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Research article

# Management of *Spodoptera exigua* on shallots in several areas of Indonesia using mating disruption with different pheromone doses

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## Abstract

**Importance of the work**: The continuous use of insecticides with the same active ingredient has resulted in the growth of insecticide-resistant *Spodoptera exigua* moth populations that can accumulate in shallot tubers.

**Objectives**: To investigate the effectiveness of using pheromones as a mating disruption approach in managing *S. exigua*.

**Material & Methods**: This study was carried out in Bantul, Nganjuk and Kulon Progo, Indonesia. In Bantul, 500 dispensers/ha were installed together with a control. In Ngajuk, 100 dispensers/ha, 200 dispensers/ha and 300 dispensers/ha were installed togeteher with a control. In Kulon Progo, 100 dispenser/ha were installed, together with a control. All treatments were replicated three times.

**Result**: Pheromone installation of 500 dispensers/ha in Bantul disrupted the *S. exigua* males from locating the females. The effectiveness of sex pheromones was also observed in Nganjuk (300 dispensers/ha, 200 dispensers/ha and 100 dispensers/ha) and in Kulon Progo (100 dispensers/ha). These experiments showed that disrupting the male-female communication was successful because male-female encounters in the treatment plots were reduced. Hence, the eggs of the *S. exigua* females were not fertilized and fewer eggs hatched. However, the effectiveness of disrupting the male-female communication decreased when the moth population in the field was high.

**Main finding**: The installation of pheromone at dosages of 100 dispensers/ha, 200 dispensers/ha, 300 dispensers/ha and 500 dispensers/ha disrupted male-female communication among low populations *of S. exigua* . Installation of pheromone in 100 dispensers/ha could be a favorable option for farmers because it had the lowest materials cost. The placement of the pheromone dispensers around the field perimeter should be considered because it might hinder *S. exigua* from entering the field. Additionally, using pheromones before planting could serve as a control technique.

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## Introduction

The shallot is a horticultural crop with high economic value, with the largest export of Indonesian shallots in 2020 being to Thailand (USD 9.30 million), contributing 67.54% of the total export value of Indonesian shallots. Other shallot export destination countries were Singapore with 18.76% (USD 2.58 million), Malaysia with 12.23% (USD 1.68 million) and Taiwan with 0.69% (USD 0.095 million). Central Java province was the largest shallot producer, contributing 32.77% of Indonesia's production, followed by the provinces of East Java (23.55%) and West Nusa Tenggara (12.76%) in second and third place, respectively, while West Java province contributed 10.42%, West Sumatra contributed 7.06% and North Sumatra contributed 1.09% of Indonesia's total shallot production (Novita et al., 2019; Susilawati and Rinawati, 2021).

*Spodoptera exigua* (Lepidoptera: Noctuidae) is a notable important pest in shallot production (Ueno, 2015; Capinera, 1969; Marsadi et al., 2017). Early instar larvae enter and feed on shallot leaves and *S. exigua* adult pest infestation starts when the plants emerge, namely, 7 d after planting (dap). The colonization period begins at 21 dap when the plants and larvae begin to grow. The egg and larval populations develop at 21 dap and 28 dap, respectively (Supartha et al., 2022). The rapid colonization of *S. exigua* after planting can cause extensive crop loss and failure.

When the larvae enter the shallot leaves, the leaves become transparent and serve as protection for the larvae from coming into contact with insecticides. Shallot farmers in Brebes, Nganjuk and Bantul provinces rely on insecticide to manage *S. exigua*. Insecticides with active ingredients of chlorfenapyr, methomyl, chlorpyrifos, and emamectin benzoate are applied every 2 d until harvest; however, 63% of the farmers had poor knowledge regarding insecticide resistances and their risks (Aldini et al., 2020). The continuous use of insecticides with similar active ingredients is associated with risks in creating insecticide-resistant populations. For example, *S. exigua* populations from Brebes and Nganjuk showed high resistance against chlorfenapyr and methomyl (Aldini et al, 2021). Furthermore, Rabelo et al. (2022) found that there was no decrease in bifenthrin resistance for at least 3 yr, even when the insecticide exposure was suspended. Insecticide resistance is exacerbated by its ability to be passed to offspring. Therefore, alternative management strategies are required.

Sex pheromones are natural insect behavior regulators that can serve as suitable chemical agents in sustainable agriculture. They have advantages over hazardous chemicals because they reduce the number and reproduction rate of male adults and do not adversely affect the natural enemies of the insects (Witzgall et al., 2010). In the last two decades, studies have mainly focused on the identification of new sex pheromones, characterization of sex pheromone perception mechanisms and the integration of these new advances in pheromone research to integrated pest management (IPM) programs. Mating disruption (MD) is probably the most successful semio-chemical-based technique in IPM (Stelinski et al., 2014; Rizvi et al., 2021). MD has been applied in many countries. For example, in 1981, it was implemented in more than 40,000 ha of cotton fields in California and Arizona in the USA to manage pink bollworm (*Pectinophora gossypiella*), resulting in a damage reduction of 5% in MD-treated fields compared with 30% in untreated fields (Carde and Minks, 1995). Another pest that has been successfully managed using this technology is *Cydia molesta* that damages peach fields in China, other countries in Asia, New Zealand and Australia (Carde and Minks, 1995). According to Kusumawati et al. (2022), the most effective technique to capture *S. exigua* is trapping them with sex pheromones.

Similar to other managing technologies, such as insecticides, biological control agents, or resistant crop varieties, MD technologies should be managed correctly to extend their effectiveness by combining them with other management strategies. In addition, MD has been reported to be effective against low or moderate populations (Lestari et al., 2020). The current study aimed to determine the effectiveness of MD at different dosages in several areas. In addition to its ability to manage susceptible *S. exigua*, this technology was expected to be effective against other insecticide-resistant populations. The definition of effectiveness in this study was that the synthetic sex pheromones could disrupt male-female communication among *S. exigua*, as indicated by fewer moths being captured in the treatment plots compared to the control plots.

## Materials and Methods

### *Field experiment*

This study was carried out in the three provinces known as shallot production centers: Bantul, Nganjuk, and Kulon Progo. The study used Pheromone EXI RB (Z-9-tetra decanol: 10 μg/dispenser; Z-E-9-12-tetra decadienyl acetate: 90 μg/dispenser) produced by CV. Nusagri, Indonesia. Several studies revealed that the best practice is to uniformly distribute pheromone dispensers in the crop field at rates of 200/ha, 300/ha and 500/ha (Mitchell and Mayer, 2001; Benelli et al., 2019). Based on this, the study applied dispensers at rates of 100/ha, 200/ha, 300/ha and 500/ha. The treatment at each location consisted of a pheromone dispenser and a pheromone trap. Pheromone traps simulate the sex pheromones produced by female insects to attract male insects, with the pheromone dispensers acting as mating disrupters. The following research procedures were carried out at each location.

## *Bantul*

### *Experimental design*

The research design was a completely randomized design (CRD) consisting of two treatments and three replications in three different fields. In each selected field, two treatments were established: the pheromone (500 dispensers/ha) and the control—both plots contained 3 ha of shallot plants. The control plot was 100–200 m from the edge of the treatment.

Pheromone traps, consisting of an adhesive dispenser and a shield, the pheromone dispenser was installed 10 d after setting the pheromone Traps. Five traps were installed in the pheromone treatment plot—one at the intersection of the diagonal lines and two each on the diagonal line. In the control treatment plot, only one pheromone trap was installed. All traps were set at shallot plant height and the pheromone dispenser was replaced every 2 wk.

### *Observations*

The number of moths captured in the pheromone traps in the treatment and control plots was observed every 3 d from the time the traps were placed until harvest. The moths captured were taken from traps to ensure the data for the following observation were precise.

### *Data analysis*

A t-test was carried out on the number of moths captured in the treatment and control plots before and after the installation of the pheromone dispenser, with a significant difference level set at the 5% level.

## *Nganjuk*

### *Experimental design*

The experiment used a randomized complete block design with three treatments, each replicated three times. The treatments were different dosages of sex pheromones represented by different numbers of dispensers (100/ha, 200/ha or 300/ha) in the shallot plantation. Each treatment size was 1 ha and treatments were separated by a minimum of 50 m. Each block was separated by a distance exceeding 100 m. The distance between dispensers differed among the three treatments depending on the dosages and the traps were placed systematically. In each plot, five traps were placed on each of the outer borders (north, south, west and east), and 30 traps were placed in the middle of the plot, spread in three rows (10 traps/row). The traps and dispensers were placed 7 d before planting and replaced with new ones after 1 mth of exposure in the field. During the whole season, only one replacement was used because the population number toward the end of the season was very low.

### *Observations*

In each plot, the five traps on each outer border were observed weekly by collecting and counting the number of males captured per trap. In addition, the 30 traps were observed from the middle of the plot spread in the three rows (10 traps/row). Observation of the border and middle plots was performed on the same day with a weekly interval. The first observation was made 1 d before planting started, with the next observation being conducted at 7 dap. The following observations were conducted weekly until harvest.

### *Data analysis*

The number of males captured in the border traps was compared with that from the middle plots to evaluate the effectiveness of the MD technology. Qualitative analysis was performed, and analysis of variance and a least significant difference test were adopted to determine the significant differences among the treatments at $p < 0.05$.

## *Kulon Progo*

### *Experimental design*

The studies in Kulon Progo were conducted twice: when the *S. exigua* population was low and high. The research design was a CRD consisting of two treatments, namely, 100 dispensers/ha and the control. The shallot planting area in each treatment was 5 ha, 100 m apart. The first field was used for the MD treatment; the second was the control (without MD). In the treatment plot, the synthetic pheromone for *S. exigua* was applied evenly at a density of 100 dispensers/ha. The pheromone dispenser was installed on the same day as planting. Ten pheromone traps were installed in the treatment and control plot to determine the effect of MD on the attractiveness of male moths to female moths. No pheromone replacement was performed for the MD or pheromone traps.

### *Observations*

The number of male moths captured in the traps set in the communication disturbance area (treatment plots) and in the control plots was recorded every week for 2 mth.

### *Data analysis*

Data on the *S. exigua* male moths captured in the pheromone and control plots were analyzed using a t test at the 95% confidence level.

## Results and Discussion

### *S. exigua imagoes captured in Bantul*

Installing the pheromone traps at 500 dispensers/ha in Bantul effectively disrupted the male orientation to locate females, resulting in a lower number of imagoes captured in the treated plots compared to the control (Fig. 1). The average number of moths captured before pheromone application was not significantly different between the treated and control plots. In contrast, the number of imagoes captured after pheromone application significantly differed between the treatment and control plots. The lack of a significant difference between the treatment and control plots before application indicated that the plot used for pheromone application had the same conditions as the control plot as the initial populations tended to be the same. The average of moths in the control plot increased from 3.00 moths/trap/d to 4.12 moths/trap/d, whereas in the treatment plots, moth captured decreased from 2.49 moths/trap/d to 0.03 moths/trap/d.

### *S. exigua imagoes captured in Nganjuk*

In Nganjuk, a study using a low dose of 500 dispensers/ha was conducted to observe its effectiveness on *S. exigua*. The results for Nganjuk also showed the effectiveness of managing *S. exigua* using all three dosages tested in this study (Fig. 2). Before planting, the numbers of males captured in traps at all three dosages were not significantly different between the perimeters and middles of the experimental plots. However, after planting, significant differences in the average moth captured were only found in the middles of the experimental plots. The numbers of male imagoes captured in the middles of the plots were significantly lower than those captured in the perimeter plots. The average numbers of moths captured in the middle areas of the treated plots before planting using 100 dispensers/ha, 200 dispensers/ha and 300 dispensers/ha were 0.07 moths/trap/d, 0.06 moths/trap/d and 0.03 moths/trap/d, respectively. After planting, the average numbers of moths captured were 0.19 moths/trap/d, 0.10 moths/trap/d and 0.07 moths/trap/d, respectively.

### *S. exigua imagoes captured in Kulon Progo*

The research in Kulon Progo confirmed the results in Nganjuk, that is, using 100 dispensers/ha of pheromones disrupted communication among *S. exigua.* In Kulon Progo, during low populations there were significantly different numbers of moth captured between the plots treated with 100 dispensers/ha and the control plots. In the treatment plots, the number of male imagoes captured was 0.33 moths/trap/d, which was significantly lower than for the control plot at 8.67 moths/trap/d. During high populations, no significant differences in the number of

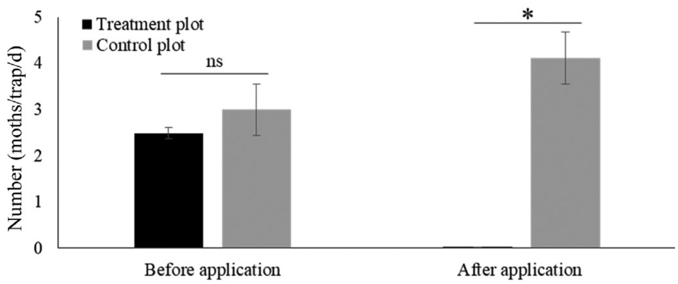


**Fig. 1** Numbers of *Spodoptera exigua* moths captured in Bantul before application and after application, where * = significantly ($p < 0.05$) different; ns = non-significantly ($p \geq 0.05$) different; Columns represent mean and error bars indicate ± SD.

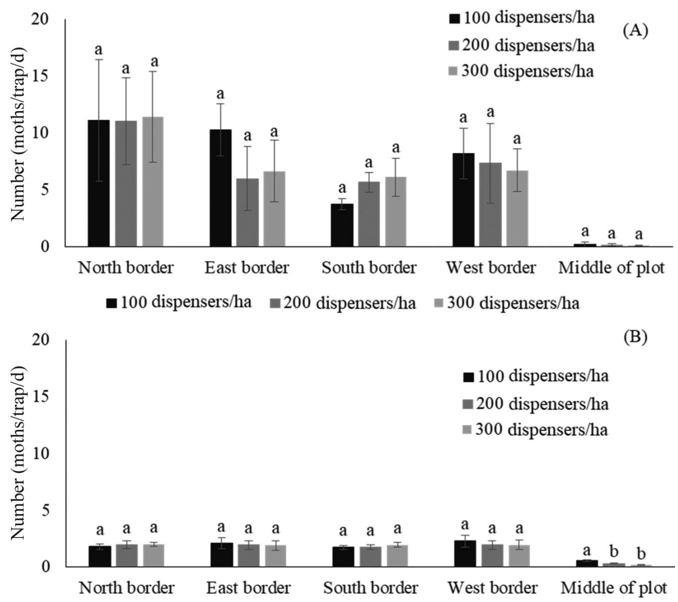


**Fig. 2** Numbers of *Spodoptera exigua* moths captured in Nganjuk: (A) before shallot planting; (B) after shallot planting, where (B), where same lowercase letter above columns among treatments indicates no significant ($p \geq 0.05$) difference based on least significant differences, and error bars indicate ± SD.

captured moths were found between the treated and untreated plots (Fig. 3). The number of captured moths was high and corresponded to high damage intensity until harvest.

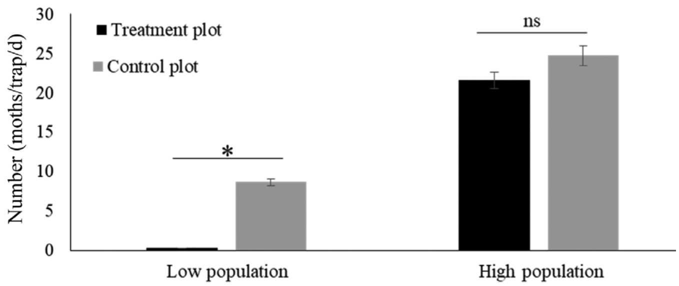


**Fig. 3** Numbers of *Spodoptera exigua* moths captured in Kulon Progo low and high populations, where * = significant ($p < 0.05$) difference, and ns = non-significant ($p \geq 0.05$) difference, columns represent mean and error bars indicate ± SD.

Insect sex pheromones can be used to manage pests directly or indirectly through their use in monitoring insect pests, as a mass trapping tool, such as in MD, or in combination with insecticides to attract pests that are then killed by the insecticide (Haynes et al., 1984; Miller et al., 1990). The application of sex pheromones in shallot production may reduce the need for insecticide application. *S. exigua* management using sex pheromone has been reported to be an efficient, cheap and environmental-friendly method to increase farmers' income in Cirebon to IRP 16,300,000/ha (USD 1042.65) (Haryati and Nurawan, 2009). The results in Bantul showed that the pheromone trap installation using 500 dispensers/ha disrupted the males from locating the females. Later results in Nganjuk and Kulon Progo also showed the effectiveness of using sex pheromones. Experiments in Bantul showed that disrupting male-female communication was successful because the number of male-female encounters in the treatment plots was reduced. Hence, the *S. exigua* females were not fertilized and the eggs did not hatch. In Nganjuk, the installations of 100 dispensers/ha, 200 dispensers/ha and 300 dispensers/ha had similar effectiveness in managing *S. exigua*. The dosage of 100 dispensers/ha had the same effect as 500 dispensers/ha for disrupting male-female communication among *S. exigua* for low/moderate population conditions. The experiments in Nganjuk also showed that the numbers of male imagoes captured in the middles of the plots were lower than those captured on the perimeters. For some observation periods, no male imagoes were captured. This finding showed that installing the pheromone traps on the perimeters restricted *S. exigua* from entering the treatment area. The decrease in the numbers captured before and after the treatments indicated that installation before planting could be an effective control measure against *S. exigua*.

The effectiveness using 100 dispensers/ha to manage *S. exigua* was strengthened by the results in Kulon Progo. However, the effectiveness of disrupting male-female communication decreased when the moth population in the field was high. When the population was low, the number of captured males was lower in the treated plots than in the control. The low number of male moths captured in all traps in all locations implied that MD was effective. These results were consistent with those reported by Mansour et al. (2017), who showed the total number of male *Planococcus ficus* captured in their nontreated MD plots was eightfold higher than for the treated plots. The inability of male *P. ficus* to locate the pheromone trap indicated that they could not locate the females, with MD later reducing the offspring, resulting in reduced damage on the crops (Suckling et al., 2014). No mating between males and females resulted in the eggs oviposited by females being sterile. The moths captured in Kulon Progo during high moth populations were not able to prevent severe damage. This finding was consistent with those from Borchert and Walgenbach (2000), who showed that the strategy of communication disruption for tufted apple bud moths (*Platynota idaeusalis*) was not effective at high populations. However, MD was effective at low populations. Felland et al. (1995) also demonstrated that tufted apple bud moths at high populations caused higher damaged in plots treated using MD compared to those treated with insecticides. Using pheromones to disrupt communication is not recommended for high pest populations, indicating that this strategy should be combined with other approaches.

The successful indicators of pheromones as communication disruptors should not be solely based on the number of captured males but also on a decrease in crop damage intensity, a decrease in insecticide residue and an increase in pest parasitization. Low captured in MD plots were a good measure of the effectiveness of communication disruption (Ferracini et al., 2021). MD is a highly selective management technique with low effects on nontarget organisms, including natural enemies of the target pests. Nusyirwan (2013) demonstrated that no larvae or eggs were parasitized due to high and continuous insecticide application. Therefore, further research should evaluate the effect of MD on pesticide residue and the increase in *S. exigua parasitization* in shallot productions. Thus, specific investigations regarding background population density, dispersal and mating/oviposition behavior are essential for a viable management strategy. In addition, the cost-efficiency of using MD technology as pest control must be evaluated.

The installation of pheromone traps at 100 dispensers/ha, 200 dispensers/ha, 300 dispensers/ha and 500 dispensers/ha disrupted male-female communication among *S. exigua* in low populations. The pheromone trap installation of 100 dispensers/ha could be a good option for farmers because it has the lowest materials cost. Pheromone placement on the perimeters of fields must be considered because it might hinder *S. exigua* from entering the field. In addition, the use of pheromones before planting should be considered as a control technique. MD can be combined with other management technologies for implementation in Indonesia.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

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