Research Article

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Control measure of sweet potato weevil (*Cylas formicarius* Fab.) (Coleoptera: Curculionidae) in endemic land of entisol type using mulch and entomopathogenic fungus *Beauveria bassiana*

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Abstract: Sweet potato weevil *Cylas formicarius* (Fab.) is the main obstacle for sweet potato production in various countries. Root damage caused by *C. formicarius* larvae reduced root yield up to 100%. The aim of this study is to test the measures using mulch and entomopathogenic fungus *Beauveria bassiana* for controlling *C. formicarius* in endemic land of entisol type. The control measure tested was the use of straw mulch and plastic mulch as well as the application of the entomopathogenic fungus *Beauveria bassiana*. The research was conducted at the experimental station at Indonesian Legumes and Tuber Crops Research Institute, Malang from July to December 2018. The results showed that the measure for controlling *C. formicarius* using straw or plastic mulch combined with the entomopathogenic fungus *B. bassiana* produces root yields between 17 and 26 t/ha. Using plastic mulch as a cover for mounds with the application of the fungus *B. bassiana* is more effective and efficient in controlling *C. formicarius* than the insecticide deltamethrin. Plastic mulch can physically inhibit the process of laying eggs and the formation of *C. formicarius* larvae, while *B. bassiana* is toxic to eggs, larvae, and adults of *C. formicarius*. The efficacy of control measure using plastic mulch and the application of *B. bassiana* can reduce yield losses by up to 96.76%. Technological innovation using plastic mulch to cover the mound with the application of the entomopathogenic fungus *B. bassiana* can be recommended to control *C. formicarius* on land endemic to the entisol type.

Keywords: *Beauveria bassiana*, *Cylas formicarius*, straw, mulch, plastic, sweet potato

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1 Introduction

Cylas formicarius is one of the major pests in sweet potato in various parts of sub-tropical and tropical areas including Indonesia. The larvae are the highly destructive phase that takes approximately 7 days after the eggs are laid (but the hatching period depends on temperature, moisture, and relative humidity) [1–4]. The phase of the *C. formicarius* insect that can cause root damage is the larval stage, formed from the egg phase that hatches after approximately 6 days after being laid. The larval phase of *C. formicarius* consists of three instars that last approximately 35 days in the root before the pupa stage is formed. The adult stage formed from the pupa immediately penetrates the root skin to the outside of the soil surface to find food sources and produce eggs. Measure for controlling *C. formicarius* pests has not yet been found because the destructive stages of *C. formicarius* are in the roots within the soil, making it difficult to obtain appropriate, effective, and efficient measure [5,6].

Synthetic insecticides are effective to the adults because the adults live above the soil surface. The application of synthetic insecticides is effective when it is coupled with the choice of type of active ingredient, concentration, and time and method of application is right on the target [7–9]. Meanwhile, the larval phase inside the roots is still able to survive and bore the roots in the soil until the food source runs out. Several researchers previously stated that soil conditions' structure greatly influences root damage due to *C. formicarius* attacks, especially in endemic land. This condition is caused by soil structures that easily crack/break in the dry season, such as entisol, making it easier for the adult to penetrate the soil surface while laying their eggs. Apart from that, the higher ridge also affects the safety of the roots from borer attacks because the roots are not exposed openly as they are protected in the ground. This condition is caused by the movement of the *C. formicarius* insect, which is very active if there is a disturbance in its surroundings. Besides, the insect also has the ability to pretend to be dead or immobile in order to avoid threats that endanger its existence [10,11].

Control measure of *C. formicarius* on entisol land with alluvial structures is more difficult; this condition is due to the fact that the land cracks easily during the dry season so that gaps are formed, which can make it easier for the adult to reach the base of the stem to lay their eggs. Entisol soil conditions are generally poor in organic matter so that their water holding power and capacity is very low. Control technique that can be applied to overcome these land conditions is to add organic material and apply mulch to cover the plant mounds so that insects are prevented from reaching the base of the sweet potato stems [12]. Another report states that the use of mulch made from organic materials derived from straw, shallots, tobacco, and chilies can also protect roots from damage by *C. formicarius* attacks in the soil. This condition is caused as the organic materials used contain metabolite compounds and vegetable pesticides, which are able to repel adult insects from laying eggs at the base of the stem [13,14]. Apart from increasing plant fertility, mulch covering mounds can also inhibit weed growth and egg laying [15–18]. Black or silver plastic mulch is more effective as a soil cover to protect and defend roots from *C. formicarius* attacks than other types of mulch [19,20].

Meanwhile, other researchers reported that the application of the entomopathogenic fungus *B. bassiana* through the soil surface with the right frequency will be more effective in controlling sweet potato weevil pests compared to other methods [21–24]. Furthermore, previous literature [25–29] recommend that biological control measure for sweet potato weevil can be carried out in combination with the application of the entomopathogenic fungus *B. bassiana*. Application of *B. bassiana* through the soil surface at the right frequency was more effective in controlling pests in the soil compared to other methods [30]. Due to the efficacy of plastic mulch and the entomopathogenic fungus *B. bassiana* in suppressing sweet potato damage due to borer attacks, these two measure components can be applied or tested in entisol fields.

The aim of this research is to study the technological components of mulch and the entomopathogenic fungus *B. bassiana* for controlling the sweet potato weevil pest *C. formicarius* on endemic land of the entisol type.

2 Materials and methods

2.1 Description of the study sites

The research was conducted at the experimental station at Indonesian Legumes and Tuber Crops Research Institute (ILETRI), Kendalpayak, Malang, East Java, Indonesia, from July to December 2018. The entisol land used in this study was declared as a location that has endemic criteria for sweet potato weevil pest attacks. The condition of the land at the time the activity took place was during the dry season, so that the soil cracked easily, which made it easier for the adult female to penetrate the surface of the soil to lay their eggs at the base of the sweet potato plant stems.

2.2 Treatments and experimental design

The research was arranged using a randomized block design consisting of six treatments and each treatment was repeated four times. The treatments tested were T1 = mound covered with straw mulch; T2 = mound covered with plastic mulch; T3 = mound covered with straw mulch and given *B. bassiana* at planting time, 30, 45, 60, and 75 days after planting (DAP); T4 = mound covered with plastic mulch and given B. bassiana at planting time 30, 45, 60, and 75 HST; T5 = application of chemical insecticide (deltamethrin) at planting time 30, 45, 60, and 75 HST; and T6 = not treated. The type of plastic mulch used in this research was black silver plastic which was applied before planting time. Each treatment used two bunds and each bund was 20 m long. The straw mulch used was the rice paddy plants collected after rice was harvested. Straw mulch was applied before sweet potato planting time. The research implementation consisted of several activities as follows:

2.2.1 Land preparation

The land was cultivated by plowing twice because the type of soil used was an alluvial structure entisol. The soil was loosened and given 3 t/ha of organic fertilizer and 2 t/ha of calcium mixed at the time of loosening the soil, 1/3 of 400 kg/ha of inorganic fertilizer at a dose of 90 kg N/ha (200 kg Urea/ha), 25 kg P_2O_5/ha (50 kg TSP/ha), and 50 kg K_2O/ha (100 kg KCl/ha) is given at the time of planting, while the remaining 2/3 of the dose is given at 30 DAP. The soil was formed into bunds with a height of 40 cm, the distance between the mounds was 100 cm, and then each bund was covered with straw mulch for treatments

T1 and T3. The bunds in treatments T2 and T4 were covered with plastic mulch, while those in treatments T5 and T6 were not covered using mulch. Straw mulch given at about 2 t/ha before planting covered the entire soil surface, especially the top of the mounds in treatments T1 and T3,. The plastic mulch used to cover the entire surface of the mounds in the T2 and T4 treatments was given a hole at the top of the mound, which was used to stick the sweet potato cuttings to be planted according to the spacing between the cuttings of about 25 cm.

2.2.2 Sweet potato cuttings

Planting sweet potato cuttings in this research activity was carried out in the dry season, July 16 2018, so that the land conditions were in accordance with the planting process carried out by the local farmers. The sweet potato variety used was Cilembu, obtained from potato development farmers in Tumpang District, Malang Regency, East Java. Sweet potato cuttings used as planting material are from the plant's top, measuring 25 cm. The entire leaf stalk was cut off from the cuttings obtained from the land, leaving only two stalks at the top of the cuttings to avoid excessive evaporation. Furthermore, the sweet potato cuttings were soaked in shallot extract (*Allium cepa*) for 60 s so that the cuttings are free from scab infection (*Sphaceloma batatas*). The cuttings were drained for 24 h before planting. The cuttings are planted by sticking the base of the stem into a mound about 10 cm deep into the soil.

2.2.3 Biopesticide fungus *B. bassiana*

The *B. bassiana* fungus was obtained from the corpse of the *C. formicarius* insect from a sweet potato trader in Tumpang, Malang (East Java) in 2015. The fungus was then isolated and identified by comparing the morphological and physiological characters of the *B. bassiana* strain Tumpang 1 fungus isolate (TMP1) with that reported by Becerra et al. [26], Coates et al. [27], Humber [28,29]. The identified *B. bassiana* fungus isolate, namely, strain TMP1, was then propagated on media supplemented with 10% chitin to increase conidia production and fungal virulence as an efficacy test material.

The efficacy test of the *B. bassiana* fungus isolate, which has the ability to kill insects with a mortality rate of up to 99%, has been carried out on all stages of the *C. formicarius* insect . The multiplication of the fungus on the growth media was maintained until it was approximately 21 days after incubation. Then, it was put in a 500 mL Erlenmeyer flask to which sufficient amount of sterile water was added. Furthermore, the grading agent (Tween 80 as much as 2 mL/L) was added and then shaken using a shaker for approximately 60 min so that all the formed conidia had fallen off. The conidial suspension was filtered to obtain the conidial supernatant of *B. bassiana* and then counted using a hemocytometer to obtain a conidia density of around 10^7/mL. The first application of the *B. bassiana* fungus in the T3 and T4 treatments was carried out at planting time, as a cutting treatment, by immersing the cuttings in a suspension of *B. bassiana* conidia for about 60 min. Conidia suspension was sprayed at the base of the stem at a volume of 20 mL per plant or the equivalent of 600 L/ha for a population of 30,000 plants. Follow-up applications are carried out starting at 30, 45, 60, and 75 DAP, by spraying at the base of the stem. The application was carried out in the afternoon with the hope that there would be no influence from UV light so that the efficacy of the fungus could play a maximum role in suppressing the attack of the sweet potato weevil.

2.2.4 Application of synthetic insecticides

This type of synthetic insecticide with the active ingredient deltamethrin with the commercial name of Decis is used at a dose of 5 mL/L which was only applied to T5 treatment (farmer cultivation method). The application of the synthetic insecticide deltamethrin was carried out at planting time by soaking the cuttings in a synthetic insecticide solution for 30 minutes, then the next application was carried out at the ages of 30, 45, 60, and 75 HST. Treatment of sweet potato cuttings using chemical insecticides follows the method usually used by local farmers for cultivating sweet potatoes.

2.2.5 Plant maintenance

Plant maintenance was done by weeding, turning stems, watering, and hilling. Weeding activities were carried out at 30 and 60 DAP, especially in treatments T1, T3, T5, and T6, while treatments T2 and T4 were not weeded because the bunds were covered using plastic mulch. Stem turning was carried out at 45 DAP with the aim of preventing the stem from sticking out in various places and concentrating the formation of roots only at the base of the main stem. Stem turning activities were carried out, especially in treatments T1, T3, T5, and T6, because plastic mulch was not used, whereas for treatments T2 and T4, it was not carried out. Cultivation was carried out at the age of 60 DAP in treatments T1, T3, T5, and T6 to ensure the formed roots were better protected from the *C. formicarius* egg-laying process.

2.3 Data collection and measurement

The variables observed were: (1) the total number of roots per plant, (2) the weight of the roots per plant, (3) the average diameter of the roots on each plant, (4) the percentage of root damage observed destructively by splitting the indicated roots, attacked by borers after harvest, (5) number of *C. formicarius* eggs per plant, (6) number of *C. formicarius* larvae per plant, and (7) yield of root weight per hectare. All data were obtained from the average of ten sample plants in each treatment. Meanwhile, the results for root weight per hectare were obtained from the average root weight of ten sample plants and then converted to hectares.

Root damage due to infestation of *C. formicarius* larvae was observed and measured based on damage scores which were divided into five levels using the method suggested by Talekar [31]. Score 0 = without any sign of rattling on the roots (0%); score 1 = root damage caused by *C. formicarius* larvae between 1 and 25%; score 2 = root damage caused by *C. formicarius* larvae between 26 and 50%; score 3 = root damage by larvae of *C. fromicarius* between 51 and 75%; and score 4 = root damage by larvae of *C. formicarius* >76% (roots not suitable for consumption). Furthermore, the results of the root damage score on the sample plants were used to calculate the intensity of root damage caused by *C. formicarius* using a method that was developed and modified by Rees et al. [32,33].

$$\mathrm{ID} = \frac{(\sum n \times v)}{Z \times N} \times 100\%, \tag{1}$$

where ID is the intensity of root damage (%), n is the number of roots that are drilled on the v scale, v is the root damage scale value, N is the total number of roots observed, and Z is the highest value of root damage scale.

2.4 Data analysis

All data obtained with a normal distribution were then analyzed using the MINITAB 14 program; If there are differences between treatments, then the multiple range test (Duncan's Multiple Range Test) is continued at $\alpha = 0.05$ level.

3 Results

3.1 Influence of control measure on the number of eggs per plant

Adults of sweet potato weevil pests usually lay the eggs at the base of the stem before the formation of roots or at the time of root formation. The number of eggs was observed destructively by slowly cleaning the base of the stem from the remnants of soil attached to the part between the base of the stem and the root. The results showed that the highest average number of eggs occurred in the control or without treatment (T6), which reached 39 eggs/plant (Figure 1). The number of eggs in the straw mulch treatment (T1) appeared much lower than that in the without treatment (T6). However, the number of eggs in the T1 treatment was not significantly different from the chemical

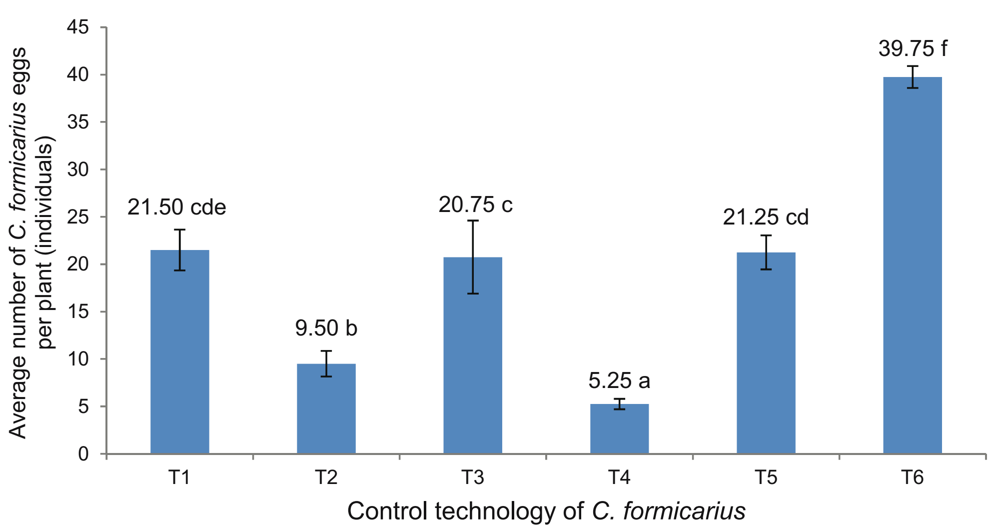

Figure 1: The average number of *C. formicarius* eggs found in each Cilembu sweet potato plant with various control technologies.

insecticide treatment (T5). In the treatment of covering the mounds using straw combined with the entomopathogenic fungus *B. bassiana* and applied six times (T3), the number of *C. formicarius* eggs found was slightly lower when compared to the chemical insecticide treatment (T5), which was 20 eggs/plant although both the treatments did not differ significantly. The application of straw mulch as a cover for the mounds in the T1 treatment physically prevented the adult from laying eggs at the base of the stem so that the number of eggs found did not differ significantly from the efficacy of chemical insecticides (T5).

The results of the research showed that the lowest average number of *C. formicarius* eggs occurred in T4 and T2, namely, the application of plastic mulch as a cover for the embankment combined with the application of *B. bassiana* fungus. By using plastic mulch in the treatment, T2 only found around 9.50 eggs/plant. Meanwhile, in treatment T4, if plastic mulch was combined with *B. bassiana* fungus, the number of eggs found was only 5.25 eggs/plant.

3.2 Effect of control measure on the number of *C. formicarius* larvae

The research results showed that the highest average number of larvae that bore roots on each plant was found in the chemical insecticide application treatment (T5), namely, up to 15 individuals/plant. The average number of larvae in T5 was greater when compared to that in without treatment (T6), namely, around 14 individuals/plant, although the two types of treatment were not significantly different (Figure 2). This condition is thought to be done incorrectly by applying the chemical insecticide compound to the target insect because the application is aimed at insects above the plant's surface, so it is only possible to kill the adult if it is on the target. Meanwhile, insect activity is very active if disturbances are considered to threaten the existence of insects, such as spraying activities in the area. The more eggs laid at the base of the stem, the more chances the larvae will survive. This condition occurs because there are no chemical insecticide compounds that have the ability to kill the egg stage. Judging from the average number of eggs laid in the chemical insecticide treatment, it reached 21 per plant (Figure 1). Thus, the chance of survival for *C. formicarius,* which develops from the egg stage to larvae when treated with chemical insecticides (T5), reaches 71%.

The egg stage is the initial phase of insect development, after hatching, the insect will develop to form the larval stage. Meanwhile, all larval stages from instar 1 to 3 are able to burrow into the roots in the soil, causing damage to the formed roots. Therefore, the more eggs the adult lays at the base of the sweet potato stem, the more larvae will be formed and ultimately the level of damage caused will also be more severe.

3.3 Effect of control measure of *C. formicarius* on sweet potato roots

The research results showed that the number of roots obtained was around 3.3–4.8 roots/plant. The highest number of roots was obtained from the treatment of plastic mulch combined with the entomopathogenic fungus *B. bassiana* which was applied five times (T4), namely, 4.8 roots/plant (Table 1).

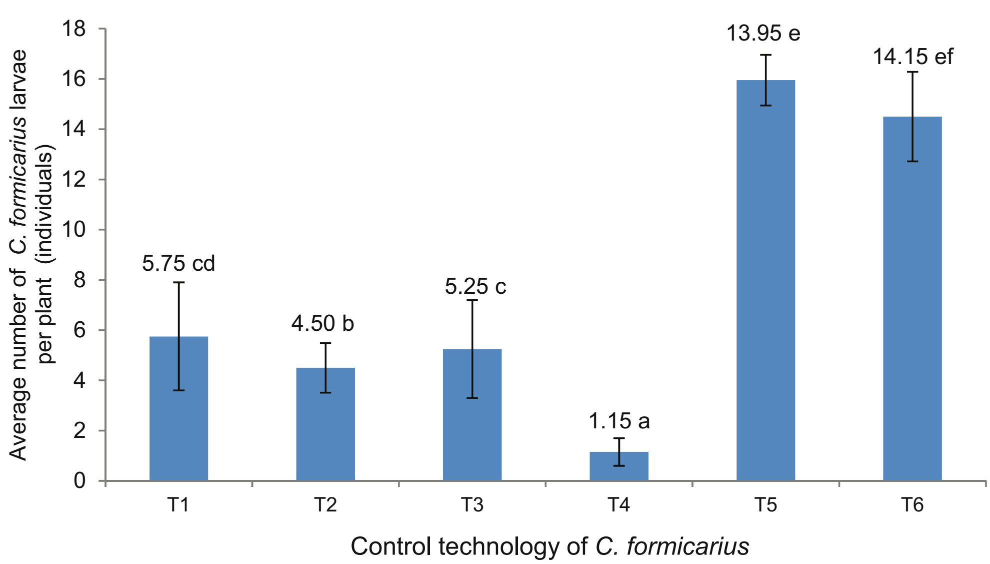

Figure 2: Average number of *C. formicarius* larvae in roots using various control technologies.

However, treatment T4 was not significantly different from the number of roots in treatment T3, namely, 4.60 roots/plant. The lowest number of roots occurred in the straw mulch treatment (T1), namely, only 3.30 roots/plant. However, T1 was not significantly different from the plastic mulch treatment (T2) and without treatment (T6), with 3.4 and 3.6 roots/plant, respectively. Meanwhile, after applying chemical insecticides using the active ingredient deltamethrin, 3.8 roots/plant were obtained. The number of roots obtained in the chemical insecticide treatment was indeed higher when compared to the T1, T2, and T6 treatments, but the efficacy of T5 was also determined by other supporting characters.

The mean diameter of the roots ranged from 3.9 to 4.5 cm and the highest diameter was obtained from plastic mulch treatment alone or in combination with the entomopathogenic fungus *B. bassiana*. Meanwhile, the lowest average root diameter was obtained from the straw mulch treatment and untreated control, namely, around 3.9 cm. The mean value of root diameter obtained from straw mulch combined with the entomopathogenic fungus *B. bassiana* (T4) reached 4.5 cm/root (Table 1). However, the diameter of the roots in the T4 treatment was not significantly different from the single plastic mulch treatment (T2). The average root diameter obtained in treatment T4 was higher when compared with treatments T1 and T5. However, the average root diameter obtained was not significantly different from the five types of control measure tested. This condition was due to the fact that the average root diameter obtained from the five types of control measure was almost uniform and there were no significant differences.

The weight of the roots for each plant is obtained from all the roots formed and weighed at harvest time. The results showed that the weight of the roots obtained ranged from 453 to 829 g/plant (Table 1). The highest root weight was obtained from plastic mulch treatment combined with the fungus *B. bassiana* (T4), which reached 829.15 g/plant. The root weight in the treatment of straw mulch combined with the fungus *B. bassiana* was also relatively high, reaching 788.25 g/plant. However, root weight in T3 treatment was not significantly different from root weight in plastic mulch (666.34 g/plant), straw mulch (571.67 g/plant), and chemical insecticide applications (598.76 g/plant). Meanwhile, the lowest root weight was obtained in T6 (without treatment), namely, only 453.10 g/plant.

Table 1: Average number, root weight, and root diameter of each plant on various control techniques of *C. formicarius*

Treatment	Average number, weight, and diameter of roots		
	Number or roots	Root diameter (cm)	Root weight (g/plant)
T1	3.30def	3.9abc	571.67bc
T2	3.40de	4.5a	666.34bc
T3	4.60ab	4.4ab	788.25b
T4	4.80a	4.5a	829.15a
T5	3.80c	4.4ab	598.76bc
T6	3.60cd	3.9abc	453.10d
DMRT 5%	0.55	0.9	104.40
CV (%)	13.18	16.63	16.61

Column numbers followed by the same letter are not significantly different in the DMRT test at the 5% level.

3.4 Effect of control measure on the level of root damage causedby *C. formicarius*

Root damage was calculated based on the number of roots ingested by *C. formicarius* larvae at various levels of damage using a modified score [34–36]. The study's results showed that damage to roots ingested by *C. formicarius* larvae ranged from 2 to 51% (Figure 3). The highest level of damage, reaching 51.60%, occurred in the root without treatment (Figure 4). Root damage in the straw mulch treatment (T1) was quite high, namely, 38.96%, not significantly different from control measure using chemical insecticides, namely, 36.12%.

The straw mulch treatment, combined with the *B. bassiana* fungus, caused the control efficacy to increase, as evidenced by the level of root damage decreasing by 10%, namely, from 38.96 to 28.86%. Likewise, when the plastic mulch treatment was combined with the fungus *B. bassiana*, the control efficacy increased 13% from the infested roots by around 15% to just 2%.

3.5 Root weight

The root weight yields obtained ranged from 13 to 26 t/ha with the highest yield achieved by the T4 treatment (26.76 t/ha) and significantly different from the other treatments. The T3 treatment yielded a relatively high root weight of around 23.65 t/ha and was higher than the straw mulch (T1), plastic mulch (T2), and chemical insecticide (T5) treatments with 17.15, 19. 99, and 17.95 t/ha, respectively (Figure 5).

4 Discussion

4.1 The influence of control measure on the number of eggs per plant

The number of eggs in the straw mulch treatment (T1) appeared much lower than in the uncontrolled treatment

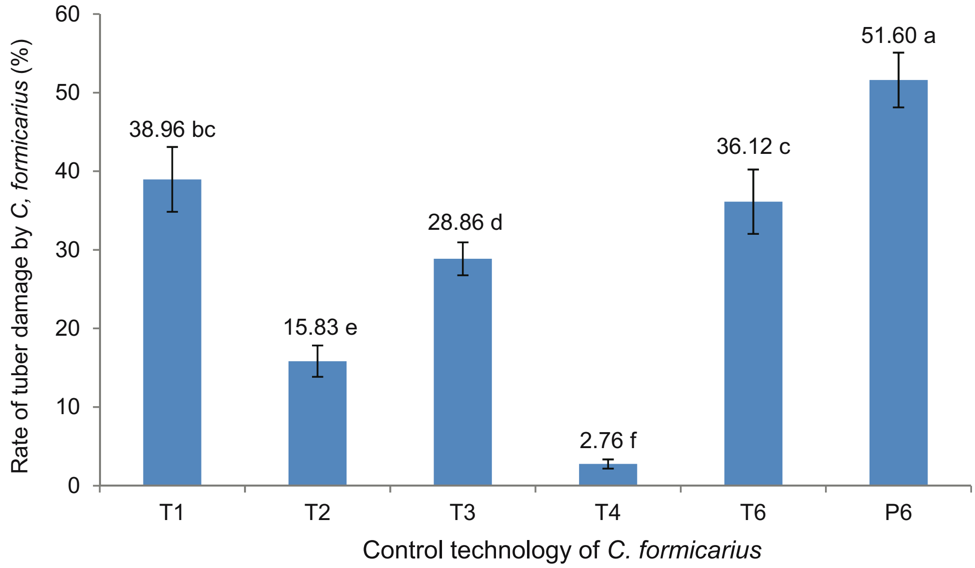

Figure 3: The average level of root damage by *C. formicarius* larvae under various control technologies.

Figure 4: Yield performance of Cilembu variety roots under various *C. formicarius* pest control techniques.

(T6). However, the number of eggs in the T1 treatment was not significantly different from the chemical insecticide treatment (T5). In the treatment of covering the mounds using straw combined with the entomopathogenic fungus *B. bassiana* and applied six times (T3), the number of *C. formicarius* eggs found was slightly lower when compared to the chemical insecticide treatment (T5), which was 20 eggs/plant although both treatments did not differ significantly. According to [33], the use of various types of mulch from plant organs that contain metabolites has a positive effect on protecting roots from the attack by *C. formicarius*, especially on land that has a character that cracks easily during the dry season, by dispelling *C. formicarius* adult from laying eggs.

The application of straw mulch as a cover for the mounds in the T1 treatment physically prevented the adult from laying eggs at the base of the stem so that the number of eggs found did not differ significantly from the efficacy of chemical insecticides (T5). Suppose the straw mulch is combined with the application of the entomopathogenic fungus *B. bassiana* six times, then the efficacy of the treatment (T3) becomes better than the efficacy of chemical insecticides because the number of eggs found is less. This condition is caused by the volatility of metabolite compounds produced by the fungus *B. bassiana*, which can affect insect behavior, one of which is the process of laying eggs [37,38].

Based on the number of eggs found on each plant in this study, it is clear that the plastic mulch treatment was more effective in suppressing *C. formicarius* from laying eggs when compared to the straw mulch or chemical insecticide treatment. This condition is caused by plastic mulch physically making it difficult for adult activity to reach the surface of the base of the plant stem. In addition, the volatile compounds from the toxins produced by the fungus *B. bassiana* can affect the egg-laying process because the insect is not interested in coming to the plant [39–41]. This fact is supported by research results [42,43], which indicate that the entomopathogenic fungus *B. bassiana* is able to inhibit the egg laying process of *C. formicarius*. Therefore, the number of eggs found in the application treatment using the *B. bassiana* fungus was very limited compared to the treatment not using the fungus.

4.2 Effect of control measure on the number of *C. formicarius* larvae

The number of larvae found in the straw mulch treatment combined with the *B. bassiana* fungus was relatively low when compared to the chemical insecticide treatments. Meanwhile, the plastic mulch treatment combined with the *B. bassiana* fungus was far more effective in suppressing the number of larvae found. Plastic mulch treatment can physically hinder the egg-laying process because the ovipositor has difficulty reaching the surface of the base of the stem. In addition, waves of UV light from plastic mulch can confuse adult, so they are not interested in laying their eggs on plants [44–46]. Plastic mulch can function as a physical factor that can inhibit the process of insect pest laying eggs in the soil so that the number of larvae that will develop is also limited [47].

The efficacy of the combination of plastic mulch with the fungus *B. bassiana* is because the conidia suspension of

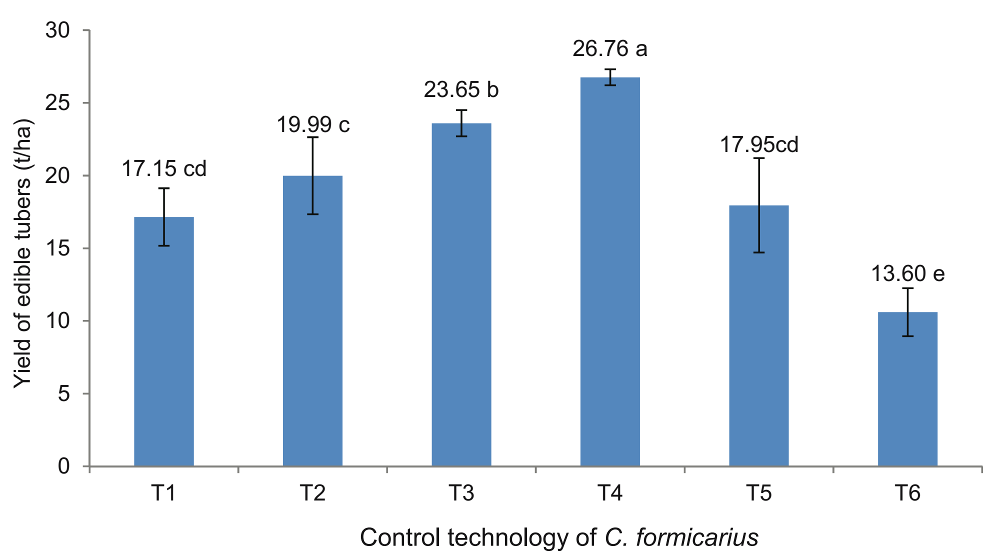

Figure 5: The effect of various *C. formicarius* sweet potato weevil control technologies on the weight yield of edible roots.

the fungus which is applied to the surface of the base of the plant stem can work more optimally. This condition is caused by increasing the soil moisture, especially at the base of the stem, which is covered with mulch so that eggs laid by adult females can become infected with fungi because fungi produce various types of toxins, which can cause eggs not to hatch to form larval stages. Toxins produced by *B. bassiana,* such as beauvericin, tenellin, beauverolides, and oosporein are ovicidal, so they are very toxic in thwarting the hatching of *Tetranychus evansi* eggs and various other types of pests [48–50]. The excess ovicidal properties of the entomopathogenic fungus *B. bassiana* were also reported to be able to kill the order Diptera, Culicidae, and eggs of *Tetranychus urticae* [51–53]. The efficacy of the ovicidal properties of the entomopathogenic fungus *B. bassiana* in preventing the hatching of the egg phase of *C. formicarius* has also been reported by Reddy et al. [54]. This phenomenon can prove that the efficacy of the entomopathogenic fungus *B. bassiana* has an important role in determining the success of controlling sweet potato weevil pests. Thus, this entomopathogenic fungus can be recommended as a technological component to control the sweet potato weevil *C. formicarius* in an integrated pest control program because of the toxicity of the toxin it produces [55,56].

4.3 Effect of control measure on the level of root damage caused by *C. formicarius*

The straw mulch treatment, combined with the *B. bassiana* fungus, caused the control efficacy to increase, as evidenced by the level of root damage decreasing by 10%, namely, from 38.96 to 28.86%. Likewise, when the plastic mulch treatment was combined with the fungus *B. bassiana*, the control efficacy increased 13% from the infested roots by around 15% to just 2%. Roots that have been infested by *C. formicarius* larvae, even with a low level of damage, are declared unfit for consumption because the roots contain furan terpenes and coumarins, which can be toxic to consumers [57]. The results of the research showed that the application of plastic mulch which was used to cover the mounds and coupled with the application of the entomopathogenic fungus *B. bassiana* could increase or protect root damage from borer attacks. The effectiveness of plastic mulch in maintaining the productivity of sweet potatoes obtained has also been reported in Papua New Guinea [58]. This condition is due to the fact that land humidity can be controlled, especially during the dry season, as well as being able to suppress the growth of existing weeds. Meanwhile, the efficacy of the entomopathogenic fungus *B. bassiana* is able to protect roots from larval attacks, which are very limited in number [16].

4.4 Root weight

Controlling sweet potato weevil using chemical insecticides is considered less effective because it is only comparable to T1 and T2 as reported by Ownley et al. [59]. The disadvantage of controlling sweet potato weevil pests using chemicals besides being less effective is that the root products are exposed to chemical insecticide residues. Apart from that, applying chemical insecticides can kill natural enemies and cause poisoning or environmental pollution [60–62]. The results of the study by Prayogo and Bayu [63] indicated that the application of the fungus *B. bassiana* was more effective and more prospective in controlling *C. formicarius* in sweet potato weevil endemic fields in South Kalimantan when compared to the efficacy of the insecticide deltamethrin.

5 Conclusion

Straw and plastic mulch treatments can inhibit the egg-laying process and the formation of *C. formicarius* larvae at the base of the stem and its efficacy is comparable to the insecticide deltamethrin. The treatment of plastic mulch and the entomopathogenic fungus *B. bassiana* applied five times resulted in an yield of root edible for consumption reaching 26.76 t/ha, while the deltamethrin insecticide treatment was only 13.60 t/ha. The efficacy of measure to control the sweet potato weevil pest *C. formicarius* using plastic mulch with the entomopathogenic fungus *B. bassiana* has reached 96.76%, the root products obtained are also more organic, so the selling price is higher than conventional products. Therefore, plastic mulch measure with the application of the entomopathogenic fungus *B. bassiana* five times starting at planting and then 30, 45, 60, and 75 DAP can be recommended as a technological innovation for controlling *C. formicarius* in endemic entisol type land.

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