International Journal of Design & Nature and Ecodynamics
Vol. 20, No. 6, June, 2025, pp. 1427-1434
Journal homepage: http://iieta.org/journals/ijdne

Boosting Antioxidant Activity in Butterfly Pea via Banana Peel-Tithonia Organic Fertilizers

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https://doi.org/10.18280/ijdne.2006xx

Received: 22 May 2025
Revised: 17 June 2025
Accepted: 22 June 2025
Available online: 30 June 2025

Keywords:
antioxidant, butterfly pea, organic fertilizer, planting media, productivity, secondary metabolites

ABSTRACT

Butterfly pea (*Clitoria ternatea*) is a promising source of natural antioxidants due to its high anthocyanin, flavonoid, and phenolic content. This study aimed to optimize its productivity and antioxidant activity through the application of liquid organic fertilizer (LOF) from Kepok banana peel and Mexican sunflower green manure, combined with different planting media on Andisol soil. The research used a completely randomized design with two fertilizer types and four planting media, repeated three times, resulting in 72 experimental units. Conducted at Trawas Experimental Farm and the Soil Laboratory of UPN "Veteran" East Java from April to June 2024, results showed that the combination of soil and compost with Mexican sunflower green manure yielded the highest plant biomass (231.09 g). Meanwhile, the combination of soil and raw husk with Kepok banana peel LOF significantly increased antioxidant activity by 24.17%. The highest harvest index (0.29) was also observed in the soil-compost combination. Soil and compost improved water retention and nutrient availability, while raw husk may have triggered stress responses and activated secondary metabolite production. These findings suggest that appropriate organic fertilizer and planting media combinations can enhance both biomass and antioxidant content of butterfly pea flowers.

1. INTRODUCTION

Public awareness of the importance of a healthy lifestyle and using natural ingredients is increasing. This has led to a shift in preference from synthetic drugs to plant-based alternative medicines (phytopharmaca), which are considered safer and have minimal side effects. One plant that has begun to be widely utilized is butterfly pea (*Clitoria ternatea*), which is known as a medicinal and ornamental plant [1]. Butterfly pea flower parts are bright blue from anthocyanins, a group of flavonoids that also function as natural antioxidants [2]. The content of bioactive compounds such as anthocyanins, flavonoids, and phenolics in butterfly pea flowers makes them highly potential to be developed as raw materials for antioxidant supplements, herbal teas, and natural cosmetics [3]. Anthocyanins play a role in neutralizing free radicals, protecting cells from oxidative stress, and preventing various degenerative diseases such as cancer, diabetes, and cardiovascular disease [4, 5] bioactive compounds' content results from plant secondary metabolism [6]. The content of these compounds can be influenced by genetic and environmental factors such as nutrient availability and growing media conditions [7].

The availability of nutrients plays a significant role in the biosynthesis of secondary metabolite compounds [8]. Lack of macro-nutrients such as nitrogen (N), phosphorus (P), and potassium (K) can put physiological pressure on plants, which has an impact on changes in metabolic patterns. Under nutrient deficiency conditions, plants shift primary metabolic activities and biomass formation to secondary metabolic pathways to adapt to environmental stress. Secondary metabolites such as flavonoids, phenols, alkaloids, and tannins, which play an important role in the plant defense system, often experience increased synthesis in response to nutrient limitation [9]. Several organic fertilizers, such as vermicompost, have been reported to influence the accumulation of antioxidants in plants by modulating soil fertility and plant physiology. However, studies comparing the effects of different types of organic fertilizers, particularly banana peel-based liquid organic fertilizer (LOF) and Mexican sunflower green manure, on the antioxidant content of butterfly pea remain limited.

The use of organic fertilizers is an environmentally friendly alternative to replace inorganic fertilizers that have the potential to pollute the environment. Organic fertilizers can improve soil quality physically, chemically, and biologically [10]. In addition, using organic fertilizers in the long term does not cause degradation of soil quality and can support a sustainable agricultural system. Liquid organic fertilizer from Kepok banana peel is an environmentally friendly alternative that can be used in organic farming systems [11]. Bananas are one of the fruits that are often consumed, so the amount of banana peel waste is also quite large. However, the utilization of banana peel waste is not optimal. One way to utilize the waste is to turn it into LOF. This LOF contains essential nutrients such as N, P, K, and C, which are sources of nutrients for plants [12]. On the other hand, green fertilizer from Mexican sunflower plants (*Tithonia diversifolia*) is known to have a high biomass content, which can improve soil fertility and support plant growth [13]. *Tithonia diversifolia* biomass easily decomposes and releases nitrogen, phosphorus, and potassium into the soil, making it effective as a fertilizer [14]. The combination of banana peel LOF and *Tithonia diversifolia* green manure may offer a synergistic effect, potentially through regulation of the carbon-to-nitrogen (C/N) ratio, thereby enhancing nutrient availability and plant secondary metabolite production.

Planting media is important in providing an optimal growing environment for plants and will affect plant productivity [15]. A combination of growing media, such as soil, compost, raw husk, and roasted husk, creates balanced physical and chemical soil conditions, such as good aeration, optimal water holding capacity, and availability of nutrients and microbial activity that support plant metabolism. Compost is rich in organic matter and microorganisms that can improve soil fertility [16]. Raw husks increase porosity, while soil provides essential macro and micro nutrients. Roasted husks provide good pore structure and help stabilize the pH of the media [17]. The combination of planting media and organic fertilizer can ameliorate andisol soils. In particular, andisol soils—which are volcanic ash-derived soils characterized by high phosphate fixation capacity (over 85%) due to the dominance of non-crystalline minerals like allophane—are often challenging for plant growth because of limited available phosphorus [18]. Nevertheless, Andisol has high fertility potential when managed properly, due to its large cation exchange capacity (CEC) and good water-holding capacity. The application of organic materials such as compost or green manure can help reduce phosphate fixation by competing for adsorption sites on soil minerals, thereby increasing phosphorus availability for plants. This study was conducted to determine the best combination of planting media that can increase productivity and antioxidant activity of butterfly pea (*Clitoria ternatea*) on andisol soil by supporting the development of sustainable agriculture.

2. MATERIALS AND METHODS

2.1 Experimental design

This research was conducted using a completely randomized design (CRD) with the treatment of organic fertilizers (LOF Kepok banana peel (K1)) and green fertilizer Mexican sunflower (*Tithonia diversifolia* (K2)) and a combination of planting media (soil (T0), soil and raw husk (T1), soil and burnt husk (T2), and soil and compost (T3)). The treatment combinations were repeated 3 times, and each replication had three samples, so there were 72 experimental units.

2.2 Plant material

The seeds used are purple-colored butterfly pea seeds with a single petal. The seeds used are seeds of butterfly pea flower plants that are uniform in size, clean, undamaged, pithy, and not wrinkled. Before planting, the seeds were soaked for 12 hours in plain water to stimulate the growth of sprouts. Next, the seeds were sown using a seedling tray and transplanted into polybags with a planting distance of 20 × 20 cm when the plants were 7 days after planting (DAP).

2.3 Application of Mexican sunflower *Tithonia diversifolia* green manure

Mexican sunflower green fertilizer was given 1 week before transplanting. Mexican sunflower green fertilizer is given by chopping Mexican sunflower plants (*Tithonia diversifolia*), then spreading it on the surface of the planting media in polybags and covering it again with planting media.

2.4 Application of Kepok banana peel LOF

Making LOF of Kepok banana peel was done 3 times. Preparation of LOF begins with preparing 4 kg of banana peel and cutting it into small pieces or chopping it. Next, 50 ml of EM4 and 200 ml of molasses were ripened for 2 hours. Subsequently, 16 liters of water were added to this mixture, bringing the total volume to approximately 16.25 liters (16,000 ml water + 200 ml molasses + 50 ml EM4). This results in an EM4 concentration of approximately 0.31% v/v (50 ml EM4 / 16,250 ml total volume * 100%). The mixture was then stirred and covered to ferment for 10 days. The fermentation process lasted for 10 days at an average ambient temperature of approximately 28°C, with daily temperature fluctuations ranging from 30–32°C during the day to 24–26°C at night. Occasionally, open the lid of the container to reduce gas in the fertilizer and stir for 10 minutes until day 7. The banana peel liquid organic fertilizer used is 1,000 ml. After all the LOF is finished, EC and viscosity are checked using a digital measuring instrument. The application of Kepok banana peel liquid organic fertilizer was given three times, starting when the plants were 15, 25, and 35 DAP, with the doses of LOF of 60 ml, 100 ml, and 140 ml, respectively.

2.5 Analysis of Kepok banana peel LOF and Mexican sunflower green fertilizer

LOF content analysis was conducted at the Soil Laboratory of the Faculty of Agriculture, National Development University "Veteran", East Java. The test parameters carried out were the measurement of N-total using the Kjeldahl method [19], C-organic using the W-Black-Spectro method, and P-total and K-total with the AAS wet-soaking method [20]. Mexican sunflower (*Tithonia diversifolia*) green manure was prepared by manually cutting/chopping the plant parts (leaves and tender stems) into small pieces, approximately 3-4 cm in size. A total of 240 grams per treatment of this chopped material was then used. This material has a C/N ratio of approximately 8.03:1, indicating its potential for rapid decomposition and nitrogen release into the soil.

2.6 Analysis of planting media combinations

Planting media analysis was conducted at the Agrotechnology Land Resources Laboratory, Faculty of Agriculture, UPN "Veteran" East Java. The test parameters were soil pH with the potentiometric method, C-Organic with the Walkey-Black method, total N with the Kjeldahl method, available P with the Olsen and Bray I method, and total K with the AAS method.

2.7 Antioxidant content analysis and moisture content analysis

The anthocyanin content of butterfly pea flowers is determined by laboratory tests using butterfly pea flower extracts harvested during the first harvest. The butterfly pea flower plant extract used was 10 grams and had the criteria of being perfectly open, not deformed, and uniform in color. Analysis of antioxidant content was carried out using the DPPH method [21]. Antioxidant activity testing study [22] stated that testing antioxidant activity with the DPPH method uses vitamin C as a control with concentrations of 2, 3, 4, 5, 6 ppm. The crude extract of *E. cottonii* algae from each treatment was diluted to obtain a 10 mg/mL concentration. The next stage is diluted so that the sample concentration of 10, 30, 50, 70, 90 ppm is obtained. The diluted crude extract of butterfly pea flower was taken as much as 0.2 mL and put into a vial tube, then 50 µL of 0.8 mg/mL DPPH solution was added. The mixture was homogenized and left for 30 minutes in the dark. A UV-VIS spectrophotometer measured optical absorbance at a wavelength of 517 nm. The antioxidant activity of the samples was determined by the amount of DPPH radical uptake inhibition, by calculating the percentage of DPPH uptake inhibition. The IC 50 value of each sample concentration was calculated using the linear regression equation formula. Analysis of flower moisture content was carried out using the gravimetric method.

$$\% \, inhibition = \frac{(absorbance \; standard - absorbance \; sample \; \times 100\%)}{absorbance \; standard}$$

2.8 Data analysis

The soil analysis results, organic fertilizer, and antioxidant content were analyzed descriptively. Data on crop yield and plant moisture content were analyzed using Analysis of Variance (ANOVA). If the value obtained is significant, it is further tested using the Honest Significant Difference (HSD) at the 5% level.

3. RESULTS AND DISCUSSION

3.1 Planting media analysis

Table 1 shows that all media combination treatments have relatively high fertility status, especially in phosphorus (P available) and potassium (K-dd) parameters. The pH value of all media ranged from 5.5 to 6.3 and was classified as slightly acidic. This condition is still within the optimal pH range for butterfly pea plants (*Clitoria ternatea*) growth, which are known to tolerate acidic to neutral pH ranges [23].

The highest total nitrogen (N) content was found in the combination of soil and compost (0.49%), which is classified as moderate. In comparison, the combination of soil and burnt husk showed the lowest N content (0.18%), which is classified as low. Moderate nitrogen content is important in supporting vegetative growth and the formation of enzymatic compounds that play a role in the biosynthesis of secondary metabolites. However, excess nitrogen inhibits the synthesis of antioxidant compounds because it focuses on cellular growth [24]. The C-organic content of all media showed a high category (≥2.5%), with the highest value in soil and compost media (6.4%). High organic matter content supports soil structure, increases cation exchange capacity (CEC), and becomes an important substrate for the activity of soil microorganisms [25].

Phosphorus availability in all media was very high, with the highest value in soil and compost media (379 ppm). Phosphorus plays an important role in energy metabolism and the biosynthesis of phenolic compounds and flavonoids, the main antioxidant compounds in butterfly pea flowers. Similarly, all media's potassium content (K-dd) was very high, especially in soil and compost media (3.86 me/100g). Potassium is known to support osmotic regulation, protein synthesis, and also plays a role in the biosynthetic pathway of secondary compounds such as anthocyanins and flavonoids [26].

While this study focused on short-term effects, the potential long-term impact of using raw husks on soil properties should be considered. Raw rice husks, with their high C/N ratio and lignin content, decompose slowly and may gradually release organic acids during decomposition. Although the initial pH of the growing media containing raw husks was slightly acidic (5.9) and suitable for butterfly pea growth, prolonged and repeated application could lead to slight acidification over time. Microbial activity during decomposition may also induce nitrogen immobilization, further influencing soil acidity. This aspect was not addressed in the current study and warrants further investigation.

Table 1. Analysis of planting media

Parameters	Results	Criteria	Results	Criteria
	Soil (Control)		Raw Soil and Husk	
pH H_2O	6.00	slightly sour	5.9	slightly sour
Total N (%)	0.30	medium	0.23	medium
C organic (%)	3.60	high	3.7	high
Available P (ppm)	158.00	very high	106	very high
K-dd	1.83	very high	2.41	very high
	Soil and Burnt Husk		Soil and Compost	
pH H_2O	6.30	slightly sour	5.5	slightly sour
Total N (%)	0.18	low	0.49	medium
C organic (%)	2.50	high	6.4	high
Available P (ppm)	199.00	very high	379	very high
K-dd	2.85	very high	3.86	very high

3.2 Fertilizer analysis

Based on Table 2, the results of laboratory analysis show that liquid organic fertilizer (LOF) from Kepok banana peel has a very low content of total nitrogen (N-total) and organic carbon (C-organic), which are 0.02% and 0.25%, respectively. On the other hand, this LOF's total phosphorus (P-total) and total potassium (K-total) contents were very high, at 0.27% and 0.17%, respectively. This indicates that banana peel LOF is more a source of macronutrients, phosphorus, and potassium than organic matter or nitrogen. Banana peel has a high potassium content, so it can be an alternative source of potassium nutrients [27].

Green fertilizer from Mexican sunflower plants (*Tithonia diversifolia*) shows a more balanced and rich nutrient composition, with N-total content of 4.01%, C-organic 32.2%, P-total 0.01%, and K-total 2.71%. The high nitrogen and carbon content of Mexican sunflower plays an important role as a basic nutrient provider for vegetative growth and a substrate for soil microorganisms [28]. High phosphorus and potassium also support the growth, flowering, and ripening processes [29].

Table 2. Content analysis of Kepok banana peel LOF and Mexican sunflower green fertilizer (*Tithonia diversifolia*)

Parameters	Yield (%)
Kepok Banana Peel LOF	
N total	0,02
C organic	0,25
P total	0,27
K total	0,17
Mexican Sunflower Green Fertilizer	
N total	4.01
C organic	32.2
P total	0.01
K total	2.71

3.3 Butterfly pea plant biomass

Based on the analysis results in Table 3, it is known that the interaction between the combination of planting media and the type of organic fertilizer has a significant effect on the biomass of butterfly pea flower plants. The soil and compost planting media treatment combined with Mexican sunflower green fertilizer produced the highest plant biomass, 231.09 grams. This result was significantly different from the other treatments.

Table 3. Interaction of organic fertilizer and planting media combination on plant biomass of butterfly pea plants

Plant Biomass (gram)		
Planting Media Combination	Kepok Banana Peel LOF	Mexican Sunflower Green Fertilizer
Land	74.30 b	97.16 bc
Raw Soil and Husk	36.61 a	66.49 ab
Soil and Burnt Husk	122.10 c	122.62 c
Soil and Compost	125.35 c	231.09 d

Note: Numbers followed by the same letter in the same column were not significantly different from the 5% HSD test.

The treatment interaction in this study shows that the type of planting media used strongly influences the effectiveness of organic fertilizer. The use of compost is known to improve the quality of soil structure and the availability of nutrients in the soil. Compost can increase soil colloids to increase cation exchange capacity, which can support the availability of soil nutrients and reduce nutrient losses due to leaching [30]. Mexican sunflower green manure has a very high content of total nitrogen (4.01%), organic carbon (32.2%), phosphorus (3.96 mg/100g), and potassium (2.71 mg/100g). This complete nutrient content greatly supports the vegetative growth of plants. When combined with supportive media such as soil and compost, Mexican sunflower green manure can significantly increase plant biomass. This is based on research conducted by Blaise et al. [31].

Using banana peel, LOF showed lower results, especially on soil or soil with raw husk. This could be due to the low nitrogen content (0.02%) and organic carbon (1.32%) in banana peel LOF, although the phosphorus and potassium contents were high. The nutrient content will affect plant growth and development. The Kepok banana peel in LOF will affect the plant mechanism and the biomass produced [27].

3.4 Harvest index of butterfly pea plants

Table 4 shows that the treatment of the combination of planting media significantly affects the harvest index of butterfly pea flowers at the age of 70 DAP. The highest harvest index value was found in the combination of soil and compost (0.29), while the lowest was in the combination of soil and raw husk (0.15). Compost has a positive potential to increase harvest index due to its high organic matter content, which can increase soil nutrient availability and cation exchange capacity. Compost also provides plant-available nutrients due to the decomposition process that occurs during the composting process, so that the available elements can be absorbed, positively impact plant growth and development, and correlate to the harvest index.

Table 4. Harvest index of butterfly pea plants

Planting Media Combination	Harvest Index
Land	0.26 a
Raw Soil and Husk	0.15 a
Soil and Burnt Husk	0.24 a
Soil and Compost	0.29 a
Types of Organic Fertilizers	
Kepok Banana Peel LOF	0.23 a
Mexican Sunflower Green Fertilizer	0.71 b

Note: Numbers followed by the same letter in the same column were not significantly different from the 5% HSD test.

The single treatment with Mexican sunflower green manure gave the highest harvest index value of 0.71. Mexican sunflower green manure is rich in nitrogen, phosphorus, and potassium, and has a high C-organic content, supporting the optimal development of the generative parts of the plant. These nutrients are important in forming seeds and flowers, the main components in determining the harvest index. The use of organic fertilizers can increase the activity of soil microorganisms, which can increase the availability of nutrients in the soil and can be used by plants to carry out their metabolism. Using organic fertilizers has been proven to increase the harvest index in corn and peppers [32, 33]. Whereas in the single treatment of Kepok banana peel LOF, although it contains high P and K elements, it has a low nitrogen and C-organic content, so that it affects vegetative growth that is less than optimal, resulting in the formation of non-optimal generative results. This correlates to a lower harvest index value than the results of this study.

3.5 Moisture content of plantain

Based on the data in Table 5, the interaction between the combination of planting media and the type of organic fertilizer significantly affected the moisture content of butterfly pea flower plants. The combination of planting media with soil and compost treatment, combined with Mexican sunflower green fertilizer, gave the highest moisture content, which was 53.54%, significantly different from other treatments according to the 5% HSD test.

The combination of soil and compost has a high water retention capacity, which can provide optimal moisture for plant roots. Based on research conducted by Stone et al. [34], compost increased the water retention capacity of sandy soils. Compost increases cation exchange capacity and soil biological activity, while Mexican sunflower green manure supplies essential nutrients that promote cell growth and tissue turgor. This combination allows plants to absorb and store water in plant tissues more effectively. Plants' moisture content improves overall plant health, as water is essential for almost all plant physiological processes. This is based on research [35] that water functions as a regulator of plant moisture and nutrient solvents, nutrient transport media, metabolic reactions, and raw materials for processing.

While the combination of planting media using soil and roasted husk combined with LOF pisang Kepok showed the highest plant moisture content, it was not significantly different compared to the mixture of soil and LOF pisang Kepok, as well as soil and raw husk combined with LOF pisang Kepok. It is suspected that the application of LOF Pisang Kepok did not significantly affect differences in plant moisture content.

Table 5. Interaction of organic fertilizer and planting media combination on the moisture content of plantain plants

Average Plant Moisture Content (%)		
Planting Media Combination	Types of Organic Fertilizers	
	Kepok Banana Peel LOF	Mexican Sunflower Green Fertilizer
Land	40.98 bc	49.10 c
Raw Soil and Husk	50.01 c	37.59 ab
Soil and Burnt Husk	43.71 c	39.64 b
Soil and Compost	35.06 a	53.54 d

Note: Numbers followed by the same letter in the same column were not significantly different from the 5% HSD test.

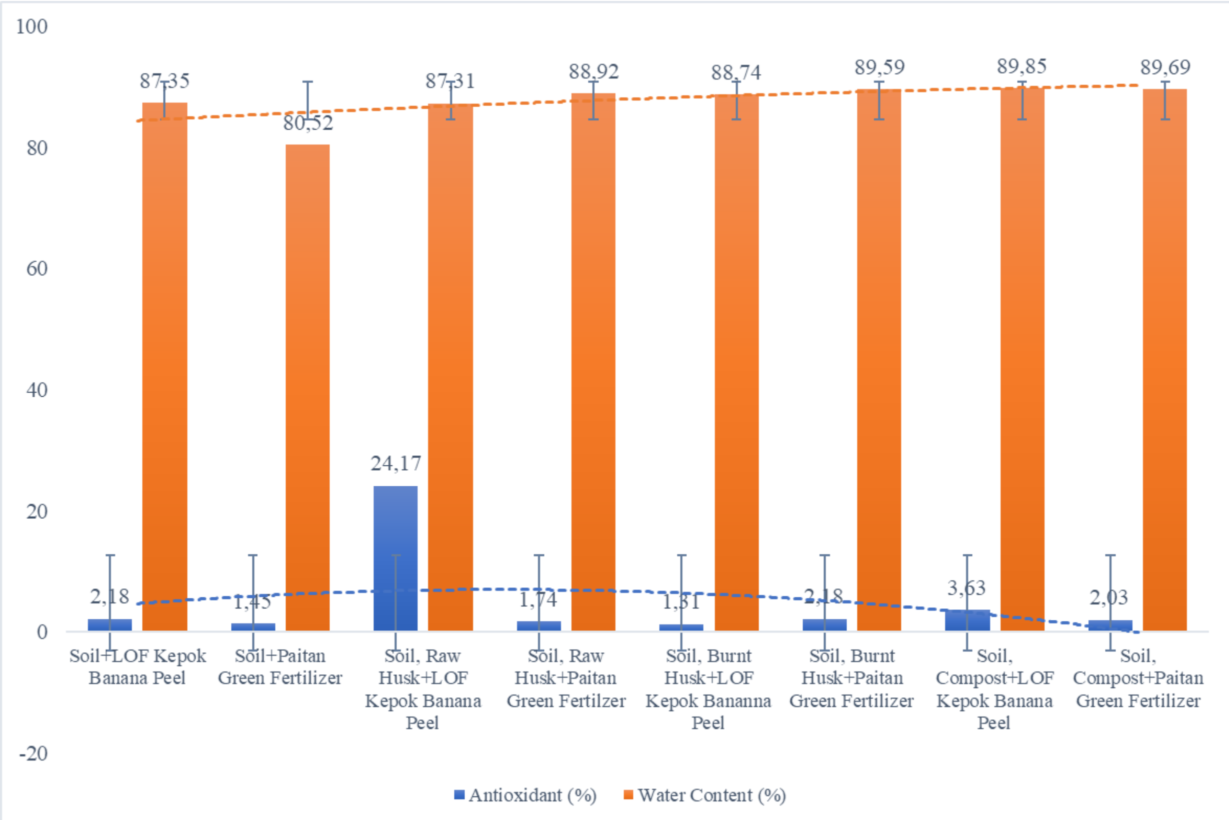

Figure 1. Graph of antioxidant activity and moisture content of the flower *Clitoria ternatea*

3.6 Antioxidant activity and moisture content of *Clitoria ternatea* flowers

Based on Figure 1, the moisture content test shows an increasing trend from all treatments. Meanwhile, the highest antioxidant in butterfly pea flower was found in treating soil, raw husk, and LOF of Kepok banana peel (Figure 2). Antioxidants in the combination treatment of Soil and Raw Husk + LOF Kepok Banana Peel showed the highest antioxidant activity, which amounted to 24.17%. This figure was much higher than the other treatments, ranging from 1.31% to 3.63%. This indicates that the combination of growing media and the type of organic fertilizer used is very influential and effective in inducing the synthesis of secondary metabolites, especially antioxidant activity.

The use of raw may induce a mild physiological response in plants. Such conditions might lead to a shift from primary to secondary metabolic pathways, which is associated with the plant's adaptive or defense mechanisms. Raw husk contains a very high C/N ratio, so soil microorganisms will attempt to decompose the husk using nitrogen around the roots. This causes nitrogen to become unavailable to plants and triggers physiological stress. Nutrient deficiency can trigger abiotic stress in plants that can increase the content of secondary metabolites, such as cannabidiol in *Cannabis sativa* [36]. Nitrogen deficiency affects the physiological activities of *A. argyi*. This is evidenced by an increase in the content of total phenolic acids and flavonoids compared to the control. There is an increase in gene expression in 15 genes that play a role in flavonoid biosynthesis, such as chalcone synthase (CHS), chalcone isomerase (CHI), and flavanone 3-hydroxylase (F3H) [37]. In addition, nitrogen deficiency causes an increase in the activity of antioxidant enzymes such as reactive oxygen species (ROS) [38]. Raw husk has a rough texture and is not weathered so that the plant media becomes too porous, which causes water loss and leads to drought (abiotic stress). In addition, raw husks are thought to still have allelopathic compounds such as phenolic acid or lignin that can inhibit root growth.

Nutrients can affect the antioxidant activity of plants. Nutrients absorbed by plants will affect the metabolic processes that occur in plants. Liquid organic fertilizer from banana peels contains important elements such as potassium (K), phosphorus (P), and several micronutrients that can support the activity of phenolic compound-forming enzymes, including phenylalanine ammonia-lyase (PAL), a key enzyme in the phenylpropanoid biosynthetic pathway (Figure 3). The phenylpropanoid pathway begins with phenylalanine as a precursor, derived from the shikimate pathway linked to glycolysis and the pentose phosphate pathways [39]. This pathway generates diverse secondary metabolites, such as lignins, flavonoids, and anthocyanins, through sequential enzymatic reactions involving cinnamate 4-hydroxylase (C4H) and chalcone synthase (CHS) [40, 41]. In *Clitoria ternatea*, specific enzymes like malonyltransferase further modify anthocyanins (e.g., delphinidin derivatives), enhancing pigment stability and antioxidant properties [42, 43]. These metabolites play critical roles in plant defense and human health, underscoring the pathway's ecological and pharmacological significance.

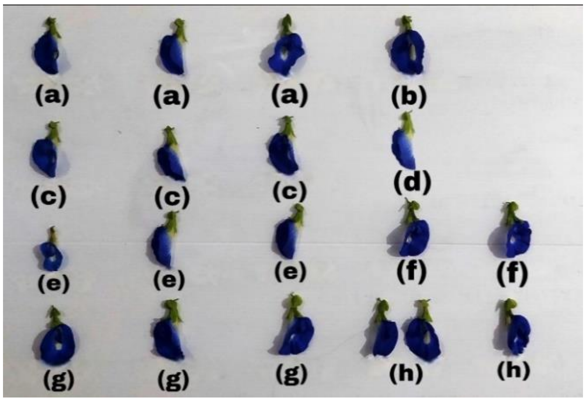

Figure 2. Flower phenotype of *Clitoria ternatea:* (a) T0K1, (b) T0K2, (c) T1K1, (d) T1K2, (e) T2K1, (f) T2K2, (g) T3K1, (h) T3K2

The treatment with the highest antioxidant activity also showed the lowest plant moisture content. This reinforces the notion that metabolic energy transfers from primary metabolic activities, such as water uptake and biomass synthesis, to secondary metabolic activities that produce bioactive compounds. A decrease in plant moisture content can indicate that the plant adapts to environmental stress through increased production of antioxidant compounds.

The treatments of soil and compost combined with Mexican sunflower green manure and soil and roasted husk combined with Mexican sunflower green manure, despite producing high moisture content (89.69% and 88.59% respectively), only showed antioxidant activity of about 2.03% and 2.00% (Figure 1). This suggests that the abundant availability of water and nutrients is more directed toward vegetative growth and primary metabolism, rather than the formation of secondary metabolite compounds. This suggests a possible trade-off between high biomass and low antioxidant activity, where favorable growth conditions promote primary metabolic processes such as photosynthesis and protein synthesis, supporting vigorous vegetative growth, rather than the production of secondary metabolites. These defense related compounds are often associated with moderate environmental constraints or limited nutrient availability, which act as elicitors for their biosynthesis. In this study, the high nutrient supply from treatments combining compost or roasted husk with Mexican sunflower green manure likely shifted resource allocation toward biomass accumulation rather than antioxidant production. Although *Tithonia diversifolia* is known to enhance soil fertility and plant growth, this benefit may come at the cost of reduced phytochemical content, particularly antioxidants. Therefore, modulating nutrient and water inputs to create controlled stress conditions could help optimize secondary metabolite production.

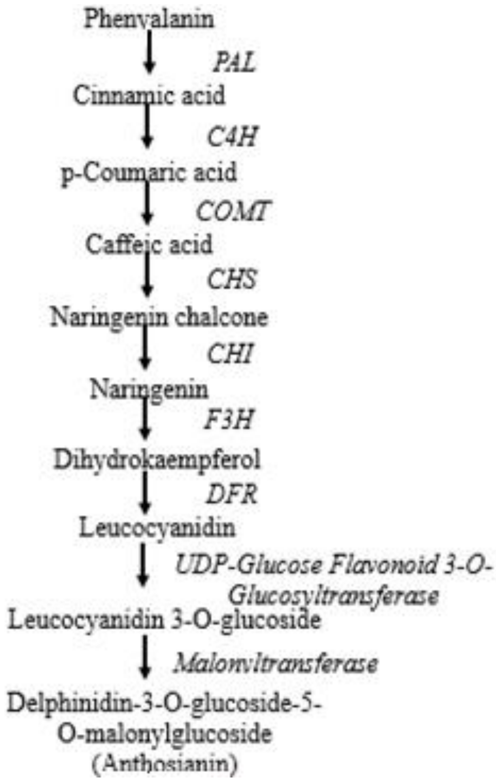

Figure 3. Schematic representation of the phenylpropanoid pathway in *Clitoria ternatea*

4. CONCLUSIONS

Based on the study, the application of organic fertilizers such as Mexican sunflower green fertilizer (*Tithonia diversifolia*) and banana peel liquid organic fertilizer (LOF), in combination with different planting media (soil, raw husk, burnt husk, and compost), significantly affected both the biomass production and antioxidant activity of butterfly pea (*Clitoria ternatea*), where the highest biomass and harvest index were observed in plants grown on soil and compost media supplemented with Mexican sunflower green fertilizer, making it ideal for maximizing yield. In contrast, the use of banana peel LOF on soil and raw husk media was found to significantly enhance antioxidant activity, making this combination more suitable for producing phytochemically rich flowers. However, it should be noted that antioxidant activity was only measured at the initial flowering stage, which may not represent changes throughout the entire growth period, thus calling for further research to monitor antioxidant dynamics over the full growth cycle to better understand how agricultural practices influence secondary metabolite development and focus on determining the optimal ratios of these organic amendments to further refine these practical recommendations.

ACKNOWLEDGMENT

The authors would like to express sincere gratitude to the Laboratory of Physiology, Tissue Culture, and Microtechnique, Faculty of Agriculture, National Development University "Veteran", East Java, for the facilities provided during the research. Appreciation is also extended to all academic supervisors and laboratory technicians for their valuable guidance, technical assistance, and moral support throughout the research process. It is hoped that the findings of this study will contribute positively to the advancement of scientific knowledge and the development of horticultural plant breeding in Indonesia.

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