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The effectiveness of citronella oil to control main pest on cabbage *Plutella xylostella* in the field

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Abstract

One of the constraints to cabbage production is pest infestation. Cabbage caterpillars, including *Plutella xylostella*, are pests that must be considered. The pests can reduce the yield by up to 90%. One of the causes of the decline in cabbage production is the attack of *P. xylostella*. Until now, control measures against *P. xylostella* still rely on synthetic insecticides, whose application can have negative effects. For this reason, alternative environment-friendly technologies are needed. One of these alternative technologies is citronella oil as a botanical pesticide. This research activity aims to evaluate the potential of citronella oil as a pest control agent for *P. xylostella*. The research activities were carried out in two stages: laboratory research and field research. Laboratory experiments aim to understand citronella oil's mode of action to reduce the population of *P. xylostella*. Field experiments aimed to determine the potential of citronella oil to suppress the population of *P. xylostella* in cabbage plantations during one growing season. The treatment of this study was the frequency of citronella oil application. The results showed that citronella oil could suppress the population of *P. xylostella* in the field and harm the growth and behavior of this pest. The mode of action of citronella oil to suppress the *P. xylostella* population includes feeding inhibitors, egg-laying inhibitors, repellents, and insecticides. Citronella oil has no adverse effect on the natural enemy, *Diadegma eucerophaga*. These results indicate that citronella oil has the potential as a botanical pesticide that could help implement environment-friendly technology.

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Introduction

Cabbage (*Brassica oleracea* L. var. *capitata*) is a critical horticultural commodity with a high economic value in Indonesia. It is known that cultivation is an essential source of employment for small-scale vegetable farmers, contributing to household food and nutritional security and an alternative source of income generation leading to poverty reduction (Kondo *et al.,* 2014).

Cabbage has high nutritional value because it contains vitamins C, A, and B1; the minerals calcium, potassium, phosphorus, sodium, chlorine and sulfur; and contains anticancer compounds (Adiyoga *et al*., 2004). Global cabbage production ranges from 30-70 tons per hectare (Anonymous, 2017). For Indonesia, cabbage production in 2021 was relatively low at 22.47 tons of ha (BPS, 2018). One of the factors causing the low cabbage production in Indonesia is the attack of pests and plant diseases.

One primary pest that routinely attacks cabbage plants is the cabbage leafworm *Plutella xylostella* (Permadi & Sastrosiswojo, 1993). If no control measures are taken, the yield loss caused by *P. xylostella* can reach 100%. Until now, control measures against *P. xylostella* pests by farmers still rely on the use of synthetic insecticides (Djojosumarto, 2008). These insecticides can be applied at least once a week and, on average, twice a week. Excessive and continuous use of synthetic pesticides can lead to negative impacts such as environmental pollution and crop residues; pest resistance, recurrence, and the emergence of secondary pests (Prabaningrum *et al*., 2013); and cause a reduction in natural enemies (Mulyaningsih, 2010).

In Indonesia, resistance of *P. xylostella* was first reported by Ankersmith (1953) against dichloro diphenyl trichloroethane due to this insecticide's intensive and continuous use. The resistance of these pests to acephate and triazophos was reported by Sastrosiswojo *et al*., (1989). The pest has become resistant to fipronil, deltamethrin, profenofos, and abamectin (Moekasan *et al*., 2004). Implementing an integrated pest management (IPM) system is necessary to support efforts to reduce cabbage yield loss and maintain environmental security and the health of consumers and farmers. In this IPM system, several technological components are integrated to effectively and efficiently suppress the *P. xylostella* population. In order to enrich the control technology components and reduce the intensity of synthetic insecticides, it is necessary to find alternative control technology components based on local resources that are environment-friendly. One of the alternative technologies is to evaluate the potential of essential oils to control pests, including *P. xylostella*. The results of previous studies, both from abroad and within the country, indicate that essential oils can inhibit development and even kill plant-disturbing organisms (Wilson *et al*., 1997; Kazuhiko *et al*., 2003; Saad *et al*., 2017).

One essential oil that needs to be tested as a botanical pesticide against *P. xylostella* is citronella oil. It is because this essential oil has the potential to control pests on other plants. Citronella oil is repellent to several significant pests of crops, including *Helopeltis antonii* on cocoa (Nurmansyah, 2016), onion warehouse pest *Ephestia cautella* (Hasyim *et al*., 2014), mealybug *Bemisia tabaci* which attacks chili plants (Saad *et al*., 2017). Citronella essential oil is a repellent, antifeedant and deterrent to insect oviposition (Willis *et al.,* 2013; Wany *et al*., 2013). Fikri *et al*., (2010) also stated that citronella compounds are stomach poisons that can kill Jatropha curcas thrips.

This study aimed to determine the potential of citronella essential oil as a population control agent for *P. xylostella* through laboratory and field research. The success of this research provides an opportunity to develop the use of citronella oil as a pest control agent for plants, especially *P. xylostella* on cabbage plants.

Materials and Methods

The research activities have been carried out in Balitjestro, Balitsa Lembang laboratories, IP2TP Berastagi, and farmers' land in Ngantru village, Malang district, East Java. The experiment was conducted from September to December 2022.

Laboratory research

Laboratory research aims to determine the effect of essential oils on the behavior, fecundity, and mortality of *P. xylostella* pests. The experimental design was a completely randomized design.

The activity implementation began with the mass propagation of *P. xylostella* pests in the greenhouse. The propagation required propagation cages; artificial food honey dripped on cotton. The cabbage seedling had been provided for adult pests laying their egg. A magnifying glass was used to monitor the growth stages of *P. xylostella* in the propagation cage. Mass propagation began with taking imago of *P. xylostella* from the field using a mouth respirator, maintained in a rearing box with liquid honey food.

After obtaining the F1 derivative, the derivative from the first instar began to be treated according to the predetermined treatment. *P. xylostella* larvae were collected from the rearing cage and transferred to the cabbage leaves for treatment using a paintbrush. Two methods have been used to test the repellency of citronella oil against *P. xylostella* nymphs. There were filter paper and feeding methods.

Filter paper method

The filter paper was divided into two parts: one was dripped with citronella oil, and the other was without citronella (control). The filter paper was dried and placed in a Petri dish according to the treatment. Ten larvae of *P. xylostella*, instar - 3, were placed in the center of the filter paper then the Petri dish was closed. The treatment in this study was citronella oil concentrations of 1, 2, 3, and 4 mL/L. Each of these was repeated five times. Observations were 24, 48, 72, 96, and 120 hours after treatment.

Feeding method

This experiment used cabbage leaves with 5↔5 cm sizes of leaves divided into two parts: one part was dripped with citronella oil, and the other was dripped with water as a control. The cabbage leaves were dried and placed in a Petri dish according to the treatment. Ten *P. xylostella* larvae, instar one, were placed in the center of the cabbage leaves, and then the Petri dish was closed. The treatments in this research were citronella oil concentrations of 1, 2, 3, and 4 mL/L. Each of those treatments was repeated five times. The observations were done 1, 2, 3, and 4 days after treatment. Percent repellences for filter paper and feeding assay determined using the formula:

$$\text{Percent repellency} = \frac{NC - NT}{NC + NT} \text{ X } 100\%$$

NC = number of *P. xylostella* larvae in the control treatment;
NT = Number found in the treatment.

The egg-laying repellency test by *P. xylostella* imago was conducted as follows: The activity began by making a solution of citronella oil treatment, namely concentrations of 1, 1.5, and 2 mL/L, recommended doses of synthetic pesticides, and control. The leveling agent added to the test material could dissolve/form an emulsion with water. The solution for those treatments was made in a mineral water glass, and pieces of young cabbage leaves were dipped into it approximately 5↔5 cm for 5 seconds. The leaves were then air-dried. After drying, the leaves were placed in a gauze cage randomly. The cell contained all treatments. After that, 4-5 female imago were put into a plastic box and closed. For food, the imago was given honey solution dripped on cotton. Observations were done five days after treatment. Each of them was repeated six times. The observations were on the number of eggs laid in each treatment. The formula calculated the percentage of egg-laying inhibitors (R%):

$$R\% = \frac{\text{Total egg on control} - \text{Total egg on treatment}}{\text{Total egg on control}} \text{ X } 100\%$$

To determine the effect of citronella oil on the imago fecundity and feeding the instars on cabbage leaves with citronella. The treatments were citronella oil concentrations of 1, 2, 3, and 4 mL/L and control. The treatment method for the fecundity parameter was: i) making 10↔10 cm pieces of cabbage leaves, as many as ten pieces per treatment; ii) the pieces of leaves were then dipped in a solution of essential oil according to the treatment and synthetic insecticides. Tweezers are needed to dip the cabbage leaves in citronella oil solution. Pieces of cabbage leaves are then air dried; iii) after the cabbage leaves are dry, the first instar of *P. xylostella* pests is placed and one first instar larvae is placed on each piece of cabbage leaves. The observation parameter is the number of eggs produced by female pest imago derived from treated larvae. Observations were until the pest died.

Several concentrations carried out the application test to determine the insecticidal activity of citronella. The treatment, namely 0.5, 1, 2, 3, 4 mL/L, and control (without application of citronella). Each treatment consists of four replications. The treatment method for the mortality parameter is: i) making 10↔10 cm pieces of cabbage leaves, as many as four parts per treatment; ii) each piece of leaf is placed in ten-third instar larvae; iii) sprayed with essential oil solution according to the treatment and synthetic insecticide.

It was sprayed using a hand sprayer. It is necessary to add grading and wetting agents to facilitate citronella oil to form an emulsion with water. Observations were on the number of individual larvae that died. Mortality observations were made every 1, 2, 4, 6, 12, 24, and 120 hours after treatment. We calculated the lethal doses of 50 and 95.

Field research

This study aimed to determine the ability of citronella oil to suppress the *P. xylostella* population in the field and its effect on the presence of the natural enemy *Diadegma eucerophaga* larval parasitoid. The design used in this study was a group-randomized design with four treatments and five replications. The treatment was the frequency/interval of citronella oil application, namely: 1 time a week; 2 times a week; farmer's pesticide application, namely the active ingredient pesticide imidacloprid at a dose of 1 cc/l interval once a week; control/no control measures. The amount used for applying citronella oil is two cc/l. The consideration of this dose is the best from lab tests, but in the field, it does not cause toxicity risk to cabbage plants. The cabbage population in each treatment was 50 plants. In each replication, 10 sample plants were taken for pest observation of *P. xylostella* and parasitoid *D. eucerophaga*. The planting system and care of research plants refer to the standard of cabbage cultivation by the Indonesian Vegetable Research Institution. The treatment started from the last week of September 2022 until the plants were harvested. Observations of the larval population of *P xylostella* pests were carried out every week from the plants that were 15 days old until harvest by counting the larval population on the sample plants. Observations of the parasitoid *D. eucerophaga* were conducted once a week, starting from 15 days old until harvest, by counting the number of imagos found on the sample plants.

Results and Discussion

The results of the effectiveness test of citronella oil to control *P. xylostella* populations in the field are shown in Figure 1.

Figure 1 shows that the population of *P. xylostella* in the field was relatively low. The highest mean population was 42 individuals per 10 plants or 4.2 individuals/per plant. The treatments and observations caused this result coincided with high rainfall in October and November (Table 1). Rainy days were 22 and 25 days, totaling 335 and 394 mm. The study started at the end of September until November 2022.

However, from the population data of *P. xylostella*, it can be seen that applying citronella oil can suppress the population of *P. xylostella* at a concentration of 2 cc/l applied once and twice a week. The ability did not show a significant difference with insecticide application. This is because essential oils, including citronella, adversely affect insect life. These adverse effects include repellents, feeding deterrents, oviposition deterrents, and insecticides (Istianto and Emilda, 2021). Other studies have proved that citronella oil harms insects such as *Helopeltis antonii* (Nurmansyah, 2016), *Bemisia tabaci* (Saad *et al*., 2017), *Diconocoris hewetti* (Wiratno *et al*., 2011) and *D. piperis* (Rohimatun and Laba, 2013). Laboratory research showed the ability of citronella oil to suppress *P. xylostella* populations through work as a repellent, oviposition deterrent, feeding deterrent, and insecticide.

Table 1. Rain conditions during the research in Ngantru village, Malang district.

Weather parameter	Month (2022)		
	September	October	November
Precipitation (mm)	79	335	394
Rainy days (day)	7	22	25

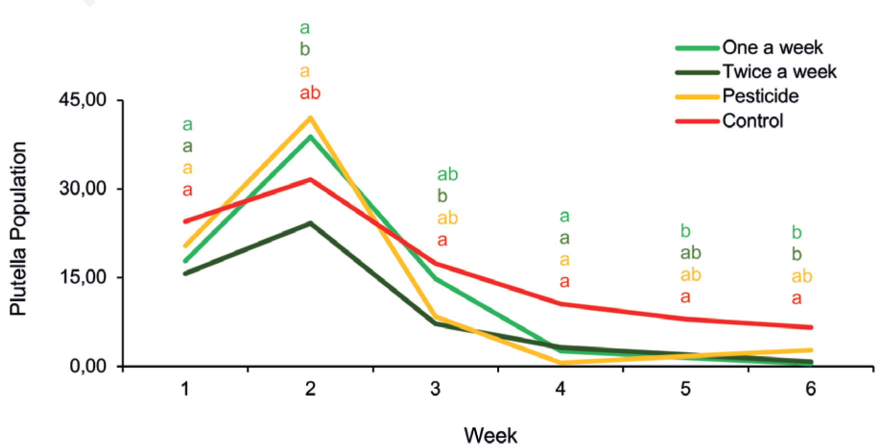

Figure 1. Mean population of *Plutella xylostella* per 10 cabbage plants in the treatments (individual). Graphs followed by the same letter in the respective observation show no significant difference based on the Tukey test at a 5% level.

The citronella oil as an inhibitor of egg-laying *P. xylostella* imago

The results of this egg-laying inhibitor test are shown in Table 2. Based on the data in Table 2, it can be seen that citronella essential oil can reduce egg laying by *P. xylostella* imago on cabbage host plants. Couty *et al*. (2006) reported that female *P. xylostella* imago utilizes aroma compounds produced by plants to find and lay eggs on the host plant (cabbage). These compounds include (Z)-3-hexenyl acetate, (E)-2-hexenal, and (Z)-3-hexene-1-ol (Sarfraz *et al*., 2006). The citronella oil aroma, such as citronellal, citronellol, and geraniol (Burdockc 2002), can disrupt the attractant compound aroma. Those can cause *P. xylostella* imago not to find or dislike their eggs lying on cabbage plants. Schoonhoven *et al*., (2005) stated that the presence of scent from non-host plants would disrupt host-seeking behavior by insects. From the treatments, citronella oil application of 1.5 and 2 cc/l gives the best egg-laying inhibiting effect.

Repellency testing of citronella oil against P. xylostella *larvae*

Two methods were tested to determine the repellency effect of citronella oil: the filter paper method and the feeding method. The test results are shown in Tables 3 and 4.

The results of the observation of repellency of *P. xylostella* larvae in the "Filter paper" method are presented in Table 3. From the data, it can be seen that all concentrations of citronella oil tested have repellent effects on *P. xylostella* larvae. The repellency value's magnitude differed in each treatment tested and observation time. At 48 hours after treatment, it was observed that the higher the concentration, 3 and 4 cc/l, the highest level of repellency was 100%.

Similarly, with feeding methods, all treatments tested showed the ability to repel *P. xylostella* larvae. The repellency values of citronella oil were higher when the oil concentration increased (Table 4). These results align with those found by Sharififard *et al*., (2018) about the repellency of essential oils being positively correlated with the concentration used. The higher the concentration used, the higher the level of repellency.

The feeding deterrent effect of citronella oil on P. xylostella *larvae*

This activity was carried out by treating the feed of *P. xylostella* larvae with citronella oil. The feeding deterrent effect was observed on the eggs produced by female imago, with the assumption that the low consumption of larvae eating cabbage as a host will reduce the nutrients that are fulfilled for the growth of larvae to imago. De Souza *et al.* (2021) mentioned that the lack of larval vitality and decreased female fertility is due to insufficient food intake to meet nutritional needs. The effect of citronella essential oil treatment on cabbage leaves as food for *P. xylostella* larvae on egg production is shown in Table 5

Table 5 shows that the higher concentration of citronella oil applied to cabbage leaf feed causes the lower production of *P. xylostella* imago or the increase in the percent decrease in egg production compared to imago derived from larvae fed cabbage leaf feed without citronella oil. It indicates that citronella oil can suppress the food-stimulating ingredients in cabbage leaves and cause dislike so that consumption of cabbage leaves is reduced. Feeding stimulants contained in cabbage are flavonoids (van Loon *et al*., 2002).

Table 2. Number of eggs laid by *Plutella xylostella* imago during their lifetime.

Treatment	Replication						Mean ± SE
	I	II	III	IV	V	VI	
Control	25	27	19	19	35	31	26.0±2.6 d
Inseticide	21	18	16	16	14	11	16.0±1.4 c
1 cc/l	17	11	11	20	14	23	16.0±2.0 c
1.5 cc/l	0	6	7	9	11	7	6,7±1.5 b
2 cc/l	0	5	0	7	0	0	2.0±1.3 a

SE, standard error.

Table 3. Repellency of citronella oil against *Plutella xylostell*a larvae with filter method paper until 48 hours after treatment.

No	Treatments	Repellency level (%) in observation (HAT) Mean ± SE					
		1	3	6	12	24	48
1	Citronella oil 1 cc/l	46.67 a	51.72 b	51.72 b	51.72 b	51.72 b	51.72 a
2	Citronella oil 2 cc/l	80.00 c	40.00 a	33.33 a	37.93 a	71.14 a	72.72 b
3	Citronella oil 3 cc/l	71.41 bc	100.0 d	100.0 d	100.0 c	100.00 c	100.00 c
4	Citronella oil 4 cc/l	65.52 b	84.00 c	80.95 c	65.22 b	100.00 c	100.00 c

SE, standard error; HAT, hour after treatment.

Table 4. Repellency of citronella oil against *Plutella xylostella* larvae by feeding method until 48 hours after treatment.

No	Treatments	Repellency level (%) at observation (HAT) Mean ± SE			
		1	2	3	4
1	Citronella oil 1 cc/l	60 b	48 a	44 a	40 a
2	Citronella oil 2 cc/l	32 a	40 a	44 a	54 ab
3	Citronella oil 3 cc/l	80 c	72 b	68 b	72 b
4	Citronella oil 4 cc/l	92 c	84 c	76 b	76 b

SE, standard error; HAT, hour after treatment.

Reduced food intake causes nutritional needs for growth, and egg production needs not to be met, so the number of eggs produced is lower than the control.

The insecticidal effect of citronella oil on P. xylostella *larvae*

The results showed that citronella oil also has an insecticidal effect on individual *P. xylostella*. Information on the insecticidal effect is shown in Table 6.

The data shows that the number of larvae that died between treatments varied and was different from the control. The higher the concentration of lemongrass oil tested, the higher the number of dead *P. xylostella* larvae. The highest efficacy value occurred at concentrations of 3 and 4 mL/L at 100%, and the lowest occurred at a concentration of 0.5 mL/L at 57.7%. From these results, it can be seen that citronella oil effectively controls *P. xylostella* pests on cabbage plants. This result follows the findings of Papulwar *et al*., (2018), who reported that the mortality of *H. armigera* larvae due to essential oil treatment of 100% occurred 120 hours after treatment.

The mechanism of essential oils as insecticides against insects works in several ways: i) inhibiting the activity of enzymes that are important for normal metabolism in the insect body (Liao *et al*., 2016) so that an imbalance occurs, which causes insect death; ii) essential oils in the nervous system of many insects act as neurotoxins that cause paralysis followed by death (Jankowska *et al*., 2017); iii) penetration of certain chemical compounds contained in essential oils in the insect cuticle causing death (Tak & Jsman, 2015); iv) the complexity of the chemical composition in essential oils causes an increase in insecticidal activity when applied as a mixture of compounds rather than a single compound (Kim *et al*., 2021).

The probit analysis showed that the LC50 and LC95 of citronella oil against *P. xylostella* larvae were 0, 46 and 3.17 cc/l, respectively. For comparison, the LC50 and LC95 of insecticide made from imidacloprid were 0.26 and 1.28 cc/l, respectively.

The evaluation was also conducted on the effect of citronella oil application treatment on the natural enemy, the *Diadegma Eucerophaga* population. The observation results of this parasitoid population in the test treatments are shown in Figure 2.

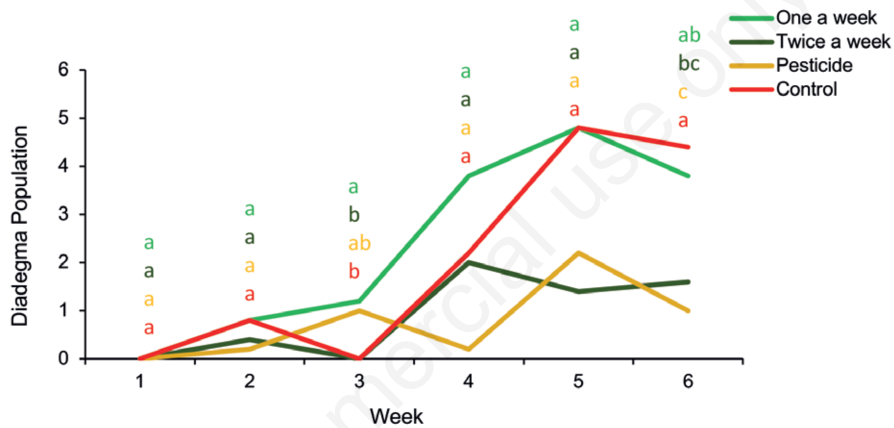

Figure 2. Mean *Diadegma eucerophaga* population per 10 cabbage plants in the tested treatments (tails). Graphs followed by the same letter in the same observation show no significant difference based on the Tukey test at a 5% level.

Table 5. The number of eggs laid by *Plutella xylostella* imago grown from larvae that fed on cabbage treated with citronella oil at several concentrations.

Treatment	Number of eggs laid on cabbage (eggs) mean ± SE	Inhibition of egg production (%) Mean ± SE
Citronella oil 4 mL/L	38,0±1.8 a	62,6±1.5 c
Citronella oil 3 mL/L	48,3±0.7 b	52,3±1.6 b
Citronella oil 2 mL/L	52,0±4.7 b	49,1±4.1 b
Citronella oil 1 mL/L	68,0±2.4 c	33,0±0.9 a
Control/no citronella oil	101,5±3.0 d	

SE, standard error.

Table 6. Percent of dead *Plutella xylostella* larvae from a population of 10 at 120 hours after treatments (%).

Treatment	Replication				Average
	1	2	3	4	
Citronella oil 0.5 mL/L	60	70	30	70	57,5
Citronella oil 1.0 mL/L	70	50	90	80	72,5
Citronella oil 2.0 mL/L	80	70	80	90	80
Citronella oil 3.0 mL/L	100	90	100	100	97,5
Citronella oil 4.0 mL/L	100	100	100	100	100
Control/no treatment	0	0	0	0	0

Figure 2 shows that the population of *D. Eucerophaga* during the observation fluctuated with no significant difference between treatments. However, the population of this natural enemy, on citronella oil treatments, tends to be higher than it on pesticide treatment, especially on a once-a-week application of citronella oil. In the last remark, the population of natural enemies on citronella oil application once/week and control was significantly higher than that of natural enemies on the insecticide treatment. It means that the application of citronella oil is safe for natural enemies of *P. xylostella*.

Conclusions

The results showed that citronella oil could inhibit the growth and development of *P. xylostella*. This ability is more visible in laboratory tests. In field conditions, the effect of citronella oil on suppressing the pest population was also apparent but could have been more optimal. This is because the treatment was conducted during the rainy season. Further tests must be completed during the dry season to ensure the potential of citronella oil as a pest control agent for *P. xylostella* in the field. Citronella oil inhibits the development of *P. xylostella* in several ways, namely as a repellent, feeding inhibitor, egg-laying inhibitor, and insecticide. The application of citronella oil also showed no adverse effect on the population of *D. eucerophaga.*

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