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Research Article
Detection of Glucose Aversion Behavior Development in German Cockroaches, *Blattella germanica* L. (Dictyoptera: Blattellidae) in Indonesia

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Abstract

Background and Objective: Glucose aversion in German cockroaches *Blattella germanica* L., which are exposed continuously to glucose-containing baits, is known as a rapid behavioral resistance phenomenon. This study was aimed to detect behavioral development of Glucose aversion in German cockroaches in Indonesia. **Materials and Methods:** Twenty one strains of German cockroaches collected from 12 provinces in Indonesia from the period of 2007-2011 were used in this study. Each of the collected strains was divided into 2 different groups, where the first one was subjected to three steps of selections, while the second one was unselected. The 1st step of selection was aimed to find individuals that responded negatively to glucose-containing agar. The selected individuals were then subjected to the next selection step i.e., exposure to glucose-containing agar and 0.03% fipronil. The 2nd step of selection was conducted in triplicates with 5 day intervals. The survivors of this step were then raised and designated as parental and filial-1 groups. The 3rd step of selection was exposures of the groups of parental, filial-1 and unselected to maxforce forte 0.05 gel. **Results:** The results showed that from 21 strains tested, there were 4 strains (JKT-a, JKT-b, BDG-b and PKU-b) to be potent to develop glucose aversion behavior. The highest tolerance to sugar-containing baits was shown by the JKT-b strain. **Conclusion:** This report resulted the first information on behavioral resistance mechanisms of German cockroaches to glucose in Indonesia that is important as a reference in planning German cockroaches control in Indonesia.

Key words: Bait, glucose, behavioral resistance, German cockroaches

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

German cockroaches, *Blattella germanica* Linnaeus (Dictyoptera: Blattellidae) are one of the most harmful pests and are known as the most important urban pest insects[1], because their presence might cause harm in many aspects of live including human health, aesthetics and economics. In Indonesia and all over the world, many ways to control German cockroaches have been attempted mostly using insecticides. Nonetheless, continuous and intensive use of insecticides would increase the resistance of cockroaches to various types of insecticides[2-4] that may influence the success of the control program.

The levels of resistance to insecticides of several strains German cockroaches from various parts of Indonesia have been reported to be very high. For example, the HHB-JKT strain of German cockroaches has been resistant to permethrin with a resistance ratio of 1013 times[3]. German cockroaches in the GFA-Jakarta strain have also been reported to be resistant to fipronil, which is the latest generation of insecticides to control cockroaches and is only available in bait packaging[5]. The resistance level of German cockroaches in the GFA-Jakarta strain against fipronil, which was applied topically was high, with a resistance ratio (RR50) of 45 times[3].

Considering the possible development of resistance and environmental pollution due to the use of spray insecticides, the control of German cockroaches with baiting techniques began to be carried out in the United States in the early 1980s. However, the use gel baits in Indonesia started in late 1990s. Until now, gel baits are still listed in the Indonesian Pesticide Commission, where there are several brands with imidacloprid, fipronil and thiamethoxam as active ingredients[6].

A bait is a mixture of insecticides with feed and phagostimulant. The insecticides commonly used in a bait are hydramethylnon, fipronil or imidacloprid, while the phagostimulant commonly used in a bait is sugar[7-9]. Some advantages of baits are their safety, effectiveness in low-dose active ingredients so that they are not harmful to humans and pets. Baits are easy to use, almost odorless and effective in most conditions. Furthermore, baits can also be applied in sensitive places, such as hospitals, restaurants, hotels, various modes of transportation and other places where spraying insecticides should be avoided[9,10]. Although baits are usually effective, some German cockroaches have developed unique feeding behaviors in response to the baits used, resulting failures in bait-based German-cockroach controls. The declining of bait performance is due to glucose aversion, a behavior resistance phenomenon, where glucose is a component of phagostimulants in a bait, although glucose is a universal metabolic fuel for insects[11-14]. The glucose aversion was first reported to have occurred in the United States in 1990, which included the areas of Florida, California, Puerto Rico and even reportedly occurred in South Korea[13]. Fructose, glucose, maltose and sucrose stimulate the feeding response in the Jwax strain. In contrast, these four sugars are avoided by the Cincy strain, while in the Dorie strain only maltose and sucrose stimulate the feeding response. The Cincy strain also produces smaller ootheca and fewer eggs than non-averse strains (Jwax and Dorie strains)[8,9]. In Malaysia, 12% of the 41 wild-type strains of German cockroaches were found to potentially develop the behavior of glucose aversion[15].

It is known that insects and other animals have the ability as a form of adaptation, to avoid poisonous foods[16,17]. Thus, the knowledge of behavioral resistance in German cockroaches is important in designing a bait-based German roach control strategy. The aim of this study was to investigate the potential development of glucose aversion behavior in 21 strains of German cockroaches in Indonesia.

MATERIALS AND METHODS

Location and time: This research was conducted in Laboratory of Entomology, School of Life Sciences and Technology, Institut Teknologi Bandung from June, 2015-March, 2017.

German cockroaches: Twenty-one strains of German cockroaches from 12 provinces in Indonesia were used in this study (Table 1). One standard insecticide susceptible strain of German cockroaches from Vector Control Research Unit (VCRU) the Universiti Sains Malaysia, reared in the Entomology Laboratory of School of Life Sciences and Technology-Institut Teknologi Bandung starting from 2007. The VCRU strain is a susceptible standard strain to insecticides that has never been exposed to insecticides. In general, cockroaches were reared using the method described by Noland *et al.*[18]. The laboratory rearing and experiments were conducted under the temperature of 23-30°C, humidity of 55-75% and a 12:12 photoperiod.

Materials used: The material used included the fipronil 89.6% (Min Tech) insecticide dissolved in Acetone Pro Analysis, Maxforce forte 0.05 gel with active ingredient 0.05% fipronil (PT Bayer), agar, cat food (Essential brand) and D (+) -glucosa anhydrous from Merck CAS-No. 50-99-7.

Laboratory experiment: Current study tested two groups of German cockroaches to represent each strain. Group I consisted of individuals that had previously been treated with

Table 1: Locations for taking cockroaches in field strains

No.	Strain name	Location	City	Collect time
1	ACH	Restaurant	Banda Aceh	February, 2010
2	MDN-a	Restaurant-1	Medan	February, 2010
3	MDN-b	Restaurant-2	Medan	February, 2010
4	MDN-c	Restaurant-3	Medan	February, 2010
5	PDG	Food court	Padang	February, 2010
6	PKU-a	Bakery-1	Pekanbaru	February, 2010
7	PKU-b	Bakery-2	Pekanbaru	February, 2010
8	JMB	Supermarket	Jambi	February, 2010
9	PLB-a	Restaurant-1	Palembang	February, 2010
10	PLB-b	Restaurant-2	Palembang	February, 2010
11	PLB-c	Restaurant	Palembang	February, 2010
12	LPG	Mall	Bandar Lampung	October, 2010
13	BKL	Restaurant	Bengkulu	February, 2010
14	KLT-a	Market	Berau	June, 2010
15	KLT-b	Hotel	Balikpapan	March, 2010
16	JKT-a	Restaurant	Jakarta Utara	June, 2007
17	JKT-b	Restaurant	Jakarta Barat	February, 2011
18	BDG-a	Food stalls	Bandung	July, 2009
19	BDG-b	Food court	Bandung	November, 2008
20	BDG-c	Hotel	Bandung	February, 2011
21	SBY	Restaurant	Surabaya	May, 2007

ACH: Aceh, MDN: Medan, PDG: Padang, PKU: Pekanbaru, JMB: Jambi, PLB: Palembang, BKL: Bengkulu, LPG: Lampung, KLT: Kalimantan, JKT: Jakarta, BDG: Bandung, SBY: Surabaya

a series of selection pressures with glucose-fipronil agar, whereas group II was consisting of individuals that had never been given any selection pressure with glucose-fipronil agar. Each strain of group I followed three steps of selections. Step I was a process using a choice method to select the individuals of each strain (Table 1) that chosen plain agar. These selections were conducted on 3rd instar nymphs, adult males and non-gravid females of each strain. All individuals were starved for 2×24 h prior to the selection processes. The first step of selection applied dual chamber test arena connected with a connector[19]. In order to minimize the cockroaches creeping out of the chamber, the top of the chamber was greased with oil and vaseline. Chamber 1 was designated as a feeding chamber with two agar packages. Agar package I containing 1 M glucose and glucose was absent in agar package II (control agar). Each of these packages was placed in the opposing corner of the chamber and a water bottle covered with cotton was place in the middle. Chamber 2 was designated as a resting chamber, which consisted of a shelter to allow the tested animals to hide and take rest. The cockroaches were placed in the chamber 2 and exposed for 2×24 h. The cockroaches that selected the control agar were taken from the chamber and used for further test.

On the second step of selection, individuals of each strain that had been selected on the first step were then exposed to agar containing 1 M glucose and 0.03% fipronil for 24 h using dual chamber test arena. In the chamber 1 there were agar with 1 M glucose and 0.03% fipronil, cat foods and water in a bottle plugged with cotton. After a 24 h exposure, the survivors of each strain were taken out from the chamber and reared for 5 days for further selection. The step 2 selection was conducted in triplicates with intervals of 5 days. The survivors of the step 2 selection were reared in different places. The gravid-female survivors were separated to allow them to produce filials (F1). Thus, there were two groups of survivors of the second-step selection i.e., parental (P) and filial-1 (F1). Both groups were reared further for step 3 selection.

The step 3 selection used Maxforce Forte 0.05 gel to treat all P and F1 of survivors groups and unselected group to determine glucose aversion behavior development. After being starved for 24 h, 60 individuals were chamber tested. The chamber had a shelter, water, 0.1 g maxforce gel and 3 g cat food. Exposure to Maxforce gel was performed for 24 h and the mortality rate was observed at the interval of 24 h within a 2 week period. This selection step was conducted in triplicates for each strain. The numbers of individuals of each strain died during treatment were recorded[15,20].

Statistical analysis: Lethal time (LT_{50}) was calculated using a probit analysis under POLO-PC software program[21]. Resistance Ratio 50 (RR_{50}) was calculated by comparing the LT_{50} value of each strain collected from the field and that of the LT_{50} susceptible strain (strain VCRU)[20] and grouped as follows[22]: Susceptible ($RR_{50} \leq 1$), low resistant ($1 < RR_{50} \leq 5$), middle resistance ($5 < RR_{50} \leq 10$) and highly resistance ($10 < RR_{50} \leq 50$).

Behavioral development of glucose aversion can be seen by comparing the Resistance Ratio 50 (RR_{50}) of unselected population and the selected one, when the resistance ratio 50 (RR_{50}) of selected population is >1 and/or larger than RR_{50} of unselected it might then be concluded if the animals are potent to develop glucose aversion[15].

RESULTS

The results showed that 4 out of 21 treated strains were potent to develop behavior of glucose aversion. These strains were Jakarta-a (JKT-a), Jakarta-b (JKT-b), Bandung-b (BDG-b) and Pekanbaru-b (PKU-b) (Table 2). Individuals within the group II (unselected group) were susceptible to Maxforce forte 0.05 gel, where the RR_{50} of this group was less than 1, except for the individuals within group II of JKT-b strain had low resistance level (RR_{50} = 1.04). Table 2 also showed that individuals within group I (had selection pressure with glucose-0.03% fipronil agar) each strain of the P group showed an RR_{50} value >1 and so they were considered to be potent to develop glucose aversion behavior. The highest RR_{50} value of this group was the JKT-b strain i.e., 2.96. A similar condition was noted from population I of the Filial-1 where the RR_{50} showed a gradual increment. The rest, non-detected 17 strains, also shown their behavioral on glucose aversion where both groups of parental (P) and filial-l (F1) showed an increase in RR_{50} value, but not to the unselected (Table 2).

The parental (P) group showed slope values varied from 0.81±0.05-3.21±0.41 when they were exposed to commercial baits containing glucose. The slope value of the VCRU strain however, was only 2.38±0.18 and the lower slope value (>2) was noted from parental group of JKT-a, BDG-a, BDG-b, BDG-c, MDN-a, PDG, PLB-b, PLB-c and BKL strains. A similar condition was also noted from the filial 1 (F1) group of BDG-b, MDN-b, PDG, PKU-a, PLB-b strains (>2) and unselected group JKT-a, KLT-b, ACH, MDN-b, MDN-c, PLB-a and PLB-c strains. These data indicated that the individuals of German cockroaches gave a homogenous response to maxforce forte 0.05 gel.

DISCUSSION

Glucose aversion in German cockroaches (*Blattella germanica* L.) is a heritable behavior from parent to their descendants, through the process of selection following exposures to insecticide and glucose-containing baits[13,14,23]. In a population, cockroaches that have the ability to detect and avoid their food that contains poisons will survive, while those that do not have such a character will be eliminated

Table 2: Susceptibility of field the German cockroaches from Indonesia to Maxforce forte gel bait with 0.05% fipronil

Name strain	N	LT_{50} (day)	Slope±SEM	x^2 (df)	RR_{50}
VCRU	180	0.79 (0.66-0.93)	2.38±0.18	24.59 (12)	-
ACH					
Unselected	180	0.35 (0.19-0.65)	2.39±1.24	5.49 (1)	0.44 (0.29-0.7)
Selected-P	180	0.58 (0.45-0.75)	1.88±0.10	6.14 (11)	0.73 (0.68-0.81)
Selected-F1	180	0.45 (0.32-0.63)	1.67±0.14	10.02 (9)	0.57 (0.49-0.68)
MDN-a					
Unselected	180	0.34 (0.20-0.59)	1.82±0.63	13.91 (3)	0.43 (0.30-0.63)
Selected-P	180	0.64 (0.50-0.82)	2.11±0.19	6.80 (6)	0.81 (0.76-0.88)
Selected-F1	180	0.50 (0.36-0.71)	1.82±0.29	15.72 (6)	0.63 (0.55-0.76)
MDN-b					
Unselected	180	0.28 (0.16-0.49)	2.28±0.16	0.65 (3)	0.35 (0.24-0.53)
Selected-P	180	0.59 (0.45-0.78)	2.53±0.58	6.54 (2)	0.75 (0.68-0.84)
Selected-F1	180	0.32 (0.18-0.55)	2.59±0.08	7.12 (2)	0.41 (0.27-0.59)
MDN-c					
Unselected	180	0.33 (0.18-0.59)	2.26±0.79	7.10 (2)	0.42 (0.27-0.63)
Selected-P	180	0.51 (0.37-0.71)	1.51±0.15	14.71 (10)	0.65 (0.56-0.76)
Selected-F1	180	0.39 (0.27-0.58)	1.77±0.13	4.11 (7)	0.49 (0.41-0.62)
PDG					
Unselected	180	0.17 (0.10-0.30)	1.67±0.14	9.98 (12)	0.22 (0.15-0.32)
Selected-P	180	0.34 (0.21-0.56)	2.18±0.40	4.39 (3)	0.43 (0.32-0.60)
Selected-F1	180	0.25 (0.12-0.51)	2.37±0.16	0.25 (2)	0.32 (0.18-0.55)
PKU-a					
Unselected	180	0.16 (0.09-0.30)	1.45±0.13	9.70 (12)	0.20 (0.03-0.14)
Selected-P	180	0.73 (0.58-0.92)	1.78±0.22	53.38 (12)	0.92 (0.88-0.99)
Selected-F1	180	0.35 (0.23-0.53)	2.16±0.13	1.59 (5)	0.44 (0.35-0.57)
PKU-b					
Unselected	180	0.35 (0.25-0.51)	1.73±0.08	4.90 (12)	0.44 (0.38-0.55)

Table 2: Continued

Name strain	N	LT_{50} (day)	Slope±SEM	x^2 (df)	RR_{50}
Selected-P	180	0.91 (0.75-1.09)	1.99±0.26	69.77 (12)	1.15 (1.14-1.17)
Selected-F1	180	0.86 (0.63-1.17)	1.06±0.06	5.63 (12)	1.09 (0.96-1.26)
JMB					
Unselected	180	0.08 (0.03-0.20)	1.40±0.16	10.07 (12)	0.10 (0.05-0.22)
Selected-P	180	0.29 (0.17-0.51)	1.78±0.31	8.77 (5)	0.37 (0.26-0.55)
Selected-F1	180	0.15 (0.05-0.48)	1.40±0.61	11.23 (3)	0.19 (0.08-0.52)
PLB-a					
Unselected	180	0.30 (0.16-0.55)	2.25±0.37	1.68 (2)	0.38 (0.24-0.59)
Selected-P	180	0.43 (0.30-0.61)	1.45±0.11	11.46 (12)	0.54 (0.32-0.66)
Selected-F1	180	0.40 (0.29-0.57)	1.69±0.15	13.00 (10)	0.51 (0.44-0.61)
PLB-b					
Unselected	180	0.17 (0.08-0.40)	1.09±0.28	26.83 (8)	0.22 (0.12-0.43)
Selected-P	180	0.60 (0.47-0.76)	2.04±0.13	7.96 (10)	0.76 (0.71-0.82)
Selected-F1	180	0.50 (0.37-0.68)	2.35±0.17	1.99 (4)	0.63 (0.56-0.72)
PLB-c					
Unselected	180	0.33 (0.17-0.62)	2.50±0.97	3.02 (1)	0.42 (0.26-0.67)
Selected-P	180	0.64 (0.50-0.82)	2.01±0.20	10.86 (7)	0.81 (0.76-0.88)
Selected-F1	180	0.63 (0.48-0.82)	1.78±0.17	12.18 (8)	0.80 (0.73-0.88)
LPG					
Unselected	180	0.13 (0.06-0.26)	1.39±0.14	10.99 (12)	0.17 (0.09-0.28)
Selected-P	180	0.20 (0.08-0.51)	1.83±0.50	3.02 (2)	0.25 (0.12-0.55)
Selected-F1	180	0.15 (0.06-0.36)	1.29±0.16	4.27 (6)	0.19 (0.09-0.39)
BKL					
Unselected	180	0.06 (0.02-0.19)	1.33±0.12	5.50 (12)	0.08 (0.03-0.20)
Selected-P	180	0.79 (0.66-0.95)	2.13±0.09	5.68 (12)	1.00 (1-1.02)
Selected-F1	180	0.31 (0.21-0.47)	1.63±0.09	5.66 (12)	0.39 (0.32-0.51)
KLT-a					
Unselected	180	0.20 (0.09-0.46)	1.84±0.28	1.96 (3)	0.25 (0.14-0.50)
Selected-P	180	0.64 (0.47-0.88)	1.34±0.18	26.82 (10)	0.81 (0.71-0.95)
Selected	180	0.53 (0.38-0.73)	1.33±0.11	14.22 (12)	0.67 (0.58-0.79)
KLT-b					
Unselected	180	0.25 (0.12-0.53)	2.17±0.53	2.92 (2)	0.32 (0.18-0.57)
Selected-P	180	0.50 (0.35-0.72)	1.42±0.23	32.98 (10)	0.64 (0.49-0.77)
Selected	180	0.39 (0.24-0.63)	1.19±0.26	44.73 (10)	0.49 (0.36-0.68)
JKT-a					
Unselected	180	0.70 (0.57-0.86)	2.79±0.44	7.46 (3)	0.89 (0.86-0.93)
Selected-P	180	0.93 (0.78-1.10)	2.05±0.20	41.96 (12)	1.18 (1.18-1.18)
Selected-F1	180	0.83 (0.64-1.06)	1.41±0.09	10.43 (12)	1.05 (0.97-1.14)
JKT-b					
Unselected	180	0.82 (0.58-1.16)	0.98±0.16	41.62 (12)	1.04 (0.88-1.25)
Selected-P	180	2.34 (2.07-2.65)	1.60±0.16	41.16 (12)	2.96 (2.85-3.14)
Selected-F1	180	0.84 (0.65-1.08)	1.39±0.16	37.32 (12)	1.06 (0.99-1.16)
BDG-a					
Unselected	180	0.68 (0.51-0.92)	1.90±0.81	31.58 (3)	0.86 (0.77-0.99)
Selected-P	180	0.71 (0.59-0.86)	3.21±0.41	2.82 (2)	0.90 (0.89-0.93)
Selected-F1	180	0.69 (0.52-0.92)	1.90±0.59	20.57 (3)	0.87 (0.79-0.99)
BDG-b					
Unselected	180	0.23 (0.11-0.49)	1.71±0.42	5.88 (3)	0.29 (0.17-0.53)
Selected-P	180	1.15 (1.00-1.33)	2.15±0.15	15.13 (10)	1.46 (1.43-1.52)
Selected-F1	180	1.02 (0.92-1.14)	3.61±0.47	8.59 (3)	1.29 (1.23-1.39)
BDG-c					
Unselected	180	0.31 (0.17-0.56)	0.89±0.03	1.01 (12)	0.39 (0.26-0.85)
Selected-P	180	0.67 (0.55-0.82)	2.58±0.09	1.38 (6)	0.85 (0.83-0.88)
Selected-F1	180	0.51 (0.36-0.71)	1.87±0.14	1.97 (4)	0.65 (0.55-0.76)
SBY					
Unselected	180	0.12 (0.05-0.30)	1.17±0.14	6.41 (8)	0.15 (0.08-0.32)
Selected-P	180	0.44 (0.25-0.75)	0.81±0.05	4.38 (12)	0.56 (0.38-0.81)
Selected-F1	180	0.42 (0.29-0.62)	1.33±0.06	3.92 (12)	0.53 (0.44-0.67)

VCRU: Vector control research unit, ACH: Aceh, MDN: Medan, PDG: Padang, PKU: Pekanbaru, JMB: Jambi, PLB: Palembang, BKL: Bengkulu, LPG: Lampung, KLT: Kalimantan, JKT: Jakarta, BDG: Bandung, SBY: Surabaya, Unselected: German cockroach did not select with 1 M glucose-0.03% fipronil agar, Selected-P: German cockroach selected with 1 M glucose-fipronil 0.03% agar in the parent group, Selected F1: German cockroach selected with 1 M glucose-0.03% fipronil agar in filial group, N: Number of German cockroaches used in each bioassay, LT_{50}: Lethal time 50, RR_{50}: Resistance ratio (LT_{50} of field strain/LT_{50} of susceptible strain) from the population. By this way, repeated exposures to poison-containing food from generation to generation will increase the frequency the genes that encode this character. In German cockroaches, a population that had the behavior of glucose aversion (GA) were reportedly to have increased the frequency of individuals that have better a sensillary gustatory function that underlies glucose avoidance behavior[12,24]. Insects generally have a gustatory sensory, which specifically functions to detected sweetness (sugar) and deterrent compounds. Gustatory sensillum provides information about nutrients and food sources that are dangerous[25]. The cockroaches have GNR1 as sugar detector and GRN2 as their receptor toward deterrent compounds. The individuals, which develop glucose aversion behavior following the expose of glucose, stimulated the GRN2 but suppressed the GRN1, the glucose was then detected as bitter compound where the cockroaches dislike it and ultimately these individuals avoided the presence of glucose. Glucose aversion is an adaptive behavior due to the plasticity of sensory system to adapt with a rapid environment change[11,23].

Of the 21 field cockroaches strains tested, four strains (14.05%) were detected potentially to develop a glucose aversion behavior. The four strains are JKT-a, JKT-b, BDG-b and PKU-b. The highest tolerance to Maxforce forte 0.05 gel is shown by the JKT-b strain. This can be seen from the RR_{50} values, which were greater than 1 in both the P and F1 groups (Table 2). It was also found that the RR_{50} values of the P and F1 groups of the selected population were higher than the RR_{50} values of the unselected population. However, the RR_{50} value of the F1 group was slightly lower than that of the RR group P. This is also the case in the strains that was indicated to potentially develop the behavior of glucose aversion as well as the strains that was not indicated to potentially develop the behavior of glucose aversion. Furthermore, the Lethal Time 50 (LT_{50}) of the F1 group was shorter than that of the P group (Table 2). The LT_{50} of the filial group was shorter than that of the parental group. This presumably occurred because the proportion of cockroaches carrying the glu/glu gene in the filial group was lower and the population consisted of heterozygous (glu/glu+) or wild type (glu+/glu+) individuals[15].

Individuals that were detected to develop glucose aversion behavior (glu/glu genotype) showed some weakness on their biological parameter. They consumed very much less amount of glucose-containing baits, so they lost their body weight, slower growth and development, slower reproductive organs maturation on both sexes and shorter life span than that of the homozygotic (glu+/glu+) wild type and of the heterozygotic individuals (glu/glu+)[24,26,27].

Furthermore, in a heterogeneous population, over a long period of time, under competitive conditions, the proportion of wild type (WT) German cockroaches will exceed the glucose averse (GA), when no glucose in their food. This may occurred because GA cockroaches have a lower survival rate and a longer developmental time and the tendency of breeding between cockroaches of the same genotype[23].

Glucose aversion is one of the phenomena of behavioral resistance. The mechanism of resistance of this behavior is one the survival strategies of German cockroaches. Avoiding deadly toxins is the result of a process of adaptation to the environmental pressure experienced by German cockroaches. For example, the majority of German cockroach strains in Indonesia were highly resistance to the pyrethroids (permethrin), the commonly used insecticide to control German cockroach[3]. The present findings, which showed that several strains of German cockroach were developing glucose aversion behavior is alarming in the cockroach control program. It is alarming because insecticides baits are considered the best available method for the management of cockroach in urban settings.

CONCLUSION

Current study found 4 strains of German cockroaches in Indonesia that potentially to develop glucose aversion behavior due to continuous selection pressure of exposures to glucose-containing baits. Therefore, to design a good cockroach control strategy and to prevent the development of resistance in the future, it is suggested that monitoring of behavioral resistance as well as insecticide resistance/ susceptibility need to be continued with more German cockroach strains across Indonesia.

SIGNIFICANCE STATEMENT

This study found that a thorough understanding about that glucose aversion behavior can be beneficial for bait development. It is expected that this study will help interested parties to uncover the critical areas of bait development as well can be used to gain a better understanding about the nature of bait aversion behavior.

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