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Research

Insecticide Resistance and Resistance Management

Insecticide Resistance in *Spodoptera exigua* (Lepidoptera: Noctuidae) Populations in Shallot Areas of Java, Indonesia

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Abstract

The beet armyworm, *Spodoptera exigua* (Hübner), is a major insect pest in shallot in Java, Indonesia. To control this insect, farmers rely on the use of a narrow spectrum of insecticides leading to resistance development. The objective of this study was to determine the level of resistance of *S. exigua* populations from different areas of Java to the most widely used insecticides, chlorfenapyr, methomyl, and emamectin benzoate, as well as to cyantraniliprole which was recently introduced in Indonesia. *Spodoptera exigua* populations were collected from three major shallot production areas in Java, the Districts of Brebes, Nganjuk, and Bantul. Based on the LC_{50} values, resistance ratios of *S. exigua* populations compared to the most susceptible population from the sub-district Pundong in Bantul varied from very low to very high: 1.1- to 113.8-fold for chlorfenapyr, 16.4- to 223.6-fold for methomyl, and 1.5- to 51.7-fold for emamectin benzoate. *Spodoptera exigua* populations from the same location were more susceptible to cyantraniliprole, with a resistance ratio of 4.0- to 12.1-fold. These findings indicate that the field populations of *S. exigua* collected from major shallot areas in Java were resistant to chlorfenapyr and methomyl and less resistant to emamectin benzoate, whereas they were still susceptible to cyantraniliprole. The populations from Brebes and Nganjuk were more resistant to chlorfenapyr, methomyl, and emamectin benzoate than those collected from Bantul. To prevent the further increase of resistant of *S. exigua* populations, IPM principles need to be applied including the alternate use of insecticides with different modes of action.

Keywords: chlorfenapyr, cyantraniliprole, emamectin benzoate, methomyl, *Spodoptera exigua*

Throughout Indonesia, the beet armyworm, *Spodoptera exigua* (Hübner), is a major insect pest in shallot, *Allium cepa* L. group aggregatum, causing a yield loss ranging from 57 to 100% if the pest is not controlled properly (Ministry of Agriculture 2003, CABI 2018). To manage the populations of *S. exigua*, farmers apply insecticides throughout the growing season generally based on regular intervals (calendar spraying with 1–3 d interval). Commonly, farmers mix different insecticides in one spray solution and apply this cocktail of insecticides in rates exceeding the product recommendations (Moekasan and Basuki 2007, De Putter et al. 2017, Aldini et al. 2020).

One of the most common risks of injudicious insecticide use is resistance development of the target insect. Various studies showed that field populations of *S. exigua* have developed resistance to conventional (Ahmad and Arif 2010, Ishtiaq et al. 2012, Wang et al. 2018) as well as relatively new insecticides (Ishtiaq et al. 2012, Che et al. 2013, Ishtiaq et al. 2014, Su and Sun 2014, Ahmad et al. 2018, Saeed et al. 2019). In Indonesia, field populations of *S. exigua* also have developed resistance to a range of insecticides with different mode of actions (MoA), such as spinosad, chlorpyrifos, triazophos, beta-cyfluthrin, cyromazine, carbosulfan, thiodicarb, abamectin (Moekasan 1998, Moekasan and Basuki

2007), and to a relatively new ecdysone agonist methoxyfenozide (Wibisono et al. 2007). These results provide evidence that insecticides with unique MoA are not exempt from resistance development unless properly used.

The number of registered insecticide formulations in Indonesia to control *S. exigua* continuously increases from 187 trade names in 2013 to 267 trade names in 2018 (Ministry of Agriculture 2013, 2014, 2016, 2018). Currently, the four most commonly active ingredients used by shallot farmers in Java are chlorfenapyr, methomyl, chlorpyrifos, and emamectin benzoate which are available in 29, 27, 27, and 13 different commercial formulations or trade names, respectively (Aldini et al. 2020). The prolonged use of the same active ingredient (AI) independent of the used commercial formulation will increase the risk of resistance development in *S. exigua*. Alternated use of insecticides with different MoA is one way to prevent or delay the development of resistance in target insects.

Assessing periodically resistance levels of target insects is essential for resistance management and to control insect populations properly. The objective of this study was to determine the level of resistance of the *S. exigua* populations from different areas of Java to the three most commonly used insecticides, chlorfenapyr, methomyl, and emamectin benzoate, and to cyantraniliprole, which was a relatively new insecticide introduced in Indonesia in 2018. Methomyl was registered in 1987 followed by chlorfenapyr in 1999 and emamectin benzoate in 2001. Our results showed that populations of *S. exigua* collected in 2018 had built varying resistance levels to these three insecticides. Therefore, we continued the study in 2019 by determining resistance levels of *S. exigua* populations for cyantraniliprole to assess whether this insecticide can be an alternative for controlling *S. exigua* populations that are resistant to chlorfenapyr, methomyl, or emamectin benzoate.

Materials and Methods

Insect Collections

Between August and October 2018, *S. exigua* larvae were collected from main shallot production areas in three districts, i.e., Brebes in Central Java Province, Nganjuk in East Java Province, and Bantul in The Special Province of Yogyakarta (Fig. 1). In each district, three or four populations were collected from different sub-districts. In each sub-district, 300–350 larvae were collected from various shallot plots.

Between April and May 2019, fresh *S. exigua* populations were collected from shallot fields in the sub-district Pundong in Bantul (April 6), Larangan in the District of Brebes (May 11), and Wilangan in Nganjuk (May 18; Fig. 1). Differences in the time of collection were due to different planting times of shallot in the sub-districts. For each population, 350 *S. exigua* larvae were collected from different fields within one sub-district.

Mass Rearing

Mass rearing of the larvae collected in 2018 and 2019 took place in the laboratory in the Department of Plant Protection, Faculty of Agriculture, Universitas Gadjah Mada. Larvae were reared using standard procedures in plastic Petri dishes with a circular

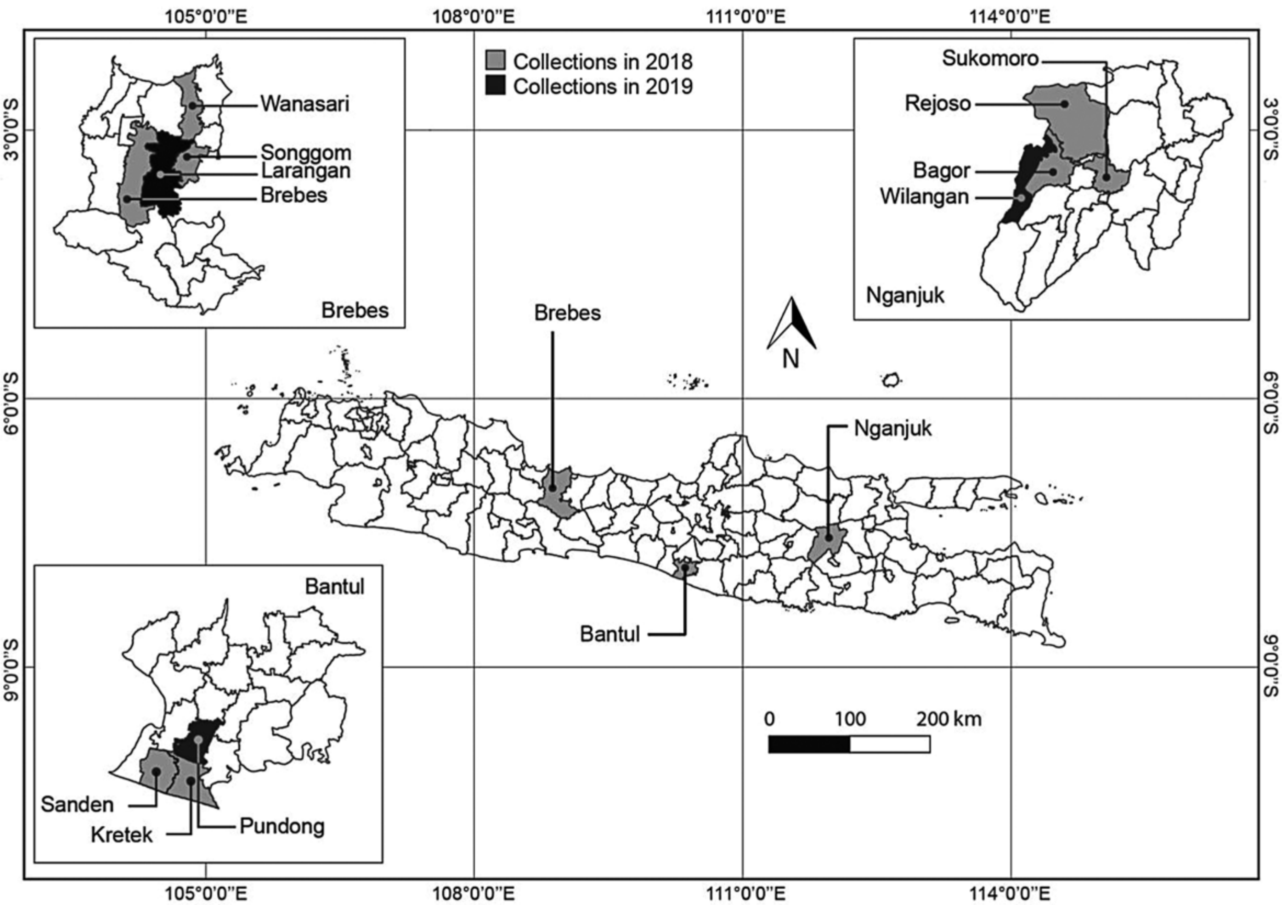

Fig. 1. Three major shallot production areas and sub-districts in Java, Indonesia, used to collect fresh *Spodoptera exigua* populations in 2018 and 2019.

nylon screen window on top for ventilation (Greenberg et al. 2001). Larvae were fed with fresh shallot leaves, whereas moths reared from the larvae were fed on 10% honey solution in cages for oviposition. The offsprings (F_1 generation) were used in the bioassays.

Insecticides

Insecticides used were chlorfenapyr (Fixus; 360 g active ingredient [AI] liter^{-1}; PT. Sentana Adidaya Pratama, Medan, Indonesia) classified in the MoA group 13; methomyl (Lannate; 400 g [AI] liter^{-1}; PT. DuPont Agricultural Products, Jakarta, Indonesia) classified in the MoA group 1A; emamectin benzoate (Abenz; 22 g [AI] liter^{-1}; PT. Advanisa Indotani, Tangerang, Indonesia) classified in the MoA group 6; and cyantraniliprole (Preza 100 g [AI] liter^{-1}; PT. DuPont Agricultural Products, Jakarta, Indonesia) classified in the MoA group 28 (Sparks and Nauen 2015).

Bioassays

All bioassays were conducted using leaf dipping against newly hatched larvae (<24 hour) of the F_1 generation. Preliminary experiments using the 2018 collections for chlorfenapyr, methomyl, and emamectin benzoate and the 2019 collections for cyantraniliprole were carried out to determine the working concentrations of each insecticide that give larval mortality ranging from 2 to 98% after 96 h exposure. Chlorfenapyr concentrations used in this study varied from 5.4×10^{-4} to 5.4×10^{2} mg (AI) liter^{-1}; for methomyl from 4.0×10^{-4} to 4.0×10^{2} mg (AI) liter^{-1}; and for emamectin benzoate from 2.2×10^{-5} to 22 mg (AI) liter^{-1}, whereas for cyantraniliprole concentrations varied from 16.7×10^{-5} to 16.7×10^{-1} mg (AI) liter^{-1}. The highest concentration used in the bioassay for the first three insecticides was the respective recommendation rate as specified on the product label, whereas the highest concentration used for cyantraniliprole was 100 times lower than its recommended rate (167 mg [AI] liter^{-1}). Tap water was used as a control and for diluting the tested insecticides. Pieces of 5-cm long shallot leaves were dipped into a solution of the prepared concentration ranges for 10 s and air dried for 30 min. The pieces of shallot leaves were then placed into test bottles of 10 cm of height and 5 cm diameter. Per insecticide five test bottles (five replicates) were used per concentration level and 10 reared F_1 larvae were then placed in each test bottle. Mortality rate was examined 96 h after exposure.

Analysis

Probit analysis was performed to determine LC_{50} values of each insecticide against each population (Finney 1971) using JMP 13.2.1 statistical software (SAS Institute Inc., Cary, NC). Mortality data from five replicates were pooled for probit analysis because there were no differences among replicates. The control mortality in this study ranged between 0 and 10% and Abbott's formula was used for correction (Abbott 1925). Two populations were considered to differ significantly in their resistance to an insecticide if 95% confidence intervals of their LC_{50} values did not overlap. In addition, the resistance ratio (RR) between two populations was calculated by dividing the LC_{50} value of a population with the LC_{50} value of the most susceptible population as reference. The reference population had the lowest LC_{50}. The resistance ratios were classified into six classes (Ahmad and Gull 2017): no resistance (RR = 1), very low (RR = 2–10), low (RR = 11–20), moderate (RR = 21–50), high (RR = 51–100), and very high (RR > 100). The probit analyses results and RR are complementary approaches. The former allows us to identify populations that differ in lethal concentrations supported by statistic evidence (95% CI), whereas the latter provides insight into the variation among populations in resistance to a particular insecticide.

Results

Resistance to Chlorfenapyr, Methomyl, and Emamectin Benzoate

Resistance levels of *S. exigua* against chlorfenapyr varied among populations collected from shallot production areas across Java (Table 1). A very high-resistant population was observed in the sub-district of Larangan (RR = 113.8). High resistance levels were further observed in the populations from Wanasari and Wilangan (RR = 59.6 and 69.1, respectively). The Sukomoro population was moderately resistant (RR = 22.8), and low to very low resistance ratios were found in the populations from Rejoso, Brebes, Bagor, and Kretek. Based on the LC_{50} values, all eight populations collected from Brebes and Nganjuk showed significantly higher lethal concentrations than the populations collected from Bantul. The populations from Sanden and Pundong in Bantul showed the lowest resistance ratios and hence were the most susceptible field populations to chlorfenapyr (RR = 1.1 and 1.0, respectively). The LC_{50} values of the three *S. exigua* populations from Bantul were not significantly

Table 1. LC_{50} and resistant ratios (RR) of *Spodoptera exigua* F1 larvae reared from collected larvae from three shallot production areas in Java, Indonesia to chlorfenapyr

District	Sub-district	n	Slope (±SE)	LC_{50}[a] (95% CI; mg [AI] liter^{-1})	χ^2	RR[b]
Brebes	Larangan	350	0.17(±0.016)	38.520 (16.740–90.000)c	6.19	113.8
	Wanasari	400	0.15 (±0.017)	20.160 (8.424–50.400)c	4.87	59.6
	Brebes	400	0.16 (±0.014)	2.160 (0.900–5.040)b	3.11	6.4
	Songgom	300	0.14 (±0.014)	14.040 (5.256–37.980)c	2.50	41.5
Nganjuk	Wilangan	400	0.14 (±0.013)	23.400 (9.288–61.704)c	2.80	69.1
	Bagor	400	0.13 (±0.012)	3.352 (1.260–8.903)bc	3.90	9.9
	Sukomoro	400	0.16 (±0.014)	7.704 (3.348–18.000)bc	6,41	22.8
	Rejoso	400	0.15 (±0.013)	4.036 (1.620–10.080)bc	4,80	11.9
Bantul	Sanden	400	0.14(±0.013)	0.356 (0.122–0.0943)ab	4,29	1.1
	Kretek	400	0.17 (±0.014)	0.828 (0.353–1.836)ab	3,97	2.4
	Pundong	400	0.14 (±0.013)	0.338 (0.115–0.878)a	7,16	1.0

[a] LC_{50} values followed by the same letter are not significantly different based on nonoverlapping 95% Confidence Interval.
[b] RR (Resistance Ratio) = LC_{50} of the field-collected population: LC_{50} of the most susceptible population (Pundong).

Table 2. LC_{50} and resistant ratios (RR) of *Spodoptera exigua* F1 larvae reared from collected larvae from three shallot production areas in Java, Indonesia to methomyl

District	Sub-district	n	Slope (±SE)	LC_{50} [a] (95% CI; mg [AI] liter^{-1})	χ^2	RR[b]
–Brebes	Larangan	400	0.19 (±0.015)	7.440 (3.320–16.400)b	3.83	169.1
	Wanasari	400	0.16 (±0.016)	9.840 (4.240–23.600)b	6.09	223.6
	Brebes	350	0.20 (±0.016)	2.600 (1.200–5.480)ab	4.39	59.1
	Songgom	350	0.17 (±0.017)	2.920 (1.360–6.080)b	3.93	66.4
Nganjuk	Wilangan	400	0.14 (±0.012)	6.800 (2.680–18.064)b	2.17	154.5
	Bagor	400	0.17 (±0.014)	9.240 (4.080–21.600)b	4.47	210.0
	Sukomoro	400	0.16 (±0.013)	1.080 (0.440–2.520)ab	4.56	24.5
	Rejoso	400	0.14 (±0.013)	8.400 (3.240–21.312)b	2.57	190.9
Bantul	Sanden	400	0.14 (±0.013)	0.720 (0.264–1.868)ab	9.20	16.4
	Kretek	400	0.14 (±0.013)	0.760 (0.280–1.892)ab	8.14	17.3
	Pundong	400	0.20 (±0.018)	0.044 (0.200–0.960)a	2.12	1.0

[a] LC_{50} values followed by the same letter are not significantly different based on nonoverlapping 95% Confidence Interval.
[b] RR (Resistance Ratio) = LC_{50} of the field-collected population: LC_{50} of the most susceptible population (Pundong).

Table 3. LC_{50} and resistant ratios (RR) of *Spodoptera exigua* F1 larvae reared from collected larvae from three shallot production areas in Java, Indonesia to emamectin benzoate

District	Sub-district	n	Slope (±SE)	LC_{50} [a] (95% CI; mg [AI] liter^{-1})	χ^2	RR[b]
Brebes	Larangan	350	0.14 (±0.015)	0.009 (0.0033–0.0242)b	5.61	7.2
	Wanasari	350	0.18 (±0.016)	0.020 (0.0088–0.0440)bc	4.39	15.0
	Brebes	350	0.14 (±0.014)	0.068 (0.0242–0.1828)bc	4.57	51.7
	Songgom	350	0.17 (±0.015)	0.026 (0.0108–0.0616)bc	3.07	20.0
Nganjuk	Wilangan	350	0.14 (±0.014)	0.014 (0.0046–0.0370)bc	6.03	10.3
	Bagor	350	0.15 (±0.015)	0.042 (0.0167–0.1056)bc	2.70	31.7
	Sukomoro	350	0.19 (±0.017)	0.062 (0.0286–0.1320)c	9.92	46.7
	Rejoso	350	0.17 (±0.016)	0.014 (0.0055–0.0308)bc	6.42	10.3
Bantul	Sanden	350	0.19 (±0.018)	0.002 (0.0009–0.0046)ab	4.83	1.5
	Kretek	350	0.16 (±0.016)	0.009 (0.0035–0.0209)bc	4.08	6.7
	Pundong	350	0.21 (±0.020)	0.001 (0.0004–0.0029)a	4.67	1.0

[a] LC_{50} values followed by the same letter are not significantly different based on nonoverlapping 95% Confidence Interval.
[b] RR (Resistance Ratio) = LC_{50} of the field-collected population: LC_{50} of the most susceptible population (Pundong).

different. In general, the *S. exigua* populations from Bantul were more susceptible to chlorfenapyr compared to those from Brebes and Nganjuk.

The *S. exigua* population collected from Pundong was also the most susceptible to methomyl (Table 2). Methomyl RR of the other 10 populations ranged from 16.4 to 223.6, indicating resistance levels varying from low to very high. The populations collected from Larangan, Wanasari, Wilangan, Bagor, and Rejoso showed very high resistance ratios to methomyl, and the populations from Brebes and Songgom were highly resistant. Except for the Brebes population, the LC_{50} values of these populations were also significantly higher than the LC_{50} of the Pundong population. The Sukomoro population was moderately resistant, whereas populations from Sanden and Kretek showed low resistance. The LC_{50} values of these three populations did not significantly differ from the Pundong population. Different from chlorfenapyr, the three populations from Bantul showed a slightly wider range of RR to methomyl but their LC_{50} values were not significantly different. Similar to chlorfenapyr, Bantul populations were much more susceptible to methomyl than populations from Nganjuk and Brebes.

The resistance ratios of *S. exigua* populations to emamectin benzoate differed less than the RR of chlorfenapyr and methomyl (RR between 1.5 and 51.7; Table 3). The three populations from Bantul were more susceptible to emamectin benzoate (RR = 1.0–6.7) than those from Brebes (RR = 7.2–51.7) and Nganjuk (RR = 10.3–46.7). The LC_{50} of eight populations from Brebes and Nganjuk was significantly higher than the most susceptible population (Pundong). Unlike in chlorfenapyr and methomyl, the three populations from Bantul responded slightly different from emamectin benzoate. The population from Kretek had a higher LC_{50} than Pundong, whereas the LC_{50} values from Sanden and Pundong were similar. In general, the populations of *S. exigua* in Bantul had a lower level of resistance to chlorfenapyr, methomyl, and emamectin benzoate than those in Brebes and Nganjuk.

Resistance to Cyantraniliprole

The LC_{50} values of cyantraniliprole for the three *S. exigua* populations varied between 0.033 and 0.099 mg (AI) liter^{-1}. The population from Pundong was the most susceptible followed by Larangan and Wilangan (Table 4). All three populations are susceptible to cyantraniliprole because their LC_{50} was far below the field recommended rate of this insecticide (167 mg [AI] liter^{-1}). However, the population from Wilangan (Nganjuk) had a significantly higher LC_{50} than the population from Pundong (Bantul).

Discussion

Chlorfenapyr was registered for *S. exigua* in Indonesia in 1999 and since then it has been the most widely used active ingredient by shallot farmers. A recent survey showed that 100, 93.3, and

Table 4. LC_{50} and resistant ratios (RR) of *Spodoptera exigua* F1 larvae reared from collected larvae from three shallot production areas in Java, Indonesia to cyantraniliprole

District	Sub-district	N	Slope (±SE)	LC_{50}[a] (95% CI; mg [AI] liter^{-1})	χ^2	RR[b]
Brebes	Larangan	350	0.16 (±0.020)	0.033 (0.013–79.754)ab	4.27	4.0
Nganjuk	Wilangan	400	0.14 (±0.010)	0.099 (0.036–253.030)b	4.04	12.1
Bantul	Pundong	300	0.20 (±0.020)	0.008 (0.003–17.915)a	3.76	1.0

[a] LC_{50} values followed by the same letter are not significantly different based on nonoverlapping 95% Confidence Interval.
[b] RR (Resistance Ratio) = LC_{50} of the resistant field-collected population (Larangan and Wilangan): LC_{50} of the susceptible population (Pundong).

34.8% of the farmers in the districts of Brebes, Nganjuk, and Bantul, respectively, used this insecticide (Aldini et al. 2020). Most likely, the widespread use of chlorfenapyr has contributed to the high resistance ratios found in the populations collected from Brebes and Nganjuk (Table 1). Low levels of resistance (RR < 2) against chlorfenapyr were reported from China (Zhang et al. 2014). Furthermore, *S. exigua* populations in Pakistan showed very low to moderate resistance (RR = 2.2–32) in the period 1998–2017 (Ahmad et al. 2018). Differences in the resistance ratios and the rate of resistance development among geographically distinct populations may be due to differences in genetic, biological, ecological, and operational factors (Georghiou and Taylor 1976). Operational factors are more controllable than the first three factors. Shallot growers in the districts of Brebes and Nganjuk mostly apply insecticides with little variation in the modes of action and on a calendar base with short intervals (1–3 d; Aldini et al. 2020). In addition, farmers in these districts grow shallot two or three times per year in a monoculture system. Such practices lead to the strong selection of *S. exigua* populations toward the development of resistance to the used insecticides.

Similar to chlorfenapyr, resistance to methomyl varied widely with the very high resistant populations (RR > 100) found in the sub-districts of Larangan and Wanasari in the district of Brebes and Wilangan, Rejoso, and Bagor in the district of Nganjuk. Resistance ratios of the other four populations in these two districts were lower (RR = 24.5–59.1), but they were still more resistant than the three populations collected from Bantul (RR = 1.0–17.5). Resistance of *S. exigua* populations to methomyl was higher than that to chlorfenapyr, maybe because methomyl was the oldest insecticide in the assessment.

The resistance ratios to emamectin benzoate in all 11 collected populations were smaller than those to chlorfenapyr and methomyl, but the trend among populations was similar. Populations collected from Brebes and Nganjuk were more resistant than those from Bantul (Tables 1–3). Emamectin benzoate was registered for controlling *S. exigua* in 2001, much later than methomyl and chlorfenapyr (Ministry of Agriculture 2001) which may explain the differences in observed resistances. Differences among the populations collected within one district or between districts may also be due to variations in insecticide use by farmers. Farmers in Bantul less frequently apply insecticides, use proper dosage, mix less insecticides, and alternate more insecticide types with different modes of action than farmers from Brebes and Nganjuk (Aldini et al. 2020). Resistance to methomyl and emamectin benzoate has also been reported in *S. exigua* in Indonesia (Moekasan and Basuki 2007). The findings in our research suggest that resistance to these two insecticides still exists related to the continuous use of both insecticides (Aldini et al. 2020). Similar resistance problems with emamectin benzoate and chlorfenapyr have been reported in other countries, such as China and Pakistan (Ishtiaq et al. 2014, Ahmad et al. 2018, Ishtiaq and Saleem 2011, Li et al. 2005).

The *S. exigua* populations from Brebes and Nganjuk showed that high to very high resistance to chlorfenapyr (Wanasari, Wilangan, and Larangan; Table 1) was also highly resistant to methomyl (Table 2). However, resistance levels to emamectin benzoate were much lower (Table 3). Resistance mechanisms to chlorfenapyr in other insects have been related to the increase in enzyme activity, such as esterase, P450 mono-oxygenase, mix function oxidase, and glutathione s-transferase (Gunning and Moores 2002, Li et al. 2005, Leeuwen et al. 2005, Li et al. 2007). Esterase and mono-oxygenase were also responsible for resistance to pyrethorid and carbamates (Soderlund et al. 1983). Furthermore, resistance in *P. xylostella* to abamectin, with the same MoA as emamectin benzoate (Sparks and Nauen 2015), was due to increased activity of mix function oxidase and carboxylesterase, decreasing the penetration rate through the cuticle and GABA bonding sensitivity (Wu et al. 2002). The multienzymes involved in insecticide resistance can explain the existence of cross-resistance in one insect population, such as the *S. exigua* resistance to chlorfenapyr, methomyl, and emamectin benzoate reported in this study. Further studies to elucidate the resistance mechanism are necessary to provide foundation for resistance management.

One of the recommendations for reducing the rate of resistance development is applying the alternated use of insecticides with different MoA and degradation pathways during the cropping season (Morse 1986, Tabashnik 1990). However, a similar degrading enzyme may be responsible for resistance to two insecticides with different MoA. Cyantraniliprole is a novel active ingredient working as a ryanodine receptor modulator within muscles and causes continuous contraction and paralyze (Sparks and Nauen 2015). Currently, only few farmers in Brebes (10%) and Nganjuk (17%) use this insecticide to control *S. exigua* (Aldini et al. 2020). *Spodoptera exigua* populations from the sub-districts of Larangan and Wilangan showed that very high resistance levels to chlorfenapyr and methomyl and moderate resistance to emamectin benzoate showed very low to low resistance levels to cyantraniliprole. The *S. exigua* population from Pundong was the most susceptible to cyantraniliprole, and the Wilangan population had the highest LC_{50} suggesting that the Wilangan population has a greater variability that may lead to a faster development of resistance. Differences in resistance levels to cyantraniliprole may be attributed to the prior use of cyantraniliprole and chlorantraniliprole in Pundong, Larangan, and Wilangan (Aldini et al. 2020), and these two insecticides have a similar MoA (Sparks and Nauen 2015). Although the Wilangan population had higher LC_{50} than the populations from Larangan and Pundong, the LC_{50} of 0.099 mg [AI] liter^{-1} was much lower than its recommended rate (167 mg [AI] liter^{-1}). This suggests that this insecticide still provides an acceptable level of control if properly used. The latter is essential because resistance of *S. exigua* to this insecticide has already been reported in China with different RR ranging from low to very high (Wang et al. 2018, Zuo et al. 2019).

Due to the farmers' pest management practices (Aldini et al. 2020) and resistance development of *S. exigua* populations for various insecticides, continuous resistance monitoring of frequently used insecticides, including cyantraniliprole, is needed. Such information can be used to advise farmers and act as early warning in resistance management. Furthermore, the high resistance levels for much-used insecticides in Indonesia call for the implementation of Integrated Pest Management (IPM) practices including the conservation of biological control agents, hand picking, monitoring, and adult trapping using sex pheromone and light traps. Combination of such IPM control measures will prolong the efficacy of registered insecticides and minimize environmental and human health risks associated with the improper use of insecticides.

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