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Effect of Black Soldier Fly Frass (BSFF) on The Growth and Yield of Cayenne Pepper (*Capsicum frutescens* L.)

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Abstract. *Cayenne pepper is a leading horticultural commodity in Indonesia. However, the productivity and quality produced have not met market expectations. One of the contributing factors is the low quality of the soil. For this reason, switching from inorganic fertilizers to organic fertilizers, such as Black Soldier Fly Frass (BSFF), is necessary because it can provide several nutrients crucial in improving the soil's physical, chemical, and biological properties. In this study, the formulation of BSFF was tested for its impact on cayenne pepper's growth response and yield. The research was arranged in a completely randomized design consisting of three treatments with three repetitions, namely P1 (100 grams of BSFF biofertilizer), P2 (250 grams of BSFF biofertilizer), and P3 (500 grams of BSFF biofertilizer). The results showed an interaction between doses of BSFF biofertilizer on plant height, physical conditions (color and size), number, and wet weight of cayenne pepper; which P3 gave the most optimal growth response and yield. In contrast to these results, all treatments reduced vitamin C to the high level of N nutrients in BSFF biofertilizer. Therefore, further research is needed to find the right dosage (below 100 grams/500 grams of media) so that cayenne pepper has a high vitamin C.*

Keywords: *biofertilizer, black soldier fly frass, cayenne pepper, growth*

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INTRODUCTION

Cayenne pepper (*Capsicum frutescens* L.) comes from the Solanaceae family which is widely cultivated in Indonesia (Sofiarani & Ambarwati, 2020) because it is a national leading horticultural commodity (Septiadi et al., 2020), and its demand always increases along with the rising population and the development of the cayenne pepper processing industry (Amanah et al., 2016). There are at least five factors as the common challenges that must be faced to prevent a decrease in cayenne pepper production, namely the environment, especially during the rainy season (Trisnawati, 2022), plant diseases and pests (Arsi et al., 2021), low-quality cayenne pepper seeds to be planted (Tangahu et al., 2022), and plant cultivation techniques that are not efficient and environmentally friendly (Sofiarani & Ambarwati, 2020). On the other hand, the decline in production and quality of cayenne pepper can also be caused by the unproductive state of agricultural land, which is indicated as land that has low soil quality, with characteristics such as little soil organic matter content, high soil content, low porosity, and slow infiltration rates (Schoenholtz et al., 2000). Even fertile soil is not necessarily productive if not appropriately managed because cayenne pepper plants cannot absorb enough nutrients to metabolize and photosynthesize (Iqbal & Hikmatyar, 2023).

Efforts to improve soil quality must start by increasing the content of soil organic matter so that it will trigger active organisms in the soil (Saputra et al., 2018). The higher the activity of soil organisms, especially those that act as ecosystem engineers, the better the porosity and stability of soil aggregates (Cardoso et al., 2013). Given the importance of soil for plants for growth and development, an effective solution is needed in the form of switching chemical fertilizers (inorganic) to organic fertilizers because organic fertilizers can improve soil quality (Ma et al., 2023). Organic fertilizers contain carbon and other nutrients in combination with carbon (Hartatik et al., 2015) because they come from dead plants, animal manure, animal parts, and/or other organic waste that has gone through an engineering process in solid or liquid form, and can be enriched with mineral materials, and/or microbes that are useful for increasing the content of nutrients and soil organic matter and improving the physical, chemical, and biological properties of the soil.

Unlike artificial chemical fertilizers that provide limited types of nutrients, organic fertilizers can provide several nutrients so that they play a crucial role in improving the soil's physical, chemical, and biological properties (Hartatik et al., 2015). Organic fertilizers can come from various sources and can be found easily. One source of organic fertilizer is BSFF. It is a type of soil improver derived from the bioconversion of organic waste by black soldier fly (BSF) larvae, which has excellent potential as a soil supplement to replace commercial fertilizers (Nuryana et al., 2022). BSFF is hygienic in soil because the population of Escherichia coli bacteria is defeated by gram-negative bacteria, making this organic fertilizer of high value and a good impact on soil fertility (Amaral et al., 2019) as well as a source of C and N needs that have a positive impact on the growth of chili plants by increasing soil respiration and increasing total soil C, N, and NH^{4+} (Meilani et al., 2022). BSFF contains both macro and micro elements needed by plants, namely nitrogen (3.276%), phosphorus (3.387%), potassium (9.74%), C-organic (40.95%), C/N ratio (12.50%), and water content (11.04%) (Nirmala et al., 2020). Based on these data, BSFF has the potential to be used as an organic fertilizer because it has the nutrients needed by plants. BSFF fertilizer also has biological properties proven to have a good effect on plants because there are groups of nitrogen-fixing bacteria and phosphate-solubilizing bacteria (Hernahadini, 2022).

Research on organic fertilizer management to support the response and growth of crop yields continues to develop, including formulating the appropriate dose for each plant because a plant has different macronutrient and micronutrient re-

quirements. For plants, fertilizer plays a role in supporting optimal plant growth and yield quality. Therefore, determining the dosage of fertilizer is necessary for plants. Excess fertilizer doses can be toxic to plants, and if plants lack them, they can cause nutrient deficiency diseases (Klammsteiner et al., 2020). Research conducted by Syifa et al. (2020) concluded that the correct dose of BSFF biofertilizer was proven to provide optimal growth of curly chili plants in terms of height, number of leaves, and leaf color. In addition, the analysis of nutrient content in BSFF conducted by Triwijayani et al. (2023) confirmed that BSFF fertilizer could meet the needs of plants because it contains organic C and N-P-K from rice residues, vegetables, and fruits with levels that meet the standards of the Minister of Agriculture (2019) concerning organic fertilizers. Based on this background, this study aims to determine the effect of BSFF organic fertilizer on the growth and yield of cayenne pepper (*Capsicum frutescens* L.) plants.

MATERIALS AND METHODS

The research was conducted for four months, from September to December 2023, at the Biology Green House of Universitas Negeri Semarang. During the study, the air temperature and humidity conditions were optimum, supporting the growth of cayenne pepper, with an air temperature of 30-34 ° C and average temperature of 31.73 ° C, and with air humidity of 50-65% and an average air humidity of 57.23%.

Research Design

This research employed a quantitative approach with a completely randomized (RAL) experimental design. The research stages began with determining a location supporting cayenne pepper plants' growth. Cayenne pepper was seeded before the experiment and then transferred into polybags. The experiment was conducted in 4 groups with treatments, namely, P_0 as control, P_1 = 100 grams of BSFF, P_2 = 250 grams of BSFF, and P_3 = 500 grams of BSFF. Two main activities were carried out so that the growth and yield of cayenne pepper can occur optimally:

1. Seeding and Transplanting

The process of seeding cayenne pepper seeds was carried out in a seedling tub that contained soil media. Seed sowing was carried out for ten days until a minimum of 2 leaves with a stem height of 10 cm were obtained. The steps taken at this stage are as follows: (1) cayenne pepper seeds ± 50 seeds were sown in a seedbed that had been given soil and moistened with water by giving a distance between seeds of ± 1 cm, (2) cayenne pepper seeds were checked periodically for five days and ensure soil conditions remain moist, (3) cayenne pepper seeds were transferred to polybags labeled with treatment, and each polybag was filled with two cayenne pepper plant seeds by giving a distance of 2 cm between plants, (4) leave the polybags with cayenne pepper plant seeds for one week before the treatment, (5) after one week, add BSFF biofertilizer, namely P_1 (100 grams of BSFF/500 grams of planting media), P_2 (250 grams of BSFF/500 grams of planting media) and P_3 (500 grams of BSFF/500 grams of planting media) with P_0 (as control; 0 grams of BSFF /500 grams of planting media), and (6) cayenne pepper plants were placed in exposed to sunlight and provide a distance between polybags of 0.5 cayenne meters.

2. Preparation and Application of Onion Natural Pesticides

The steps of preparation and application of onion natural pesticides are as follows: (1) preparing 10 grams of garlic and shallot skin in a container, (2) soaking the onion skin overnight using water and closing the onion skin container so that it is not contaminated with air, (3) filtering the onion skin soaking water in a clean container and transferring a bottle, (4) dissolving the onion pesticide with a ratio of 2 bottle caps to 1 liter of water, and (5) placing the pesticide that is ready for use into a sprayer. Watering and application of natural pesticides began after the seedling pe-

Jurnal Biodjati 9(1):190-201 May 2024

JURNAL BIODJATI

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riod (one week). Cayenne pepper plants were exposed to sunlight and provided a distance between polybags of 0.5 growth was observed regularly.

Research Parameters and Variables

The Black Soldier Fry Frass (BSFF) content test was carried out to determine the characteristics of BSFF biofertilizer in the form of the amount of N, P (as P_2O_5), K (as K_2O), Organic C, and moisture content. After it was proven and met the criteria for good organic fertilizer according to the standard of the Minister of Agriculture (2019), BSFF organic fertilizer can be applied to cayenne pepper plants with different dosage treatments. The parameter for the cayenne pepper plant growth response variable was plant height (measured from the surface of the soil to the tip of the branching leaves using a meter conducted every week after planting until harvest). For the harvest of cayenne pepper plants, the parameters were qualitative observations in the form of physical conditions, which included the color and size of the cayenne pepper observed at one harvest period; quantitative data in the form of the number of cayenne pepper (counted at one harvest period) and the wet weight of cayenne pepper (weighed at one harvest period), as well as the level of vitamin C contained.

Data Analysis

One-way ANOVA was applied to determine whether there was a significant impact of BSFF biofertilizer on the growth of chili plants in terms of stem height, as well as the wet weight of cayenne pepper which was the first harvest. After demonstrating significant results (sig<0.05) for each parameter in the One-way ANOVA statistical testing, post hoc analysis was conducted using the LSD (Least Significant Difference) test to identify treatment differences. For vitamin C, a UV-VIS spectrophotometer was used.

RESULTS AND DISCUSSION

Content Analysis of BSFF Organic Fertilizer

This research first tested the fertilizer's content to determine if BSFF biofertilizer meets the minimum requirements for a good fertilizer for plants. It can be determined that BSFF biofertilizer meets these requirements (see Table 1). The N, P, and K in BSFF biofertilizer are 5.652%, 16.78%, and 44.20%, respectively, which is higher than the minimum content as regulated by The Minister of Agriculture of the Republic of Indonesia No. 261/KPTS/SR.310/M/4/2019, namely the minimum macronutrient content ($N + P_2O_5 + K_2O$) of 2%. There was an interrelated relationship between the three macronutrients (N, P, and K) in BSFF biofertilizer. The longer the fermentation process, the more the decomposition process carried out by microorganisms will produce more ammonia and nitrogen (Trivana & Pradhana, 2017), meaning that the availability of high amounts of nitrogen indicates a more complete decomposition process (Utami & Syamsuddin, 2021). The availability of N is directly proportional to P and K because the higher the N content, the multiplication of microorganisms that break down P and use K as a catalyst in the fermentation process will increase so that the P and K content will also increase (Hidayati et al., 2011).

Meanwhile, the C-organic content (12.48%) was 2.52% lower than the minimum content (15%). C-organic content is influenced by the quality of organic matter and the activity of microorganisms that affect the composting process (Mirwan, 2015). As explained in this study, the BSFF biofertilizer used was limited to food waste (rice, fruit, vegetables, and chicken meat) obtained from Universitas Negeri Semarang canteen waste, so when tested for C-organic content, the results were not optimal. The water content in BSFF biofertilizer also exceeds the minimum content (74.96% > 8-20%). Too high water content in organic fertilizer can cause a decrease in the quality and role

of organic fertilizer for plant growth. This is because microorganisms will develop faster in the fertilizer, so the nutrient content in the sample decreases before use (Subroto, 2009). Therefore, before being applied to the planting media, BSFF biofertilizer is first dried in the

Table 1. Content of BSFF biofertilizer

No	Parameter	Unit	Results	Methods
1.	Nitrogen	% adbk	5.652	SNI 2803 : 2012 butir 6.2
2.	P as P_2O_5	% adbk	16.78	SNI 2803 : 2012 butir 6.3
3.	K as K_2O	% adbk	44.20	SNI 2803 : 2012 butir 6.4.2
4.	C organic	% adbk	12.48	Walkley-black methode
5.	Water (b/b)	%	74.96	SNI 7763:2018 butir 6.3

Note : adbk (atas dasar berat kering) : on dry weight basis

Growth of Cayenne Pepper Plants: Average Height of Cayenne Pepper Plants

The results showed that applying BSFF biofertilizer at various doses affected the height of cayenne pepper plants. The height of cayenne pepper plants consistently increased with increasing doses of BSFF biofertilizer at the beginning of planting until ready to harvest (see Figure 1). At the end of the observation, the height of cayenne pepper plants in the treatment of BSFF biofertilizer doses until ready to harvest was seen to increase by 80.08 % (P_1), 21.14% (P_2), and 184.71% (P_3) compared to the height of the control cayenne pepper plants (P_0).

Based on Table 2, there was a significant difference in the height of cayenne pepper plants (sig<0.05), where at the end of the observation, P_3 gives the highest growth of cayenne pepper plants (114.6 cm), followed by P_2 (98.9 cm), P_1 (90.4), and P_0 (50.2 cm) as the results of LSD further test in Table 3. However, based on the comparison of each treatment and the control, the difference in the height of the cayenne pepper plants from the P_1 treatment is not significant (sig>0.05) against P_0, BSFF biofertilizer as much as 100 grams/500 grams of planting media is not enough to meet nutrient needs so that the height of the cayenne pepper plants is considered not significantly different from the height of the control cayenne pepper plants.

This study proves that different doses of BSFF biofertilizer have different impacts on plant heights as well as in the previous studies (Hernahadini, 2022; Meilani et al., 2022; Purwanto et al., 2023). The character of plant height is one of the essential variables because it has an important meaning for the position of the fruit against the soil surface, especially in terms of resistance to anthracnose disease (Flowrenzhy & Harijati, 2017). In addition, plant height is an indicator of plant growth, which is the result of cell division and enlargement in the meristematic part (Purwanto et al., 2023); parts of the cayenne pepper plant that support plant height can be seen in the growth of stems and roots. A balanced size of fertilizer can help the roots absorb nutrients well and support plant growth (Rezaldi & Hidayanto, 2022). Root and stem growth in plants is also assisted by nutrients such as carbon (C), oxygen (O_2), hydrogen (H), and microelements such as sulfur (S), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). The nutrients N and K absorption by roots from the soil are necessary for the vegetative growth of cayenne pepper plants to produce a more optimal plant height than plants without fertilizer (Chairiyah et al., 2022).

Jurnal Biodjati 9(1):190-201 May 2024

JURNAL BIODJATI

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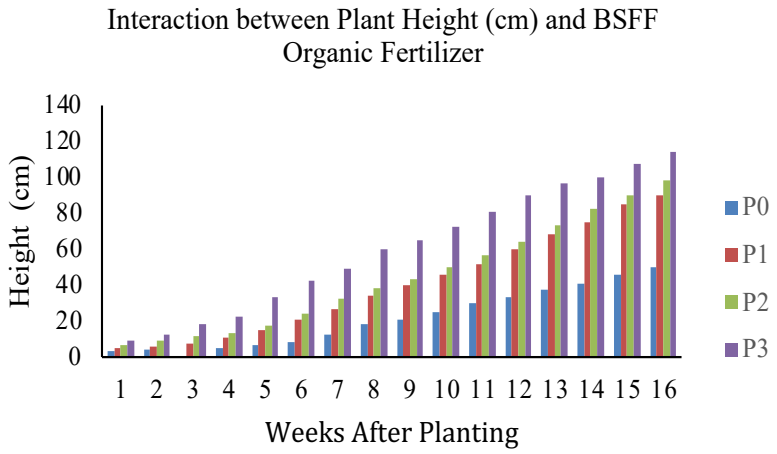

Figure 1. Interaction of cayenne pepper plant height growth with variations of BSFF organic fertilizer

Figure 2. Cayenne Pepper of P_0, P_1, P_2, and P_3

The Characteristics of Harvested Cayenne Pepper Plants

1. Physical Condition of Cayenne Pepper

The application of various doses of BSFF biofertilizer impacts the yield of cayenne pepper in terms of the physical condition of cayenne pepper, such as the color and size of the fruit. P_3 provides the highest number of fruits with larger fruit conditions, reddish-orange color, and longer size. Almost the same effect was also seen in P_2 and P_1, except that the number of fruits is less and the size is smaller. This result differs greatly from P_0, some of which were still slightly green at harvest time (see Figure 2). Good quality cayenne pepper has a bright red color, pungent aroma, and smooth skin texture (Afa et al., 2022). Cayenne pepper generally has a short round shape with pointed or conical ends and sizes that vary based on the type (Anggraini, 2020). For the size of cayenne pepper, the small category is 2-2.5 cm and 5 mm wide, while the large category can reach 3.5 cm with a width of 12 mm (Anggraini, 2020).

A plant will grow well if nutrients are available completely and in sufficient and balanced amounts (Djiwosaputro, 2012). Unbalanced nutrient availability can result in disrupted plant growth that affects the quality and quantity of the crop. Phosphor is the nutrient most affecting fruit formation (Lingga & Marsono, 2010). For consumption needs, consumers want the character of cayenne

pepper in the form of spiciness as needed, good fruit appearance, smooth skin, bright color, and free from disease (i.e. anthracnose), while for the needs of the food industry (i.e., sauce and pasta), the desired character of cayenne pepper is to have a high level of spiciness, bright red color, and the fruit must be continuous or available all the time to meet industry needs (Nurfalach, 2010).

2. Average number and wet weight of harvested Cayenne Pepper

Consistent with the results of P_3 physical conditions, the average number and wet weight of cayenne pepper, P_3 also gives the most optimal results compared to P_2, P_1, and P_0. The average yield showed that the number of ready-to-harvest cayenne pepper fruits for P_0, P_1, P_2, and P_3 is nine fruits, 24 fruits, 30 fruits, and 39 fruits, respectively. These results reinforce that providing nutrients in the form of optimal nutrients will increase plant productivity. Nitrogen is an essential element in the preparation of chlorophyll as the main component in the photosynthesis process, phosphorus is an element that provides energy for plant growth, and potassium is essential for growth as a balancer of osmosis and cell turgor pressure in the opening and closing of stomata in plants that are utilized (production) of their vegetative parts, so the increase in plant height is positively correlated with their production (Purba et al., 2020).

P_3 provides the best per-fruit wet weight of cayenne pepper. The calculation of wet weight was carried out when the plants were harvested directly by weighing. In this study, the average wet weight ready for harvest per plant is 9.81 grams (P_0), 35.34 grams (P_1), 64.38 grams (P_2), and 130.53 grams (P_3). Based on these data, the control treatment's wet weight is minimal and has very little productivity due to the unavailability of nutrients for its development. A One-Way ANOVA analysis is conducted to ensure a real difference in the wet weight of cayenne pepper, which gives a significant difference (sig<0.05) between the dose of BSFF biofertilizer and the wet weight of cayenne pepper (see Table 5). Treatment P_1 is not significant (sig>0.05) compared to P_0. It shows the dose of BSFF biofertilizer, as much as 100 grams/500 grams of planting media, which is still insufficient to meet nutrient needs, so the wet weight of cayenne pepper is considered not significantly different from the control.

The availability of adequate nutrients during growth causes plant metabolism to run more actively so that the process of cell differentiation improves and will ultimately encourage an increase in fruit weight (Haryantini & Santoso, 2000). Phosphor (P) and Potassium (K) are the main macronutrients affecting fruit weight (Erfiani et al., 2019). The two elements are interrelated because the P element determines the success of fertilization, which is related to the quality of the fruit. In contrast, the K element assists the photosynthesis process for forming new organic compounds that are transported to the storage organ, namely the fruit (Samadi & Cahyono, 2005). Therefore, adequate P and K nutrition will result in good fruit weight. This fruit weight will affect the weight of fruit per plant because the number of fruits formed determines the weight of fruit per plant (Erfiani et al., 2019).

3. Vitamin C Content of Cayenne Pepper

Vitamins are organic compounds that contribute to the process of collagen synthesis and carnitine formation, involved in cholesterol metabolism into bile acids, and the formation of the neurotransmitter norepinephrine (Rosmainar et al., 2018). One food containing vitamin C is cayenne pepper (Tatengkeng et al., 2019). Apart from getting a spicy sensation due to its capsaicin, consuming cayenne pepper also fulfills the daily requirement of vitamin C, as much as 24% of the recommended daily intake (Tatengkeng

et al., 2019). This study analyzed vitamin C levels through the UV-Vis spectrophotometric method with a calibration curve Y = 0.016 X + 0.0461 and R2 = 0.9876 at a maximum wavelength (λ) of 266 nm, as shown in Figure 3.

Based on the absorbance results (Y) and the calibration curve equation obtained, the vitamin C in the cayenne pepper P_0, P_1, P_2, and P_3 can be determined. Table 8 shows that the treatment reduces the vitamin C. During the growth period, the nutrient influencing vitamin C is N (Rosmainar et al., 2018). The higher the N in the organic fertilizer, the lower the vitamin C (Lee & Kader, 2000). The BSFF biofertilizer used in this study has N nutrients of 5.652%. This content is very much greater than the minimum required content, which is the minimum macronutrient content ($N + P_2O_5 + K_2O$) of 2%; so if it is still applied to cayenne pepper plants, the dose of BSFF biofertilizer should be reduced (below 100 grams/500 grams of media) so that the vitamin C content of cayenne pepper is good.

In addition to nutrients, vitamin C levels in fresh fruit are also influenced by the type (genetic) of fruit, growth conditions, maturity level at harvest, and postharvest handling (Winarno, 1984). Postharvest handling is related to the length of storage due to increased activity of the enzyme ascorbate oxidase, which plays a role in the breakdown of vitamin C (Cresna et al., 2014). Active vitamin C can take the form of L-ascorbic acid and L-dehydroascorbic acid, where L-ascorbate is very easily reversibly oxidized to L-dehydroascorbic acid. L-dehydroascorbic acid is also chemically very labile and undergoes further changes to L-diketogulonic acid, which has no more vitamin C activity (Paramita, 2014). The complete reaction of vitamin C changes can be seen in Figure 4.

The lower the altitude of the place, the higher the intensity of sunlight and temperature, which has an impact on the more accessible vitamin C to be oxidized, so that vitamin C levels at an altitude of 1400 m above sea level are certainly lower than at an altitude of 1900 and 2400 m above sea level (Fatchurrozak et al., 2013). Although the vitamin C content in cayenne pepper is low, it does not affect the level of spiciness (Ajis & Legowo, 2020). Finally, in addition to nutrient factors, other factors that contribute to the growth and yield of cayenne pepper plants are environmental factors, including light, temperature, soil moisture, and rainfall (Fahrudin & Mahdiannoor, 2013). At the time of the research, environmental conditions were less favorable for the growth and yield of cayenne pepper because of frequent rains that affect the water content in the soil and the amount of light that plants can absorb, affecting the photosynthesis process.

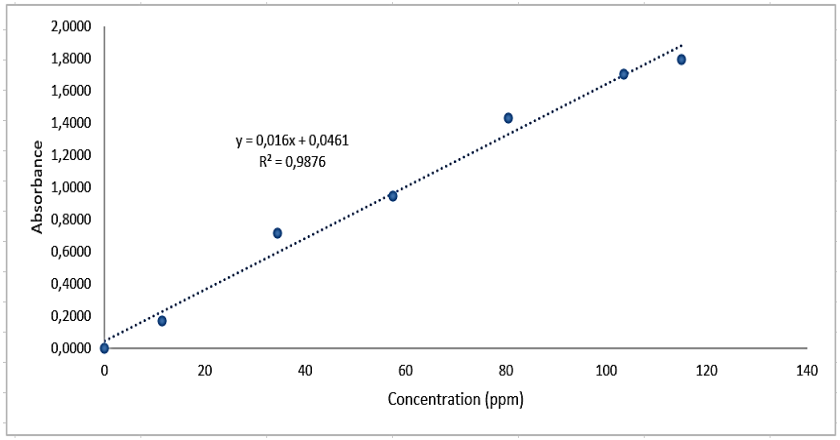

Figure 3. Absorbance Curve of Vitamin C

CONCLUSION

Based on the research, the optimal dose of BSFF biofertilizer that significantly impacts the growth and yield of cayenne pepper is 500 grams/500 grams of planting media. With this dose, cayenne pepper plants have the tallest stems, the best physical condition of the harvested cayenne pepper, and the highest productivity (average number and wet weight). However, this is inversely proportional to vitamin C because BSFF biofertilizer reduces vitamin C levels. Therefore, more detailed research must be done on the vitamin C variable to ensure the correct dose if the treatment uses BSFF biofertilizer.

AUTHOR CONTRIBUTION

RNA : reviewing the research design, analyzing research data, drafting manuscript, AH : reviewing the research design, PDM : doing experiments, collecting research data, compiling manuscript and final research report, IIF, TD, JKN, and ZR : doing experiments and collecting research data. All the authors have read and approved the final manuscript

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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