doi.org/10.17503/agrivita.v47i1.4393

Matius, A., Saili, A. R., Hamzah, N. M., Abdul Fatah, F., Che Ramli, N. K., Nur Hazwani, M. A., & Fatimah, S. (2022). Current practices and challenges of pineapple smallholder growers in managing the pineapple waste in Samarahan, Sarawak Malaysia. Food Research, 6, 35–40. https://doi.org/10.26656/fr.2017.6(S1).001

Moore, C. E., Meacham-Hensold, K., Lemonnier, P., Slattery, R. A., Benjamin, C., Bernacchi, C. J., Lawson, T., & Cavanagh, A. P. (2021). The effect of increasing temperature on crop photosynthesis: From enzymes to ecosystems. Journal of Experimental Botany, 72(8), 2822–2844. https://doi.org/10.1093/jxb/erab090

Morgan, J. W. (1999). Effects of population size on seed production and germinability in an endangered, fragmented grassland plant. *Conservation Biology*, *13*(2), 266-273.

Na Nagara, V., Sarkar, D., Neve, S., Saleh, H., Boufadel, M., Giri, S., & Datta, R. (2024). Repurposing spent biomass of vetiver grass used for stormwater treatment to generate biochar and ethanol. Chemosphere, 358, 142196. https://doi.org/10.1016/j.chemosphere.2024.142196

Pan, X., Gu, Z., Chen, W., & Li, Q. (2021). Preparation of biochar and biochar composites and their application in a Fenton-like process for wastewater decontamination: A review. Science of The Total Environment, 754, 142104. https://doi.org/10.1016/j.scitotenv.2020.142104

Park, Y., & Williams, K. A. (2024). Organic hydroponics: A review. Scientia Horticulturae, 324, 112604. https://doi.org/10.1016/j.scienta.2023.112604

Rani, D. S., & Nand, K. (2004). Ensilage of pineapple processing waste for methane generation. Waste Management, 24(5), 523–528. https://doi.org/10.1016/j.wasman.2003.10.010

Saif, S., Abid, Z., Ashiq, M. F., Altaf, M., & Ashraf, R. S. (2021). Biofertilizer Formulations. In Biofertilizers (pp. 211–256). Wiley. https://doi.org/10.1002/9781119724995.ch7

Seman, N. A., & Adam, S. (2023). The effect of pineapple peel wastes as liquid organic fertiliser on growth character of okra (Abelmoschus esculentus L.). Food Research, 7, 70–77. https://doi.org/10.26656/fr.2017.7(S2).7

Srivani, P., Yamuna, D. C., & Manjula, S. H. (2021). Influence of Growth Parameters on the Crop Yield Performance of Hydroponic Spinach (Spinacia oleracea L.) Using Correlation and Regression Models. *J. Eng. Sci. Technol*, *16*(6), 4766-4778.

Suharyatun, S., Haryanto, A., Daffa, M., Wardhana, W., Triyono, S., Purwadi, O. T., & Kusuma Wisnu, F. (2024). Improving The Growth and Yield of Pak Choy (Brassica chinensis L.) Using Cacao Pod Husk Biochar. 14(2).

Sultana, A. I., Chambers, C., Ahmed, M. M., Pathirathna, P., & Reza, T. (2022). Multifunctional loblolly pine-derived superactivated hydrochar: effect of hydrothermal carbonization on hydrogen and electron storage with carbon dioxide and dye removal. *Nanomaterials*, *12*(20), 3575.

Sun, J., Li, W., Li, C., Chang, W., Zhang, S., Zeng, Y., Zeng, C., & Peng, M. (2020). Effect of Different Rates of Nitrogen Fertilization on Crop Yield, Soil Properties and Leaf Physiological Attributes in Banana Under Subtropical Regions of China. Frontiers in Plant Science, 11. https://doi.org/10.3389/fpls.2020.613760

Thapa, B., Bhandari, P., Acharya, Y., & Phuyal, S. (2024). Application of Hydroponic System. In KEC Journal of Science and Engineering (Vol. 8, Issue 1).

Wang, O., Deaker, R., & Van Ogtrop, F. (2025). A systematic review of food-waste based hydroponic fertilisers. Agricultural Systems, 223, 104179. https://doi.org/10.1016/j.agsy.2024.104179

Wang, T., Cheng, K., Huo, X., Meng, P., Cai, Z., Wang, Z., & Zhou, J. (2022). Bioorganic fertilizer promotes Pakchoi growth and shapes the soil microbial structure. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1040437

Wichitsathian, B., Yimrattanabavorn, J. & Wonglertarak, W. (2020). Enhancement of biogas production from pineapple waste by acid-alkaline pretreatment. *IOP Conference Series: Earth and Environmental Science.* 471 012005. https://doi.org/10.1088/1755-1315/471/1/012005

Zhou, L., Liao, H., Wang, W., Li, L., Chen, H., He, X., Peng, Y., & Chen, Q. (2023). Mechanistic insights into mitigating Cd stress in plants using typical organic waste fermentation solutions. Environmental Science and Pollution Research, 31(3), 4721–4732. https://doi.org/10.1007/s11356-023-31498-1

