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Spatial and time-dependent efficacy of commercial liquid and mat-type electric vaporizer insecticides against Asian tiger mosquito, *Aedes albopictus* (Diptera: Culicidae)

액체 및 매트 전자모기향의 흰줄숲모기에 대한 시공간적 살충활성 연구

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Abstract

Spatial and time-dependent efficacy of commercial liquid and mat-type electric vaporizer insecticides against Asian tiger mosquito, *Aedes albopictus* (Diptera: Culicidae)

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Since electric vaporizers including mat and liquid type insecticides continuously emit the active ingredients into the surrounding air, it is crucial to understand and properly monitor their deposition and spatial distribution in the treated areas. In the present study, the evaporation of seven commercial liquid and mat vaporizers in South Korea as well as their knock-down and insecticidal activity against the female adults of the Asian tiger mosquito, *Aedes albopictus*, were examined. Insecticidal products from three manufactures had differences in the type of heaters and concentration of active ingredients, and they tend to show steady evaporation in hourly and daily monitoring in mat and liquid vaporizers, respectively, but some of the liquid vaporizers failed to meet their designated end periods. In overall, mosquitoes locating at the upper position in a Peet-Grady chamber and a field-simulated room exhibited faster knock-down activity, indicating that the insecticides evaporated from the vaporizers tend to accumulate on the ceiling area. Although most of mat and liquid vaporizers showed < 60 min of average KT_{90} values when tested in the Peet-Grady chamber (1.8 × 1.8 × 1.8

m), they failed to show any knock-down and insecticidal activity in a field-mimicking situation ($6.8 \times 3.4 \times 2.7$ m) in 2 h of observation, and $72.8 \pm 11.7\%$ and $56.7 \pm 7.3\%$ knock-down activity in mat and liquid vaporizers, respectively, were recorded in 3 h of operation. The limited efficacy of electric vaporizers in a field-simulated setting may suggest the need for the establishment of more realistic and strict regulatory standards for the household insecticides.

Keyword: *Aedes albopictus*, Electric vaporizer, efficacy, test guidelines, insecticide, Peet-Grady chamber

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Introduction

Blood-feeding arthropods, especially mosquitoes, are of great concern in public health due to their disease-transmitting attributes while they feed on humans and other vertebrates. Malaria, transmitted by the mosquitoes of the genus *Anopheles*, is the most devastating parasitic disease, which results in approximately 430,000 deaths annually (Moxon et al. 2020). Moreover, since no human vaccines have been developed for some of the serious viral diseases, such as Zika virus in South America and Central America, and Rift Valley fever virus in Africa and the Middle East which are mainly transmitted by the genus *Aedes* (Gross et al. 2016, Linthicum et al. 2016, Faburay et al. 2017), preemptive controls of the disease vector are crucial for the prevention of mosquito-borne diseases.

Asian tiger mosquito, *Aedes albopictus* are one of the most important disease vectors worldwide. Although most of the habitats are in nature which are small, restricted, and shaded bodies of vegetation with water, its life cycle is also closely associated with human habitat, and it breeds in artificial structure with standing water, often waste tires or other trash sites. It is a daytime feeder and can be found in shady areas where it rests (Koehler and Castner. 1997). *Ae. albopictus* is native to East and Southeast Asia and is known as a vector of arboviruses; Zika, Dengue, Yellow fever, and Chikungunya virus in tropical and nontropical areas (Paupy et al. 2009, Aranda et al. 2006, Martin et al. 2010). Not only arboviruses, dog heartworms, *Dirofilaria immitis* is also spread through *Ae. Albopictus* (Cancrini et al. 2003).

Geographical spread of *Ae. albopictus* has mostly arisen during 1980 to 2000 (Lounibos, 2002). It has spread from its native range to at least 28 other countries around the globe, largely through the international trade in used tires (Reiter and Sprenger, 1987). Recently, the mosquito population and activity area have increased in Southern United States due to climate change (Rochlin et al. 2013). The previous studies showed that the higher the average temperature, the wider the mosquito's range of activity. Similarly, the average annual temperature in South Korea also has risen by the largest margin (1.4°C) in the last 30 years (Jeong et al. 2020). Therefore, *Ae. Albopictus*'s activity areas in South Korea can also be expanded as well.

In urban environments including public buildings and houses, pyrethroid insecticides are the most commonly selected active ingredients (Coleman et al. 2017). Especially in the household settings, frequently selected insecticide formulations for mosquito control include mosquito coils, aerosols, liquid vaporizers, and mat vaporizers (Yoon et al. 2020). Whereas an aerosol insecticide can achieve instant insecticidal activity as directly spray to the target pest with a pressurized propellant, mat and liquid vaporizers warm up an insecticide-impregnated mat or a wick, then release the active ingredients dissolved in organic solvents into the surrounding air to provide prolonged effect by volatilizing the insecticides slowly without any undesirable smoke, as occurring while burning mosquito coils (Matoba et al. 1994, Cassini et al. 2016).

The total household insecticides sales in South Korea reached 117.7 ± 4.1 USD million in average annually, and aerosol insecticides showed the greatest sales with 59.2 ± 1.7 USD million, followed by electric vaporizers with 38.6 ± 1.9 USD million per year (32.7 ± 0.6%) in retail markets. As shown in Table 1, between 2013 and 2018, market shares of aerosols and electric vaporizers have enormous sizes that is not comparable to mosquito coils or the other categories. The three companies have 93.7% of market share in household insecticides sales; Henkel HomeCare Korea, SC Johnson Korea, and Yuhan Corporation (Euromonitor International 2019). They produce products with different kinds of ingredients and various types of mats and liquid electric vaporizers.

Table 1. Korean commercial household insecticide market shares in 5 years

Category	Annual sales (million USD)					
	2013	**2014**	**2015**	**2016**	**2017**	**2018**
Aerosol	776	753	742	729	717	631
Electric vaporizer	566	509	476	446	436	402
Mosquito coil	86	87	89	88	86	65
Bait	137	133	129	125	120	113
Repellent	29	28	28	31	34	33
etc	8	8	7	3	-	-
Total	**1,602**	**1,518**	**1,471**	**1,422**	**1,393**	**1,244**

Owing to their rapid insecticidal action, pyrethroid insecticides including allethrin, prallethrin, transfluthrin, and metofluthrin are commonly selected as active ingredients for electric vaporizers and mosquito coils (Hemingway and Ranson 2000, Ogoma et al. 2012, Vesin et al. 2013, Chin et al. 2017, Sathantriphop et al. 2019). Since electric vaporizers continuously release the insecticides along with inert solvents into the surrounding air, it is vital to elucidate the evaporation of active ingredients and solvents, and to characterize the spatial distribution and their insecticidal activity because not only the insecticides but also other inert components constructing the formulation including isoparaffinic hydrocarbon solvents may impact the human health when inhaled (Mullin et al. 1990, Bowen 1998).

While these formulation products dominate the household pest control market and are frequently used in household environments, efforts to understand their efficacy and spatial distribution in the air are limited. Moreover, although several test guidelines are available for registration and regulation purposes, there are differences in evaluation methodologies that require the development of standardized assay guidelines (Ogoma et al. 2012). Hence, the present study aimed to investigate the evaporation profiles of commercial liquid and mat vaporizers in South Korea, and their spatial distribution as well as the toxic response of mosquitoes elicited by the insecticides to contribute to the development of more efficient disease-transmitting insect prevention tools.

Materials and Methods

1. Test insects

Eggs of *Ae. albopictus* were originally obtained from the Korean Centers for Disease Control and Prevention (KCDC) in 2018. The mosquito colony was maintained in an insectary at Seoul National University without exposure to any insecticides for more than 2 years under 27 ± 2°C, 70 ± 10% RH, and a 14:10 (L:D) h photoperiod. The larvae were reared on ground cattle fodder, and a 10% sugar solution was provided for the adults. A live mouse was provided as a blood-meal source, in which the method was approved by the Institutional Animal Care and Use Committee in the university (approval no.: SNU-190418-1-2, title: Providing rodents for blood-feeding mosquitoes to assess the effectiveness of insecticides against mosquitoes). Non-blood-fed female mosquitoes aged within two to five days of post-emergence were used for the insecticide efficacy test in the present study.

Figure 1. Mosquito rearing colonies at Seoul National University.

2. Test Products and Chemicals

Two types of commercial electric vaporizers, liquid and mat types, were purchased from retail stores. As shown in Table 2, test products had differences in the heaters and composition of active ingredients. Liquid vaporizer insecticides from three manufacturers had either prallethrin (1.00 to 1.33 %, w/w) or metofluthrin (0.46%, w/w) as their active ingredients, accompanied with three types of heating devices, i.e., plug-in, timer-attached plug-in, and corded heaters (Fig. 2). As for the heating time, Happyhome® liquid vaporizers recommended 12 h of usage per day, whereas the remaining products were for 10 h a day, with a guarantee of 45 days' effectiveness. Mat-type insecticides were intended to use then discard daily, with a guaranteed working time of 15 h in Happyhome® and Homemat® products, and 12 h in F-killer® per mat, respectively. Active ingredients for mat-type insecticides were allethrin (4%, w/w) for SC Johnson's F-killer® mat, or pralletrhin (1.5%, w/w) for the other two insecticides, respectively.

Standard chemicals of allethrin (d-cis/trans allethrin, CAS number: 584-79-2, 95.88%) and prallethrin (d,d-cis/trnas prallethrin, CAS number: 23031-36-9, 96.9%) were obtained from Sigma-Aldrich (St. Louis, MO, USA), and metofluthrin (CAS number: 240494-70-6, 98.5%) was purchased from ChemService, Inc. (West Chester, PA, USA).

Table 2. Commercial electric vaporizer products tested in the present study

Types	Product name	Manufacturer	Active ingredient	Composition (%, w/w)[a]	Device Type[b]	Intended use[c]	
						day	h/day
Liquid	F-killer® liquid	SC Johnson Korea	Prallethrin	1.00	Timer[d]	45	10
	Happyhome® liquid	Yuhan Corporation	Prallethrin	1.22	T/C/P[c]	45	12
	Homemat® liquid	Henkel HomeCare Korea	Prallethrin	1.33	T/C/P	45	10
	Homemat Home Solution®	Henkel HomeCare Korea	Metofluthrin	0.46	Timer	45	10
Mat	F-killer® mat	SC Johnson Korea	Allethrin	4.00	Corded	1	12
	Happyhome® mat	Yuhan Corporation	Prallethrin	1.50	Corded	1	15
	Homemat® mat	Henkel HomeCare Korea	Prallethrin	1.50	Corded	1	15

[a]Information of A.I. concentration was obtained from the product packages.

[b]Timer-attached plug-in / Corded / Plug-in.

[c]recommended by the manufactures.

[d]Timer-type device stops heating automatically after 10 or 12 h later, with a plug-in housing.

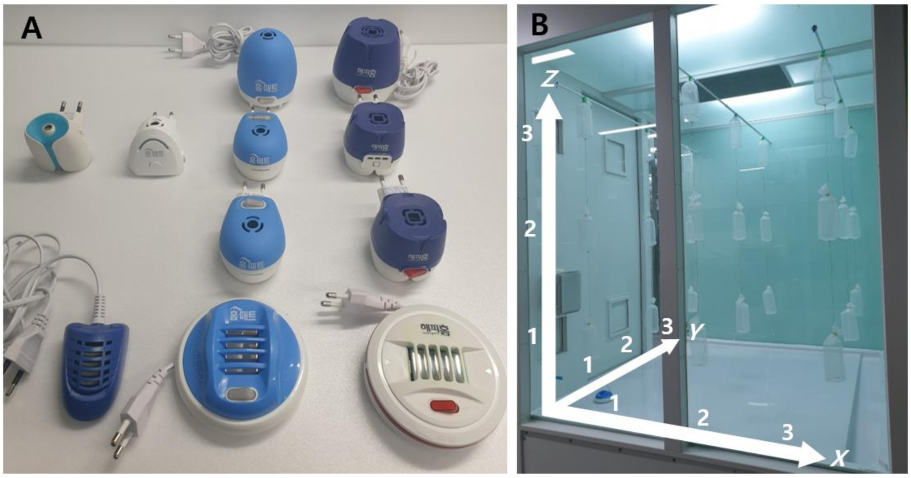

Figure 2. Heating devices tested in the present study and a schematic of the Peet-Grady chamber. (A) Heating devices for liquid vaporizers were either corded, timer-attached plug-in, or plug-in types, and all the mat vaporizers had corded types from three major manufacturers in South Korea (from top to bottom). (B) Twenty-seven nets were hung in the Peet-Grady chamber in a 3 × 3 × 3 plot and each net was labeled in a Cartesian coordinate system for a three-dimensional space in an xyz-axis scale, and coordinate (0,0,0) was set as the position of vaporizers.

3. Evaporation Speed, Temperature Measurement, and Sample Preparation

The evaporation speed of test products was examined in a test fume hood. For the liquid type insecticides, each product was inserted into its own designated heating device (plug-in, plug-in with a timer, or corded, Fig. 2), and operated for 10 or 12 h per day as following the instruction from the manufacturers. The weight changes were recorded every day up to 45 days, which was the guaranteed period for their efficacy. Unheated original product, 15, 30, and 45 cycle-ran products were subjected to the chemical analyses to examine the stability in the concentration of active ingredients. For the bioassay, 1 and 45 cycle-heated products were selected for the efficacy test against female adults of *Ae. albopictus*. As for the F-killer® liquid product, since the evaporation ended around 40 days, which was relatively earlier than the manufacture's instruction, 35 days-heated products, which showed 91.1 ± 0.7% of evaporation from the initial weight, were used for the bioassay and chemical analysis.

To examine the evaporation profile for the mat-type insecticides, 0, 3, 6, 9, 12, 15, and 18 h-heated samples of mats from three brands were prepared by using their own heating devices, and the residual amounts of allethrin or prallethrin were quantified via GC/FID (Gas chromatography and flame ionization detector) analysis. As for the bioassay, 0 and 15 h-operated samples from Happyhome® and Homemat®, and 0 and 12 h samples of F-killer® were prepared, which were the designated end-period according to the instructions of the products. All the evaporation was repeated 3 times using different heating devices.

Temperatures of heating devices were measured using a digital thermometer (DT-2, Termoproukt, Bielawa, Poland). Prior to measuring the temperature of each device, they were operated for 1 h to reach the maximum temperature with or without the insecticides. As for the liquid heaters, surface temperatures of the heating plates (Fig. 3A) and air temperatures of the discharge port (Fig. 3B) were measured, whereas for the mat vaporizers, the surface temperatures of heating plates and the underside of the mat products were recorded.

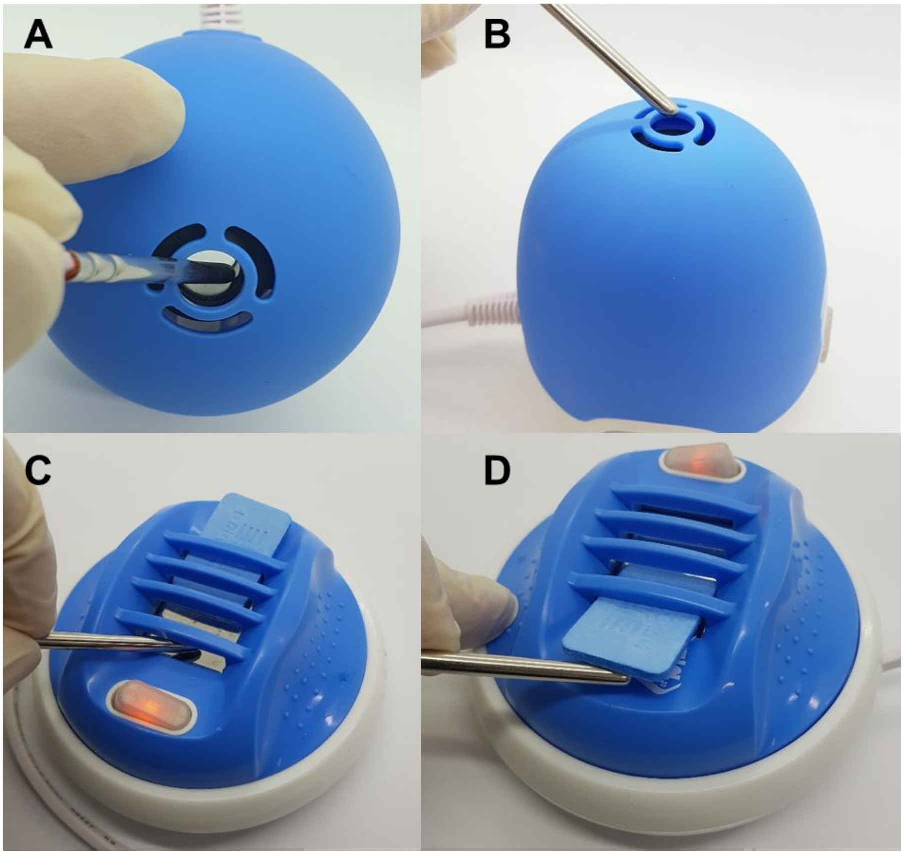

Figure. 3. Measuring temperatures of heating devices (A),(C) at the surface of the heating plate and (B) the air right above the discharging port. for the mat vaporizers, (D)the surface temperature of the heating plate as well as the underside of mats were measured. [JT1]

4. Quantitative analyses of active ingredient via GC/FID analyses

Prior to analyses, 0.5g of each sample was extracted in 10 mL of acetone (purity of 99.5%) for 1 h using a sonicator (5300EPS3, Daesong Lab Tech, Goyang, Gyeonggi, South Korea) then filtered using 0.45 μm membrane filters. Samples were analyzed by GC/FID in split mode (split ratio = 10:1) using a GC-2010 Plus system (Shimadzu Scientific, Kyoto, Japan). The injection volume was 1 μL and the oven was set 80°C for 1 min, increasing at 30°C/min to 230°C then held for 1 min, and increasing at 20°C/min to 320°C then held for 5.5 min. A DB-5 column (30 m × 0.25 mm i.d. × 0.25 μm) was used with helium as carrier gas at 1 mL/min of flow. For the quantification of active compounds, different concentrations of each standard chemicals (1 to 300 mg/L) were used to draw standard curves, and the coefficient of determination (R^2) values of allethrin, prallethrin, and metofluthrin were 0.9998, 0.9997, and 1.0000, respectively.

The concentration of active ingredients in the specific heating periods was calculated based on the equation;

$$\text{Concentration (\%) A.I.} = \frac{(C_1 - C_0)}{W} \times f \times V/10{,}000$$

where C_1 was the calculated concentration of A.I. from the test sample based on the standard curve (mg/L), C_0 was the calculated concentration of A.I. from the blank sample based on the standard curve (mg/L), f was the dilution factor, V was the volume of the extracted solution (mL), and W was the weight of the test sample. The average concentration of each evaporation period was determined from three different heated samples using different heating devices.[JT2]

5. Bioassays

5.1. Knock-down and insecticidal activity of test products in a Peet-Grady chamber

Insecticidal activity of four liquid and three mat-type insecticides on the female adults of *Ae. albopictus* was examined in a Peet-Grady chamber, followed by World Health Organization Pesticide Evaluation Scheme (WHOPES 2009) as a standardized test method for insecticides efficacy evaluation with a slight modification (no air circulation). The chamber had 1.8 × 1.8 × 1.8 m (W × D × H) in the size, with a ventilation hood and watering supplies equipped at the ceiling and the bottom, respectively, for cleaning purpose. Before each trial, the chamber was thoroughly washed with soap and cleaned again with 95% ethanol (Yoon et al. 2020). The chamber was set at 25 ± 1°C and 70 ± 10% RH, and then twenty-seven cylinder shape netting cages (ϕ 7.5 × 15 cm in height) each with 10 female adult mosquitoes were hung in 3 × 3 × 3 patterns to investigate the spatial distribution of the insecticides in the chamber. Prior to the test, the mosquitoes in the chamber were remained hung for at least 30 mins to confirm that there are no insecticides residue in the chamber, then a test insecticide was placed at the bottom corner of the chamber and operated for 1 h. Knock-down activity in each cage was monitored with a 5-min interval during the first 2 h, and then 10 and 15-min intervals until 3 h and 4 h, respectively. In a preliminary test, when the ventilator was turned on, all flying mosquitoes instantly showed knock-down activity, indicating increased exposure to the insecticide particles. In order to avoid any disturbance of the air in the chamber, the mosquito nets were stayed hung in the chamber and the mortality was recorded at 24 h post-treatment. All the bioassay was repeated at least three times using mosquitoes from different cohorts.

5.2. Efficacy of Insecticides in a Semi-Field Test Arena

To compare the efficacy of insecticides between a Peet-Grady chamber and a larger space, knock-down activity and mortality against the adult *Ae. albopictus* in a 6.8 × 3.4 × 2.7 m (62.4 m^3) room were examined using Homemat® liquid and mat vaporizers. Ten female adults of the mosquitoes were transferred into a netting cage (ϕ 7.5 × 15 cm in height), and two cages were hung on a pole, then three poles with a total of six netting cages were placed 1.5 m apart to each other (Fig. 4). The mosquitoes were stayed hung for at least an hour to adjust the surroundings and to confirm no insecticide residues affecting the efficacy. Since no 2 h knock-down and 24 h insecticidal activity was observed in a preliminary test with 2 h of operating time (data not shown), the mat and liquid vaporizers were run at the corner of the room for 3 h without opening the door or any other disturbance during the operation. After 3 h, the number of knocked-down mosquitoes was recorded, then the mosquitoes were transferred into a clean paper holding cup and provided with a 10% sugar solution on cotton wool and hold for another 21 h at 25 ± 1°C and 70 ± 10% RH. Mortality was recorded at 24 h post-treatment, and the test was repeated for three times.

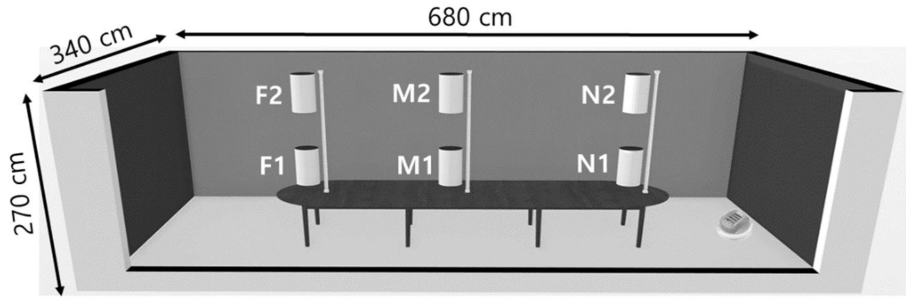

Figure. 4. A schematic of test space (62 m^3).

5.3. Data analysis

Statistical differences in the insecticidal activity and evaporation from each bioassay and heating test were determined by one-way ANOVA with Tukey's test post hoc, and a probit analysis was conducted to determine the KT (Knock-down time)$_{50}$ and KT_{90} values of liquid and mat-type insecticides by using an SPSS software (ver. 2.5, IBM, Armonk, NY, USA).

Results

1. Evaporation profiles of liquid vaporizers

Four different liquid vaporizers from three manufacturers, with a total of 8 different combinations of insecticides and heaters were tested to examine the evaporation speed as well as the concentration changes of active ingredients. As shown in Fig. 5A to 5H, daily weight changes in liquid vaporizers were recorded in all combinations (presented in lines), and A.I. concentrations (bars) in 0, 15, 30, and 45 days (35 days for F-killer®) were analyzed. Overall, a notable difference was found in the types of heaters as well as from the manufacturers. The fastest evaporation speed was found in F-killer® liquid vaporizers, which exceeded 91.1 ± 0.7% of weight loss (evaporation) from the initial stage in 35 days and ended the evaporation in 40 days (Fig. 5H). Nonetheless, the change in the composition of the active ingredient, prallethrin, was the least among the liquid vaporizers analyzed, showing the minimum variation in the average concentration of 1.11 ± 0.01% and greatest P-value in one-way ANOVA ($P = 0.837$).

Among the four liquid vaporizers tested, Homemat® liquid insecticide had the greatest A.I. concentration, with the average of 1.59 ± 0.06% of prallethrin for the initial products, whereas the content of the other insecticides, Happyhome® and F-killer®, which also had prallethrin as the active ingredient, were 1.28 ± 0.01% and 1.11 ± 0.02%, respectively. As for the Homemat® products, the evaporation curve showed relatively faster evaporation in the first half, then slowed down in the second half. For example, Homemat® in the plug-in heater (Fig. 5E) and Happyhome® in the corded heater (Fig. 5A) showed similar evaporation patterns during the observation periods, as showing 97.2% and 96.0% of evaporation at 45 days, respectively, Homemat® showed 51.4% of evaporation in 14 days, whereas Happyhome® reached 50.1% in 22 days. These relatively faster evaporations in the first half of Homemat® products were observed in all vaporizers regardless of heating devices or active ingredients (Fig. 5D to G).

Whereas Homemat® products showed similar evaporation patterns regardless of heating device, Happyhome® vaporizers showed a distinctive difference in evaporation speed according to the heaters. With the same liquid insecticides, evaporation in corded heater seemed the most reliable that it showed 96.0 ± 3.7% of guaranteed evaporation in 45 days (Fig. 5A), whereas plug-in and timer attached plug-in devices showed 56.7 ± 2.7% (Fig. 5B) and 82.5 ± 6.8% (Fig. 5C) of evaporation, respectively. Nonetheless, the evaporations were highly consistent, showing the linear evaporation pattern that the R2 values of corded, plug-in, and timer attached plug-in were 0.9989, 0.9997, and 0.9992, respectively.

To identify the cause of the difference in the evaporation speed of the products, temperatures of the heating plate as well as the discharge port were measured. As shown in Fig. 6A, the temperature of the heating plate and discharge port in F-killer® heater was significantly higher than other heaters (98.0 ± 3.3°C and 65.0 ± 0.8°C, respectively, $P < 0.05$), which may directly explain the rapid evaporation speed of F-killer® liquid vaporizers. On the other hand, plug-in and timer attached plug-in heaters from Happyhome® products failed to show any difference in the temperature, that the heating plate and discharge port displayed only 3.3℃ and 0.3℃ of difference in average, respectively, whereas the evaporation showed 25.8% of the difference.

2. Evaporation profiles of mat-type vaporizers

Since the weight change of mat-type insecticides was unnoticeable, the evaporation of three mat vaporizers from each manufacture was determined via GC/FID analyses. For the designated (recommended) operating hours of 12, 15, and 15 h in F-killer®, Happyhome®, and Homemat® products, respectively, the evaporation of active ingredients were 81.8 ± 1.8%, 82.8 ± 1.0%, and 72.4 ± 1.8%, respectively. Although the evaporation of Homemat® insecticide was relatively slower than the rest of vaporizers, it showed a more steady release of insecticides, where the other two mat products displayed > 50% of evaporation in the first 6 h of operation (Fig. 5I).

As for the temperatures of heating plates, although the surface temperature of Happyhome® heater (125.8 ± 6.1°C) was relatively higher than others, there was no statistical difference ($P = 0.253$), and the surface temperature of the underside of the mat after 1 h of operation did not show any significant difference, either ($P = 0.800$).

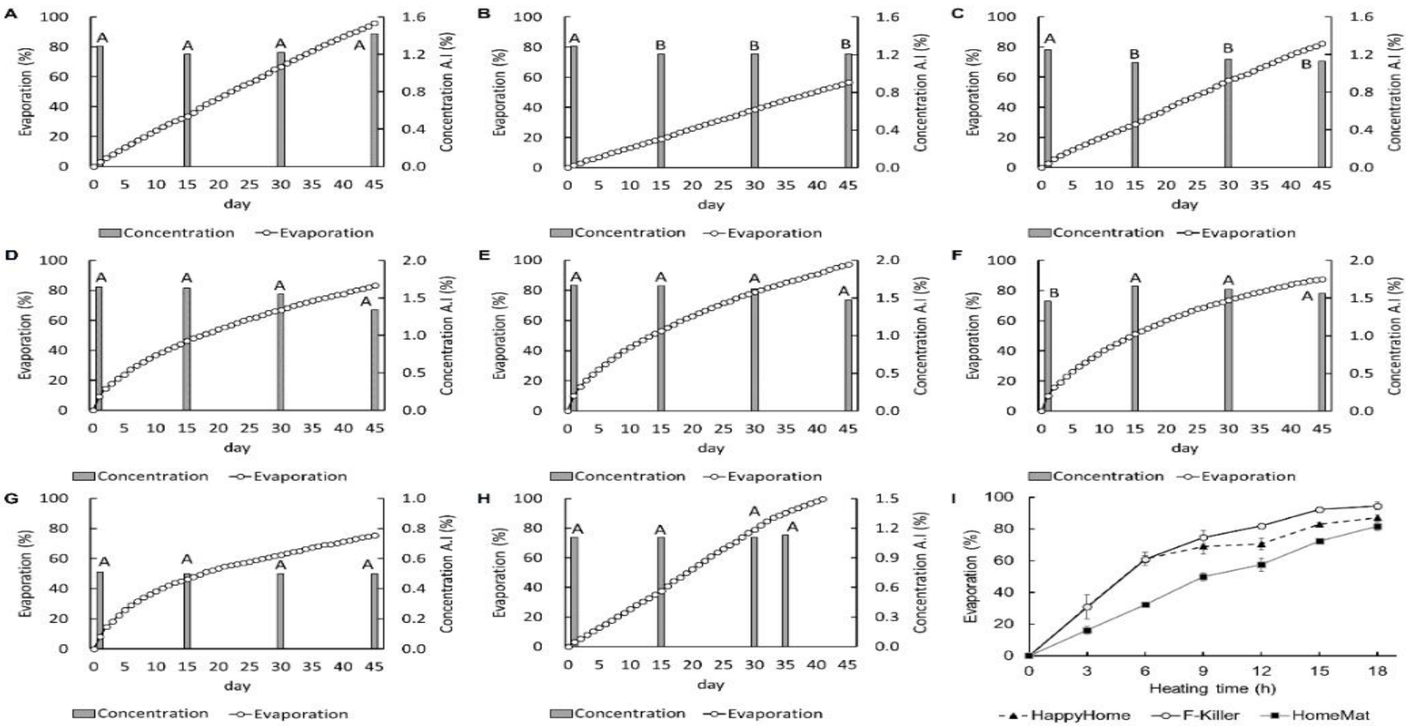

Figure. 5. Comparisons of evaporation speed of liquid and mat vaporizers using their own designated heating devices. (A)-(C) Happyhome® liquid vaporizers in corded, plug-in, and timer heaters, respectively, (D)-(F) Homemat® liquid vaporizers in corded, plug-in, and timer heaters, respectively, (G)Homemat Home Solution® vaporizer, (H)F-killer® liquid vaporizer, and (I) mat vaporizers of three manufactures. Bars with a different letter indicate significant differences (Tukey HSD test, $P < 0.05$).[JT3]

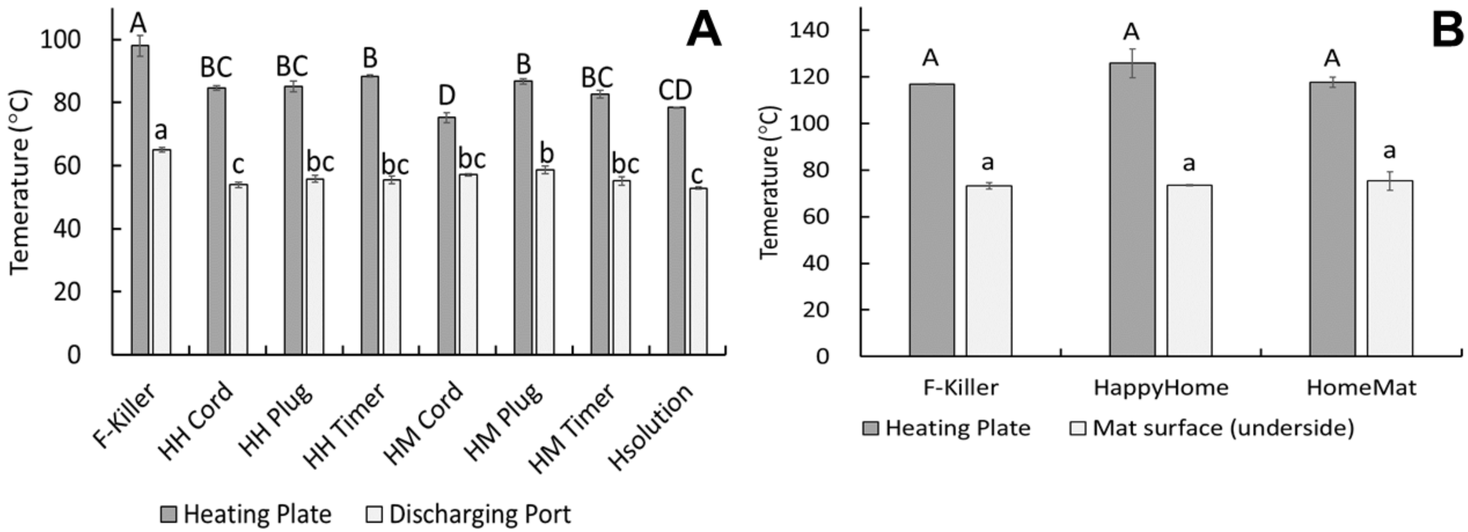

Figure. 6. Temperatures of heating devices in (A) liquid and (B) mat type heaters. Different letters in each of the upper and lower cases indicate statistical difference (Tukey HSD test, $P < 0.05$).[JT4][해5]

3. Efficacy of the Electric Vaporizers and Their Spatial Distribution in Peet-Grady Chamber

The knock-down and insecticidal activity of liquid and mat vaporizers were examined using 1.8 × 1.8 × 1.8 m size Peet-Grady chamber. For the four liquid vaporizers, when the 1 day-heated products were tested, all test products displayed < 60 min of average KT_{90} values, but it showed a notable difference based on the position of the netting cages as well as the products. Among the liquid vaporizers tested, 1 day- and 45 days-heated Homemat® liquid vaporizers, 1 day-heated Homemat Home Solution® vaporizers, 35 days-heated F-killer® liquid vaporizers, and 45 days-heated Happyhome® liquid vaporizers displayed < 60 min of KT_{90} values to the mosquitoes in all 27 netting cages in the chamber, and the rest of the liquid vaporizers showed < 120 min of KT_{90} values in all mosquitoes tested, indicating their efficacy maintains until the end of evaporation periods (Tables 3 to 16).

As for the mat type vaporizers, all three of unheated (new) insecticides exhibited < 40 min of average KT_{90} values regardless of the active ingredients they used. When the mats were introduced into the test chamber after heating for 12 or 15 h, they tend to show relatively slower knock-down activity, but they still displayed acceptable efficacy in the chamber.

The spatial distribution of evaporated insecticides showed interesting patterns, that the fastest knock-down effect was usually observed at the coordinates of 1,1,2 and 1,1,3 in an xyz-axis, but the mosquitoes located at 1,1,1 position which was adjacent to the vaporizers tend to display slower activity, indicating that the heated insecticide particles rapidly rise upward and accumulate on the ceiling first, then the particles slowly scatter into the surrounding area (Fig. 7). In most tests, the slowest knock-down activity was observed at the bottom area of the test chamber, and all mosquitoes tested showed 100% mortality at 24 h post-treatment.

Table 3. KT_{50} and KT_{90} values of 1d-heated Homemat® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	10.5	7.1 – 13.6	24.1	18.7 – 35.0	3.6 ± 0.4	135.0	0.000	40
1,1,2	10.0	8.4 – 11.4	16.6	14.4 – 20.4	5.8 ± 0.8	52.3	0.091	40
1,1,3	13.3	11.2 – 15.3	20.9	18.0 – 26.4	6.6 ± 0.8	81.0	0.000	40
2,1,1	23.4	18.2 – 28.3	46.3	37.4 – 66.1	4.3 ± 0.4	182.9	0.000	40
2,1,2	15.4	11.7 – 18.7	30.9	25.3 – 41.9	4.2 ± 0.4	130.8	0.000	40
2,1,3	14.0	11.3 – 16.5	23.6	19.8 – 31.3	5.6 ± 0.6	109.5	0.000	40
3,1,1	19.5	14.4 – 24.2	33.4	26.6 – 51.0	5.5 ± 0.5	252.7	0.000	40
3,1,2	16.0	12.3 – 19.4	31.0	25.2 – 42.5	4.4 ± 0.4	143.8	0.000	40
3,1,3	17.6	16.3 – 18.7	22.6	21.0 – 25.4	11.7 ± 1.8	28.9	0.903	40
1,2,1	22.3	16.9 – 27.3	40.9	33.0 – 59.4	4.9 ± 0.4	221.0	0.000	40
1,2,2	25.0	21.1 – 28.5	39.0	33.7 – 49.3	6.7 ± 0.6	141.4	0.000	40
1,2,3	17.3	13.2 – 20.9	30.7	25.1 – 42.5	5.2 ± 0.5	165.6	0.000	40
2,2,1	23.3	18.2 – 27.9	46.8	38.2 – 65.6	4.2 ± 0.4	160.9	0.000	40
2,2,2	21.2	18.3 – 23.8	33.2	29.1 – 40.5	6.5 ± 0.6	97.3	0.000	40
2,2,3	18.0	16.7 – 20.3	24.8	22.4 – 29.2	9.1 ± 1.2	64.5	0.008	40
3,2,1	25.2	23.5 – 26.8	36.5	33.8 – 40.2	8.0 ± 0.8	47.2	0.203	40
3,2,2	23.0	21.1 – 24.7	31.1	28.7 – 35.1	9.7 ± 1.1	55.1	0.056	40
3,2,3	18.6	16.6 – 20.5	26.0	23.3 – 31.1	8.9 ± 1.1	74.4	0.001	40
1,3,1	26.0	20.1 – 31.6	37.4	30.9 – 58.4	8.1 ± 0.8	332.2	0.000	40
1.3,2	25.7	19.9 – 30.9	50.0	40.7 – 71.6	4.4 ± 0.4	185.2	0.000	40
1,3,3	21.4	17.5 – 25.0	33.8	28.7 – 45.0	6.5 ± 0.6	162.0	0.000	40
2,3,1	29.7	23.0 – 35.7	57.1	45.9 – 87.2	4.5 ± 0.4	212.3	0.000	40
2,3,2	23.8	19.9 – 27.4	42.7	36.6 – 54.0	5.1 ± 0.4	117.1	0.000	40
2,3,3	20.7	17.5 – 23.6	31.8	27.6 – 40.2	6.9 ± 0.7	120.7	0.000	40
3,3,1	24.6	20.5 – 28.4	35.1	30.2 – 46.6	8.2 ± 10.1	190.9	0.000	40
3,3,2	18.2	17.1 – 20.7	26.4	23.8 – 30.6	7.9 ± 0.9	56.3	0.045	40
3,3,3	20.2	17.8 – 22.5	30.4	26.9 – 36.7	7.2 ± 0.8	78.6	0.000	39

Table 4. KT_{50} and KT_{90} values of 1d-heated Homemat Home Solution® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	12.7	9.6 – 15.4	24.7	20.2 – 33.6	4.4 ± 0.4	95.1	0.000	34
1,1,2	9.3	8.1 – 10.4	14.5	12.8 – 17.2	6.6 ± 0.9	21.1	0.959	34
1,1,3	13.6	12.6 – 14.6	17.3	15.9 – 19.6	12.2 ± 2.0	18	0.989	34
2,1,1	27.8	26.5 – 29.0	33.6	31.8 – 36.4	15.5 ± 2.0	39.3	0.245	34
2,1,2	18.7	16.3 – 21.0	32.7	28.5 – 40.0	5.3 ± 0.3	294.5	0.000	70
2,1,3	16.6	15.4 – 17.8	21.3	19.7 – 24.2	11.9 ± 1.9	8.7	1.000	34
3,1,1	25.9	23.9 – 27.9	35.0	32.1 – 39.8	9.8 ± 1.0	54.532	0.014	34
3,1,2	22.1	17.1 – 26.9	30.0	25.1 – 50.2	9.6 ± 1.1	251.1	0.000	34
3,1,3	18.5	17.8 – 20.2	23.9	22.2 – 26.8	11.6 ± 1.7	36.041	0.373	34
1,2,1	30.3	23.1 – 37.8	49.4	39.2 – 86.7	6.0 ± 0.5	287.1	0.000	34
1,2,2	20.9	16.4 – 25.3	27.8	23.4 – 45.7	10.3 ± 1.2	230	0.000	34
1,2,3	19.3	11.9 – 26.9	29.4	22.7 – 127.0	7.0 ± 0.4	5810.8	0.000	112
2,2,1	30.7	26.8 – 35.2	46.9	39.9 – 64.6	7.0 ± 0.5	590.3	0.000	70
2,2,2	23.7	22.0 – 25.3	30.9	28.6 – 34.9	11.1 ± 1.4	45.4	0.091	34
2,2,3	17.1	15.9 – 18.3	22.0	20.4 – 24.9	11.8 ± 1.9	7.918	1.000	34
3,2,1	26.7	25.0 – 28.3	34.0	31.7 – 37.7	12.2 ± 1.5	43.383	0.130	34
3,2,2	20.1	18.8 – 21.4	26.0	24.2 – 29.1	11.4 ± 1.7	21.878	0.930	34
3,2,3	16.8	15.6 – 18.0	21.6	20.0 – 24.9	11.8 ± 1.9	11.337	1.000	34
1,3,1	29.0	24.6 – 33.4	37.6	32.8 – 52.1	11.4 ± 1.2	208	0.000	34
1.3,2	21.1	19.0 – 24.1	31.2	28.1 – 36.3	7.5 ± 0.8	55.1	0.012	34
1,3,3	21.4	20.1 – 22.8	30.7	27.8 – 34.1	8.5 ± 0.5	307.8	0.000	90
2,3,1	27.7	24.8 – 30.5	36.7	32.9 – 44.3	10.4 ± 1.1	102.7	0.000	34
2,3,2	22.1	19.0 – 24.9	33.4	29.1 – 41.6	7.1 ± 0.7	96.1	0.000	34
2,3,3	18.5	17.2 – 19.7	23.8	22.1 – 26.8	11.6 ± 1.8	8.8	1.000	34
3,3,1	24.0	22.8 – 25.2	29.4	27.8 – 32.0	14.6 ± 2.1	25.4	0.856	34
3,3,2	19.1	17.3 – 20.7	25.6	23.4 – 29.4	10.1 ± 1.3	48.983	0.046	34
3,3,3	17.3	16.1 – 18.5	22.2	20.6 – 25.1	11.8 ± 1.9	10.658	1.000	34

Table 5. KT_{50} and KT_{90} values of 1d-heated F-killer® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	17.6	11.3 – 23.3	44.7	32.5 – 85.7	3.2 ± 0.3	187.7	0.000	34
1,1,2	13.6	10.9 – 16.0	24.9	20.9 – 32.3	4.9 ± 0.5	79.4	0.000	34
1,1,3	11.7	9.4 – 13.8	17.8	14.9 – 24.5	7.0 ± 0.9	91.0	0.000	34
2,1,1	31.4	21.5 – 41.1	48.0	37.7 – 111.9	7.0 ± 0.6	443.4	0.000	34
2,1,2	22.4	16.6 – 28.0	42.4	33.2 – 67.6	4.6 ± 0.4	205.7	0.000	34
2,1,3	15.4	14.0 – 16.7	22.6	20.6 – 25.6	7.7 ± 1.0	29.5	0.686	34
3,1,1	34.3	29.8 – 38.5	51.5	44.9 – 66.2	7.3 ± 0.7	121.9	0.000	34
3,1,2	21.4	15.4 – 26.7	37.8	29.9 – 60.4	5.2 ± 0.5	226.6	0.000	34
3,1,3	18.9	17.7 – 20.1	24.6	22.9 – 27.4	11.2 ± 1.6	34.0	0.468	34
1,2,1	34.1	28.2 – 41.4	69.4	53.7 – 118.2	4.2 ± 0.4	129.9	0.000	34
1,2,2	30.1	26.0 – 33.8	43.4	38.1 – 54.9	8.1 ± 0.8	129.2	0.000	34
1,2,3	15.4	11.9 – 18.7	24.2	19.8 – 36.0	6.5 ± 0.7	152.4	0.000	34
2,2,1	35.1	32.2 – 37.8	47.1	43.3 – 53.9	10.0 ± 1.0	73.3	0.000	34
2,2,2	20.9	17.1 – 24.2	36.4	30.8 – 47.7	5.3 ± 0.6	108.0	0.000	34
2,2,3	14.4	13.2 – 15.5	20.0	18.2 – 22.8	9.0 ± 1.2	30.2	0.653	34
3,2,1	35.3	30.7 – 39.9	50.5	43.9 – 66.0	8.2 ± 0.8	152.0	0.000	34
3,2,2	25.8	22.4 – 28.8	38.0	33.5 – 46.8	7.6 ± 0.8	101.4	0.000	34
3,2,3	17.3	15.7 – 18.9	24.1	21.8 – 28.0	8.9 ± 1.1	45.7	0.087	34
1,3,1	33.5	29.7 – 37.2	49.7	43.8 – 61.2	7.5 ± 0.7	103.0	0.000	34
1.3,2	28.1	25.3 – 30.8	40.2	36.3 – 47.1	8.3 ± 0.8	75.4	0.000	34
1,3,3	26.6	21.6 – 31.3	40.1	33.8 – 56.4	7.2 ± 0.7	192.8	0.000	34
2,3,1	34.5	30.2 – 38.9	57.2	48.8 – 75.8	5.8 ± 0.6	97.4	0.000	34
2,3,2	22.1	18.6 – 25.4	40.3	34.4 – 51.4	4.9 ± 0.5	86.7	0.000	34
2,3,3	16.4	15.1 – 17.6	22.4	20.6 – 25.2	9.4 ± 1.2	24.4	0.887	34
3,3,1	29.4	24.7 – 33.9	50.2	42.3 – 68.0	5.5 ± 0.5	121.8	0.000	34
3,3,2	24.6	22.5 – 26.6	33.6	30.7 – 38.5	9.5 ± 1.1	56.3	0.009	34
3,3,3	15.8	14.6 – 16.9	20.8	19.2 – 23.4	10.7 ± 1.5	15.3	0.998	34

Table 6. KT_{50} and KT_{90} values of 1d-heated Happyhome® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	11.6	3.5 – 18.3	50.2	32.0 – 156.7	2.02 ± 0.2	249.7	0.000	40
1,1,2	15.0	11.2 – 18.5	32.2	25.8 – 44.6	3.9 ± 0.3	137.6	0.000	40
1,1,3	20.4	16.9 – 23.4	36.4	31.2 – 45.5	5.1 ± 0.5	104.0	0.000	40
2,1,1	46.3	41.7 – 51.7	75.3	64.7 – 98.4	6.1 ± 0.6	106.9	0.000	40
2,1,2	27.0	23.8 – 29.9	42.0	37.3 – 50.1	6.7 ± 0.6	96.6	0.000	40
2,1,3	25.1	21.7 – 28.3	43.0	37.7 – 51.6	5.5 ± 0.5	91.4	0.000	40
3,1,1	26.0	19.7 – 32.2	54.1	42.4 – 84.5	4.0 ± 0.3	400.2	0.000	54
3,1,2	27.3	24.9 – 29.6	36.0	32.8 – 41.7	10.7 ± 1.2	88.2	0.000	40
3,1,3	27.6	24.2 – 30.7	42.0	37.2 – 50.6	7.0 ± 0.7	109.6	0.000	40
1,2,1	39.0	35.8 – 42.1	51.8	47.4 – 59.6	10.4 ± 1.0	108.4	0.000	40
1,2,2	41.4	38.7 – 44.2	63.5	58.0 – 71.9	6.9 ± 0.6	51.3	0.109	40
1,2,3	27.6	22.7 – 32.0	46.0	39.1 – 60.8	5.8 ± 0.5	170.7	0.000	40
2,2,1	40.1	33.3 – 49.3	106.0	77.6 – 192.5	3.0 ± 0.3	115.8	0.000	40
2,2,2	38.7	34.5 – 42.8	58.7	52.0 – 71.6	7.1 ± 0.6	122.3	0.000	40
2,2,3	28.8	18.2 – 39.4	77.6	52.7 – 235.8	3.0 ± 0.3	307.8	0.000	40
3,2,1	38.1	21.6 – 53.6	52.8	41.6 – 254.4	9.1 ± 0.8	885.8	0.000	40
3,2,2	31.1	28.1 – 37.8	45.0	40.9 – 51.6	8.0 ± 0.8	82.7	0.000	40
3,2,3	24.2	19.6 – 28.3	45.3	37.9 – 60.0	4.7 ± 0.4	142.5	0.000	40
1,3,1	41.0	31.2 – 50.8	53.1	44.7 – 103.7	11.4 ± 1.1	594.1	0.000	40
1.3,2	43.8	39.7 – 48.0	63.9	56.9 – 77.8	7.8 ± 0.7	117.8	0.000	40
1,3,3	39.9	9.7 – 82.9	64.2	45.6 – 118042.7	6.2 ± 0.5	1144.0	0.000	40
2,3,1	46.7	44.9 – 48.4	58.1	55.5 – 61.8	13.5 ± 1.4	24.8	0.971	40
2,3,2	34.2	26.6 – 42.0	72.7	55.8 – 63.0	3.9 ± 0.4	209.1	0.000	40
2,3,3	27.5	19.6 – 35.4	67.4	49.4 – 132.3	3.3 ± 0.3	238.3	0.000	40
3,3,1	33.8	29.2 – 38.3	55.8	48.0 – 71.4	5.9 ± 0.5	140.1	0.000	40
3,3,2	32.3	27.2 – 37.0	54.0	46.1 – 71.1	5.8 ± 0.5	160.7	0.000	40
3,3,3	30.6	23.4 – 37.2	62.1	49.0 – 100.9	4.2 ± 0.4	214.0	0.000	40

Table 7. KT_{50} and KT_{90} values of 45d-heated Homemat® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	22.1	10.8 – 32.4	40.0	28.0 – 124.9	5.0 ± 0.4	694.3	0.000	40
1,1,2	8.4	7.2 – 9.5	13.9	12.2 – 16.7	5.8 ± 0.8	32.6	0.791	40
1,1,3	9.7	8.5 – 10.8	14.7	13.1 – 17.5	7.1 ± 1.0	28.4	0.914	40
2,1,1	30.0	28.7 – 31.3	36.8	34.9 – 39.7	14.5 ± 1.7	32.1	0.000	40
2,1,2	23.7	20.3 – 26.7	35.9	31.5 – 44.0	7.1 ± 0.7	117.2	0.000	40
2,1,3	13.0	11.1 – 14.8	19.8	17.2 – 24.9	7.0 ± 0.9	74.3	0.001	40
3,1,1	27.8	25.0 – 30.4	37.7	34.0 – 45.4	9.7 ± 1.0	102.8	0.000	40
3,1,2	31.3	27.2 – 35.1	47.4	41.6 – 58.7	7.1 ± 0.6	142.8	0.000	40
3,1,3	18.0	16.8 – 19.1	23.2	21.5 – 25.6	11.7 ± 1.8	48.0	0.180	40
1,2,1	26.4	24.6 – 28.2	40.2	37.3 – 44.3	7.0 ± 0.7	42.2	0.376	40
1,2,2	18.8	14.0 – 23.1	34.9	28.1 – 50.9	4.8 ± 0.4	199.5	0.000	40
1,2,3	9.3	8.2 – 10.3	13.3	11.8 – 15.8	8.4 ± 1.4	27.3	0.937	40
2,2,1	28.2	27.0 – 29.5	34.1	32.3 – 36.8	15.7 ± 2.1	26.4	0.952	40
2,2,2	22.9	19.5 – 26.0	37.5	32.6 – 46.4	6.0 ± 0.6	111.8	0.000	40
2,2,3	11.9	10.0 – 13.6	17.4	15.1 – 22.7	7.8 ± 1.2	77.0	0.000	40
3,2,1	31.0	29.6 – 32.3	37.4	35.6 – 40.3	15.5 ± 2.0	24.2	0.977	40
3,2,2	24.4	21.1 – 27.3	34.7	30.7 – 43.0	8.4 ± 0.9	126.2	0.000	40
3,2,3	16.4	12.9 – 19.6	28.3	23.5 – 38.1	5.4 ± 0.5	140.8	0.000	40
1,3,1	25.6	17.2 – 33.6	53.1	39.5 – 103.3	4.1 ± 0.3	352.5	0.000	40
1.3,2	24.0	17.1 – 30.2	46.3	36.2 – 74.9	4.5 ± 0.4	279.1	0.000	40
1,3,3	16.2	15.1 – 17.3	20.8	19.3 – 23.5	11.9 ± 1.9	41.7	0.398	40
2,3,1	29.5	26.2 – 32.7	39.8	35.6 – 48.2	9.9 ± 1.0	138.6	0.000	40
2,3,2	22.8	19.1 – 26.2	35.0	30.0 – 45.6	6.9 ± 0.7	151.4	0.000	40
2,3,3	16.7	15.2 – 18.1	22.6	20.6 – 26.0	9.9 ± 1.4	50.3	0.128	40
3,3,1	26.5	24.3 – 28.3	34.7	32.0 – 39.3	10.8 ± 1.3	66.0	0.006	40
3,3,2	23.7	20.4 – 26.8	36.3	31.7 – 45.0	6.9 ± 0.7	119.1	0.000	40
3,3,3	17.6	13.1 – 21.4	33.7	27.6 – 46.4	4.5 ± 0.4	157.4	0.000	39

Table 8. KT_{50} and KT_{90} values of 45d-heated Homemat Home Solution® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	9.1	5.8 – 11.9	21.1	16.2 – 31.8	3.5 ± 0.4	108.5	0.000	34
1,1,2	10.9	9.7 – 12.0	15.7	14.1 – 18.4	8.2 ± 1.3	32.9	0.523	34
1,1,3	25.3	17.1 – 33.3	56.2	40.9 – 128.8	3.7 ± 0.4	239.3	0.000	34
2,1,1	35.7	27.2 – 45.5	64.9	49.5 – 151.9	4.9 ± 0.5	241.7	0.000	34
2,1,2	20.5	17.3 – 23.4	30.3	26.2 – 39.1	7.6 ± 0.8	111.5	0.000	34
2,1,3	28.7	19.9 – 37.2	58.3	43.3 – 136.5	4.2 ± 0.4	253.5	0.000	34
3,1,1	34.9	27.9 – 41.9	58.9	47.5 – 101.5	5.6 ± 0.6	200.4	0.000	34
3,1,2	25.2	19.8 – 30,0	42.0	34.5 – 62.0	5.8 ± 0.5	184.3	0.000	34
3,1,3	36.9	29.1 – 45.0	59.9	48.2 – 113.8	6.1 ± 0.6	239.3	0.000	34
1,2,1	32.8	24.3 – 41.3	60.4	46.5 – 130.0	4.8 ± 0.5	244.3	0.000	34
1,2,2	18.6	17.4 – 19.8	24.0	22.3 – 26.8	11.6 ± 1.7	31.9	0.569	34
1,2,3	31.1	22.3 – 40.7	62.4	45.9 – 157.6	4.2 ± 0.4	256.4	0.000	34
2,2,1	32.9	24.1 – 42.3	63.3	47.5 – 151.6	4.5 ± 0.5	248.4	0.000	34
2,2,2	26.8	24.0 – 29.5	37.0	33.2 – 44.2	9.2 ± 1.0	87.8	0.000	34
2,2,3	34.4	24.3 – 47.6	70.8	50.1 – 260.0	4.1 ± 0.4	280.6	0.000	34
3,2,1	36.3	28.3 – 45.0	62.2	48.8 – 127.7	5.5 ± 0.6	236.2	0.000	34
3,2,2	41.8	36.9 – 46.8	56.5	49.8 – 76.0	9.8 ± 1.1	160.1	0.000	34
3,2,3	39.9	34.4 – 45.4	56.5	48.9 – 79.6	8.5 ± 0.9	173.4	0.000	34
1,3,1	34.7	26.5 – 43.4	62.0	48.1 – 130.6	5.1 ± 0.5	235.5	0.000	34
1.3,2	24.1	20.9 – 27.0	33.0	29.2 – 41.6	9.4 ± 1.1	113.6	0.000	34
1,3,3	29.9	22..0 – 37.4	56.8	43.9 – 110.9	4.6 ± 0.5	224.5	0.000	34
2,3,1	35.0	27.0 – 42.8	59.0	46.9 – 112.2	5.6 ± 0.6	236.5	0.000	34
2,3,2	36.3	30.5 – 41.7	52.6	45.1 – 75.1	8.0 ± 0.8	188.6	0.000	34
2,3,3	34.2	26.3 – 42.2	60.1	47.2 – 117.1	5.2 ± 0.5	227.0	0.000	34
3,3,1	36.5	28.3 – 44.5	61.9	48.2 – 117.5	5.8 ± 0.6	236.3	0.000	34
3,3,2	37.6	32.4 – 42.7	56.5	48.5 – 78.2	7.2 ± 0.7	145.8	0.000	34
3,3,3	37.6	31.6 – 44.4	62.9	51.3 – 100.8	5.7 ± 0.6	157.8	0.000	34

Table 9. KT_{50} and KT_{90} values of 35d-heated F-killer® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	18.8	16.0 – 21.4	28.9	25.1 – 36.5	6.8 ± 0.7	89.1	0.000	34
1,1,2	16.7	15.5 – 17.8	21.5	20.0 – 24.2	11.6 ± 1.8	23.5	0.911	34
1,1,3	13.9	12.8 – 14.9	17.7	16.4 – 20.0	12.3 ± 2.1	6.8	1.000	34
2,1,1	31.1	28.1 – 34.0	42.7	38.6 – 50.3	9.3 ± 0.9	87.5	0.000	34
2,1,2	29.8	28.0 – 31.5	37.3	35.0 – 41.3	13.1 ± 1.6	47.8	0.059	34
2,1,3	23.7	21.1 – 26.1	32.9	29.7 – 38.7	9.0 ± 1.0	75.0	0.000	34
3,1,1	29.4	28.0 – 30.7	36.5	34.5 – 39.4	13.6 ± 1.7	35.7	0.390	34
3,1,2	29.7	28.2 – 31.2	38.5	36.3 – 41.6	11.5 ± 1.3	40.8	0.197	34
3,1,3	28.1	26.1 – 30.0	34.2	31.8 – 38.8	15.0 ± 2.0	64.5	0.001	34
1,2,1	32.8	30.8 – 34.8	42.2	39.3 – 47.0	11.7 ± 1.3	52.2	0.024	34
1,2,2	30.3	28.2 – 32.2	37.4	34.8 – 42.1	14.0 ± 1.7	61.4	0.003	34
1,2,3	18.3	16.9 – 19.6	25.5	23.5 – 28.5	8.9 ± 1.1	37.2	0.324	34
2,2,1	32.2	30.6 – 33.6	39.2	37.3 – 42.0	15.0 ± 1.9	22.9	0.905	33
2,2,2	30.9	29.5 – 32.2	37.3	35.5 – 40.2	15.7 ± 2.1	16.9	0.994	34
2,2,3	27.0	24.2 – 29.6	37.8	34.0 – 44.6	8.8 ± 0.9	80.1	0.000	34
3,2,1	31.4	29.9 – 32.9	39.8	37.6 – 43.0	12.5 ± 1.5	37.1	0.327	34
3,2,2	31.3	28.0 – 24.4	42.6	38.3 – 51.3	9.6 ± 1.0	104.1	0.000	34
3,2,3	26.1	23.8 – 28.2	34.4	31.4 – 39.8	10.7 ± 1.2	66.9	0.001	34
2,3,1	35.9	35.2 – 36.7	41.0	39.9 – 42.5	22.4 ± 2.1	37.8	0.999	70
2,3,2	30.1	22.0 – 36.4	43.0	35.7 – 72.5	8.3 ± 0.5	2983.2	0.000	94
2,3,3	28.4	24.7 – 31.7	43.6	38.3 – 53.8	6.9 ± 0.7	96.7	0.000	34
2,3,1	29.5	26.2 – 32.7	39.8	35.6 – 48.2	9.9 ± 1.0	138.6	0.000	40
2,3,2	22.8	19.1 – 26.2	35	30.0 – 45.6	6.9 ± 0.7	151.4	0.000	40
2,3,3	16.7	15.2 – 18.1	22.6	20.6 – 26.0	9.9 ± 1.4	50.3	0.128	40
3,3,1	32.4	28.5 – 36.2	44.6	39.5 – 56.2	9.3 ± 0.9	135.1	0.000	34
3,3,2	32.7	28.5 – 36.6	46.0	40.5 – 58.5	8.7 ± 0.9	138.1	0.000	34
3,3,3	28.9	24.3 – 33.3	43.1	36.9 – 58.5	7.4 ± 0.7	164.3	0.000	34

Table 10. KT_{50} and KT_{90} values of 45d-heated Happyhome® liquid vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	10.9	8.8 – 12.8	19.0	16.0 – 24.9	5.3 ± 0.6	68.1	0.000	34
1,1,2	8.6	7.5 – 9.6	12.7	11.3 – 15.3	7.4 ± 1.1	19.5	0.978	34
1,1,3	9.4	8.2 – 10.4	13.1	11.7 – 15.8	9.0 ± 1.8	18.3	0.987	34
2,1,1	40.8	38.9 – 42.7	54.9	51.5 – 59.9	10.0 ± 1.1	40.2	0.216	34
2,1,2	24.3	22.6 – 25.9	32.0	30.3 – 37.1	10.7 ± 1.3	43	0.138	34
2,1,3	20.6	18.7 – 22.4	30.2	27.3 – 34.6	7.8 ± 0.8	44.8	0.083	33
3,1,1	33.1	31.6 – 34.6	41.7	39.6 – 44.8	12.8 ± 1.5	28.7	0.726	34
3,1,2	26.1	24.8 – 27.3	31.3	29.7 – 34.0	16.1 ± 2.4	34.8	0.431	34
3,1,3	27.4	24.3 – 30.3	43.3	38.6 – 51.4	6.5 ± 0.6	68.5	0.000	34
1,2,1	27.2	25.9 – 28.4	32.7	31.0 – 35.4	16.0 ± 2.3	29.7	0.000	34
1,2,2	25.6	24.2 – 26.9	32.2	30.3 – 35.1	12.8 ± 1.7	39.1	0.252	34
1,2,3	11.8	10.9 – 12.7	14.9	13.7 – 17.2	12.8 ± 2.2	11.6	1.000	34
2,2,1	31.2	29.5 – 32.8	41.6	39.2 – 45.0	10.2 ± 1.1	40.7	0.199	34
2,2,2	33.5	30.3 – 36.5	47.3	42.6 – 56.0	8.6 ± 10.1	84.3	0.000	34
2,2,3	20.1	17.4 – 22.6	34.7	30.5 – 41.8	5.4 ± 0.5	61.7	0.003	34
3,2,1	36.8	34.5 – 39.0	51.0	47.3 – 56.8	9.1 ± 0.9	43.2	0.135	34
3,2,2	29.7	26.8 – 32.3	39.3	35.6 – 46.6	10.5 ± 1.2	91.6	0.000	34
3,2,3	23.6	18.4 – 28.3	47.1	38.0 – 70.3	4.3 ± 0.4	133.3	0.000	34
1,3,1	29.2	27.,7 – 30.6	36.7	34.7 – 39.8	12.8 ± 1.6	34.5	0.444	34
1.3,2	21.2	19.9 – 22.5	27.7	25.8 – 30.6	11.1 ± 1.4	223	0.923	34
1,3,3	16.0	14.8 – 17.1	20.5	18.9 – 23.3	12.0 ± 2.0	6.4	0.000	34
2,3,1	24.2	22.9 – 25.3	29.0	27.5 – 31.5	16.3 ± 2.5	16.2	0.996	34
2,3,2	35.8	31.7 – 39.7	53.2	46.8 – 67.1	7.4 ± 0.8	103.5	0.000	34
2,3,3	11.8	10.9 – 12.7	15.0	13.7 – 17.3	12.2 ± 2.1	5.2	1.000	33
3,3,1	41.4	39.9 – 43.0	50.8	48.4 – 54.3	14.5 ± 1.6	34.2	0.460	34
3,3,2	30.1	26.7 – 33.2	43.8	39.1 – 52.8	7.8 ± 0.8	92.0	0.000	34
3,3,3	23.6	20.9 – 26.0	35.1	31.5 – 41.3	7.4 ± 0.7	67.6	0.001	34

Table 11. KT_{50} and KT_{90} values of 0h-heated Homemat® mat vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	14.6	11.5 – 17.7	31.3	25.8 – 40.9	3.9 ± 0.3	242.0	0.000	66
1,1,2	15.3	14.1 – 16.4	20.5	18.8 – 23.2	10.1 ± 1.4	31.0	0.956	46
1,1,3	14.2	12.8 – 15.5	20.3	18.5 – 23.5	8.2 ± 1.2	11.6	1.000	46
2,1,1	38.3	35.9 – 40.6	59.3	55.1 – 65.3	6.7 ± 0.3	529.6	0.000	146
2,1,2	28.7	25.9 – 31.2	41.6	37.8 – 47.7	7.9 ± 0.8	90.3	0.000	46
2,1,3	24.0	23.2 – 24.8	31.4	30.2 – 32.9	11.0 ± 0.8	49.7	1.000	146
3,1,1	28.9	27.8 – 29.8	36.0	34.5 – 38.1	13.3 ± 0.9	262.9	0.000	146
3,1,2	25.1	24.2 – 26.0	33.5	32.0 – 35.3	10.3 ± 0.7	71.9	0.998	109
3,1,3	24.8	20.5 – 27.7	34.6	30.1 – 44.3	8.3 ± 0.8	186.8	0.000	46
1,2,1	35.2	32.3 – 37.9	48.9	44.8 – 55.3	9.0 ± 0.4	1046.5	0.000	146
1,2,2	21.5	9.1 – 31.5	35.0	25.0 – 142.6	6.0 ± 0.5	1651.9	0.000	66
1,2,3	21.4	20.0 – 22.7	28.1	26.3 – 30.9	10.8 ± 1.4	53.8	0.200	46
2,2,1	28.1	20.7 – 35.1	52.6	41.5 – 81.6	4.7 ± 0.3	726.3	0.000	66
2,2,2	26.4	24.1 – 28.5	36.7	33.5 – 41.8	9.0 ± 0.9	78.8	0.002	46
2,2,3	21.7	20.3 – 23.0	28.2	26.3 – 31.2	11.2 ± 1.5	7.1	1.000	46
3,2,1	29.0	24.3 – 33.5	45.2	38.7 – 58.3	6.7 ± 0.6	219.1	0.000	46
3,2,2	21.6	12.8 – 29.7	37.7	27.7 – 80.1	5.3 ± 0.4	622.9	0.000	46
3,2,3	21.4	20.6 – 22.2	27.4	26.3 – 29.0	11.9 ± 0.9	76.7	0.061	59
1,3,1	29.1	14.1 – 44.7	58.4	39.2 – 237.0	4.2 ± 0.3	995.8	0.000	46
1.3,2	29.1	16.5 – 40.9	56.3	40.1 – 147.2	4.5 ± 0.3	765.8	0.000	46
1,3,3	24.0	22.5 – 25.4	31.8	29.7 – 34.8	10.5 ± 1.2	46.9	0.435	46
2,3,1	33.2	31.8 – 34.5	44.5	42.4 – 47.4	10.0 ± 0.6	325.1	0.000	146
2,3,2	24.8	24.0 – 25.5	29.9	28.9 – 31.4	15.5 ± 1.2	83.2	0.021	59
2,3,3	23.4	22.0 – 24.8	30.6	28.6 – 33.7	11.0 ± 1.4	50.6	0.298	46
3,3,1	25.5	23.7 – 27.2	34.3	31.7 – 38.2	10.0 ± 1.1	58.3	0.105	46
3,3,2	24.5	19.5 – 28.4	32.6	28.1 – 44.8	10.3 ± 1.1	281.5	0.000	46
3,3,3	25.2	20.8 – 28.8	34.4	30.0 – 44.4	9.5 ± 1.0	226.5	0.000	46

Table 12. KT_{50} and KT_{90} values of 0h-heated F-killer® mat vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	p	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	29.5	20.1 – 40.7	64.1	45.0 – 197.3	3.8 ± 0.4	286.8	0.000	34
1,1,2	18.0	13.1 – 22.2	33.3	26.9 – 49.0	4.8 ± 0.5	158.2	0.000	34
1,1,3	12.1	10.3 – 13.8	18.6	16.1 – 23.3	6.8 ± 0.8	57.2	0.008	34
2,1,1	41.5	39.9 – 43.1	50.8	48.4 – 54.2	14.7 ± 1.7	39.3	0.246	34
2,1,2	22.4	14.6 – 30.0	59.8	41.9 – 138.8	3.0 ± 0.3	200.5	0.000	34
2,1,3	17.3	15.4 – 19.1	24.4	21.8 – 29.0	8.6 ± 1.1	57.1	0.008	34
3,1,1	31.5	28.6 – 34.4	42.2	38.2 – 49.9	10.1 ± 1.0	93.9	0.000	34
3,1,2	20.8	19.5 – 22.1	27.0	25.2 – 30.1	11.3 ± 1.6	11.7	1.000	34
3,1,3	19.4	17.9 – 20.9	25.1	23.2 – 28.6	11.5 ± 1.6	42.8	0.142	34
1,2,1	33.4	31.4 – 35.2	40.3	37.9 – 44.9	15.5 ± 2.0	58.9	0.005	34
1,2,2	29.3	27.6 – 30.9	39.5	36.7 – 43.9	9.8 ± 0.7	148.7	0.000	58
1,2,3	15.9	9.3 – 22.0	26.0	19.2 – 61.7	6.0 ± 0.6	355.6	0.000	34
2,2,1	31.1	18.2 – 45.5	49.2	36.5 – 20.6	6.4 ± 0.6	620.9	0.000	34
2,2,2	19.7	11.0 – 27.0	33.0	24.4 – 79.4	5.7 ± 0.5	417.5	0.000	34
2,2,3	16.5	15.3 – 17.7	21.2	19.6 – 23.9	11.9 ± 1.8	34.3	0.453	34
3,2,1	24.5	15.3 – 33.1	34.6	27.1 – 92.9	8.5 ± 0.8	480.9	0.000	34
3,2,2	18.3	9.4 – 26.5	33.0	23.3 – 90.2	5.0 ± 0.4	465.5	0.000	34
3,2,3	16.3	15.1 – 17.4	20.9	19.3 – 23.7	11.9 ± 2.0	9.4	1.000	34
1,3,1	30.8	29.4 – 32.1	37.1	35.3 – 40.0	15.7 ± 2.1	34.4	0.447	34
1.3,2	22.4	18.4 – 25.9	34.9	29.8 – 45.9	6.6 ± 0.7	130.4	0.000	34
1,3,3	20.4	19.0 – 21.6	26.4	24.6 – 29.4	11.4 ± 1.6	32.0	0.565	34
2,3,1	25.5	24.3 – 26.7	30.6	29.0 – 33.4	16.1 ± 2.4	15.8	0.997	34
2,3,2	22.6	20.5 – 24.6	30.0	27.3 – 35.2	10.4 ± 1.3	65.5	0.001	34
2,3,3	19.6	18.3 – 20.9	25.4	23.6 – 28.4	11.5 ± 1.7	9.3	1.000	34
3,3,1	21.9	20.5 – 23.2	28.5	26.6 – 31.5	11.2 ± 1.5	14.7	0.998	34
3,3,2	21.4	20.3 – 22.6	28.6	26.9 – 31.0	10.2 ± 0.8	99.5	0.001	58
3,3,3	17.0	15.5 – 18.5	22.0	20.1 – 25.7	11.5 ± 1.7	49.2	0.044	34

Table 13. KT_{50} and KT_{90} values of 0h-heated Happyhome® mat vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	22.1	15.6 – 28.1	45.7	35.2 – 76.1	4.1 ± 0.4	260.2	0.000	40
1,1,2	19.1	17.5 – 20.5	26.7	24.6 – 30.1	8.7 ± 0.9	59.4	0.039	42
1,1,3	17.1	15.7 – 18.4	24.1	22.1 – 27.1	8.6 ± 1.1	48.3	0.173	40
2,1,1	33.1	30.3 – 35.8	44.5	40.5 – 51.9	10.0 ± 0.9	131.4	0.000	42
2,1,2	33.0	22.0 – 44.4	68.9	49.7 – 181.5	4.0 ± 0.4	406.3	0.000	40
2,1,3	21.3	20.2 – 22.4	27.7	26.1 – 30.1	11.3 ± 1.3	38.2	0.000	42
3,1,1	37.9	36.4 – 37.4	46.0	43.9 – 49.1	15.3 ± 1.8	29.1	0.897	40
3,1,2	22.1	19.7 – 24.2	30.3	27.3 – 35.8	9.3 ± 0.9	117.7	0.000	42
3,1,3	20.7	19.6 – 21.8	26.9	25.2 – 29.3	11.4 ± 1.4	19.5	0.999	42
1,2,1	25.7	18.6 – 33.0	55.2	41.5 – 96.1	3.9 ± 0.3	278.5	0.000	40
1,2,2	28.4	24.1 – 32.4	44.1	37.9 – 58.3	6.7 ± 0.6	209.9	0.000	42
1,2,3	18.8	17.5 – 20.1	25.6	23.6 – 28.6	9.7 ± 1.3	49.2	0.150	40
2,2,1	33.5	29.3 – 37.9	49.5	42.8 – 65.2	7.6 ± 0.7	211.7	0.000	42
2,2,2	26.4	24.8 – 27.8	35.1	32.9 – 38.2	10.4 ± 1.1	40.3	0.458	40
2,2,3	18.4	16.6 – 20.1	26.0	23.6 – 30.0	8.5 ± 1.0	55.6	0.051	40
3,2,1	32.6	30.3 – 34.8	44.3	40.9 – 49.9	9.6 ± 0.9	87.4	0.000	42
3,2,2	24.1	23.0 – 25.3	31.0	29.3 – 33.4	11.8 ± 1.3	38.5	0.625	42
3,2,3	17.5	12.3 – 22.5	30.6	23.7 – 50.0	5.3 ± 0.5	288.4	0.000	40
1,3,1	32.0	29.8 – 34.0	42.9	39.7 – 48.0	10.1 ± 0.9	83.0	0.000	42
1.3,2	31.6	6.6 – 57.3	59.8	39.1 – 5932.5	4.6 ± 0.4	1111.3	0.000	40
1,3,3	24.6	22.7 – 26.4	30.8	28.5 – 35.6	13.0 ± 1.4	98.9	0.000	42
2,3,1	23.5	4.9 – 43.8	42.7	26.8 – 1156.4	4.9 ± 0.4	1220.3	0.000	40
2,3,2	22.1	20.9 – 23.2	28.8	27.2 – 31.3	11.0 ± 1.2	43.7	0.398	42
2,3,3	24.7	23.7 – 25.7	29.7	28.4 – 31.9	15.8 ± 2.0	30.9	0.896	42
3,3,1	28.1	25.5 – 30.4	37.8	34.4 – 43.7	9.9 ± 0.9	120.6	0.000	42
3,3,2	20.7	0.0 – 50.4	24.2	21.0 – 9647.0	5.8 ± 0.5	1314.9	0.000	40
3,3,3	20.3	19.0 – 21.6	26.3	24.6 – 29.1	11.4 ± 1.6	32.5	0.796	40

Table 14. KT_{50} and KT_{90} values of 15h-heated Homemat® mat vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	25.2	22.0 – 28.2	44.8	39.7 – 52.5	5.1 ± 0.4	124.4	0.000	61
1,1,2	18.9	17.6 – 20.1	24.4	22.8 – 27.2	11.5 ± 1.7	16.9	1.000	55
1,1,3	24.5	23.0 – 26.0	32.1	30.0 – 35.4	10.9 ± 1.4	23.8	1.000	55
2,1,1	49.2	45.7 – 52.5	66.3	61.3 – 74.3	9.9 ± 0.8	137.7	0.000	55
2,1,2	30.8	28.9 – 32.7	41.4	38.7 – 45.5	10.0 ± 1.0	68.4	0.105	55
2,1,3	33.8	32.0 – 35.5	45.1	42.5 – 48.8	10.3 ± 1.1	35.6	0.996	61
3,1,1	46.4	41.4 – 51.0	67.5	60.4 – 80.4	7.9 ± 0.6	218.7	0.000	55
3,1,2	34.8	33.0 – 36.5	46.5	43.9 – 50.1	10.2 ± 1.0	52.9	0.759	61
3,1,3	35.8	33.8 – 37.6	50.7	47.7 – 54.8	8.5 ± 0.7	59.2	0.540	61
1,2,1	37.6	14.4 – 55.6	59.5	42.7 – 314.0	6.4 ± 0.5	1994.9	0.000	61
1,2,2	33.3	27.6 – 38.4	58.6	50.2 – 74.1	5.2 ± 0.4	275.1	0.000	61
1,2,3	30.8	29.1 – 32.4	40.8	38.4 – 44.4	10.4 ± 1.1	40.7	0.979	61
2,2,1	41.2	35.8 – 46.1	65.5	57.5 – 80.1	6.4 ± 0.5	261.6	0.000	61
2,2,2	41.5	37.0 – 45.7	64.4	57.8 – 74.9	6.7 ± 0.5	166.8	0.000	55
2,2,3	28.9	26.5 – 31.2	38.8	35.5 – 44.4	10.0 ± 1.0	108.0	0.000	55
3,2,1	45.2	43.5 – 46.8	55.4	53.0 – 58.5	14.5 ± 1.5	41.6	0.910	55
3,2,2	38.8	29.8 – 47.0	63.1	51.5 – 93.0	6.0 ± 0.4	649.7	0.000	61
3,2,3	39.5	36.7 – 42.1	54.4	50.5 – 60.2	9.2 ± 0.8	108.3	0.000	61
1,3,1	37.2	28.6 – 45.4	67.3	54.2 – 98.8	5.0 ± 0.3	556.6	0.000	61
1.3,2	27.6	26.0 – 29.0	36.3	34.1 – 39.7	10.7 ± 1.3	41.6	0.908	55
1,3,3	29.0	27.3 – 30.7	40.5	38.0 – 44.1	8.9 ± 0.9	37.0	0.994	61
2,3,1	51.5	46.3 – 56.6	78.7	70.0 – 94.7	7.0 ± 0.5	197.6	0.000	55
2,3,2	47.6	45.3 – 49.9	62.6	59.2 – 67.5	10.8 ± 0.9	72.8	0.054	55
2,3,3	38.7	37.0 – 40.4	50.0	47.5 – 53.4	11.6 ± 1.1	60.8	0.275	55
3,3,1	38.1	27.8 – 47.7	61.0	48.6 – 100.7	6.3 ± 0.4	855.8	0.000	61
3,3,2	39.0	36.6 – 41.3	53.1	49.6 – 58.2	9.6 ± 0.9	81.1	0.013	55
3,3,3	37.6	35.4 – 39.7	48.8	45.7 – 53.6	11.3 ± 1.1	83.0	0.009	55

Table 15. KT_{50} and KT_{90} values of 15h-heated F-killer® mat vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	48.4	40.7 – 55.4	92.8	78.2 – 119.6	4.5 ± 0.3	335.2	0.000	70
1,1,2	29.8	22.7 – 36.0	66.0	54.3 – 88.4	3.7 ± 0.3	352.0	0.000	70
1,1,3	24.3	14.0 – 33.1	42.1	31.1 – 88.5	5.4 ± 0.4	1082.6	0.000	70
2,1,1	58.8	54.2 – 63.3	86.9	79.5 – 98.3	7.6 ± 0.5	194.5	0.000	70
2,1,2	41.8	33.3 – 49.5	90.2	74.2 – 124.1	3.8 ± 0.3	382.5	0.000	70
2,1,3	36.1	33.5 – 38.6	49.6	45.8 – 55.5	9.3 ± 0.8	126.9	0.000	68
3,1,1	56.1	50.1 – 61.6	89.0	79.7 – 104.7	6.4 ± 0.4	255.1	0.000	68
3,1,2	32.9	16.4 – 47.1	63.8	44.8 – 150.3	4.5 ± 0.3	1669.5	0.000	70
3,1,3	35.1	18.4 – 50.1	76.1	52.9 – 185.8	3.8 ± 0.2	1514.2	0.000	70
1,2,1	38.9	28.6 – 49.4	94.1	71.0 – 155.3	3.3 ± 0.2	623.7	0.000	70
1,2,2	25.6	21.3 – 29.2	35.3	30.7 – 45.9	9.1 ± 0.9	332.3	0.000	68
1,2,3	29.9	4.6 – 50.5	56.3	35.1 – 773.5	4.7 ± 0.3	2822.4	0.000	70
2,2,1	45.9	42.7 – 48.9	66.0	61.3 – 72.7	8.1 ± 0.6	123.9	0.000	68
2,2,2	37.9	1.9 – 68.7	72.3	44.6 – 14141.3	4.6 ± 0.3	3614.3	0.000	70
2,2,3	26.9	20.6 – 32.7	52.9	43.3 – 71.1	4.4 ± 0.3	411.6	0.000	70
3,2,1	51.2	49.4 – 53.0	64.1	61.4 – 67.7	13.2 ± 1.2	78.6	0.179	68
3,2,2	30.4	20.9 – 39.4	63.0	48.0 – 100.5	4.0 ± 0.3	779.0	0.000	70
3,2,3	45.3	40.7 – 49.6	71.7	64.5 – 83.0	6.4± 0.4	206.4	0.000	68
1,3,1	49.0	36.7 – 59.7	61.7	52.7 – 121.6	12.8 ± 1.2	1206.7	0.000	68
1.3,2	24.3	22.8 – 25.7	31.8	29.8 – 34.9	10.9 ± 1.4	15.1	1.000	68
1,3,3	33.7	31.6 – 35.6	44.9	42.0 – 49.3	10.3 ± 1.1	91.5	0.043	70
2,3,1	47.9	45.7 – 50.1	61.3	58.2 – 65.7	12.0 ± 1.1	89.5	0.042	68
2,3,2	36.2	34.4 – 38.0	48.5	45.8 – 52.4	10.1 ± 1.0	62.5	0.665	68
2,3,3	43.9	40.8 – 46.8	64.9	60.2 – 71.4	7.6 ± 0.6	114.4	0.000	68
3,3,1	54.5	52.3 – 56.6	68.0	64.9 – 72.2	13.4 ± 1.2	84.3	0.087	68
3,3,2	50.3	47.8 – 52.7	66.4	62.8 – 71.4	10.6 ± 0.9	93.8	0.021	68
3,3,3	48.9	46.2 – 51.5	64.8	61.0 – 70.1	10.5 ± 0.9	108.1	0.001	68

Table 16. KT_{50} and KT_{90} values of 15h-heated Happyhome® mat vaporizer against the female mosquito of *Ae. albopictus*

position	KT_{50} (min)		KT_{90} (min)		slope ± SE	χ^2	*p*	df
	KT_{50}	95% CL	KT_{90}	95% CL				
1,1,1	48.3	46.2 – 50.4	65.7	62.3 – 70.2	9.6 ± 0.8	89.2	0.274	82
1,1,2	33.7	30.0 – 37.1	52.1	46.2 – 62.9	6.7 ± 0.6	169.7	0.000	50
1,1,3	22.8	21.1 – 24.4	34.2	31.6 – 37.9	7.3 ± 0.8	92.5	0.201	82
2,1,1	68.0	62.1 – 73.8	111.5	100.6 – 128.6	6.0 ± 0.4	250.2	0.000	82
2,1,2	43.1	40.0 – 46.1	61.5	56.8 – 68.6	8.3 ± 0.7	166.3	0.000	82
2,1,3	35.4	31.7 – 38.8	54.9	49.3 – 63.9	6.7 ± 0.5	219.3	0.000	82
3,1,1	52.5	48.4 – 56.4	81.9	75.4 – 91.0	6.7 ± 0.4	176.5	0.000	82
3,1,2	45.7	43.6 – 47.8	62.0	58.8 – 66.4	9.7 ± 0.8	50.3	0.998	82
3,1,3	43.6	36.9 – 49.8	79.2	68.2 – 98.6	4.9 ± 0.3	405.2	0.000	82
1,2,1	43.6	41.7 – 45.6	59.1	55.9 – 63.3	9.8 ± 0.8	74.0	0.723	82
1,2,2	38.5	36.0 – 41.0	54.2	50.4 – 59.9	8.6 ± 0.7	128.8	0.001	82
1,2,3	21.8	13.5 – 29.5	38.3	28.4 – 73.5	5.2 ± 0.4	1061.7	0.000	82
2,2,1	59.9	53.8 – 65.7	99.7	88.8 – 117.5	5.8 ± 0.4	298.0	0.000	82
2,2,2	40.0	38.0 – 41.9	53.9	50.9 – 57.9	9.9 ± 0.9	74.3	0.714	82
2,2,3	26.0	24.4 – 27.4	34.3	32.2 – 37.5	10.5 ± 1.2	48.8	0.999	82
3,2,1	43.6	36.3 – 50.6	64.0	54.6 – 85.7	7.7 ± 0.6	721.3	0.000	82
3,2,2	46.3	44.1 – 48.3	62.8	59.6 – 67.2	9.6 ± 0.8	59.4	0.972	82
3,2,3	30.2	27.8 – 32.5	45.5	41.8 – 51.0	7.2 ± 0.6	122.2	0.003	82
1,3,1	38.1	36.1 – 39.9	51.1	48.2 – 55.1	10.0 ± 1.0	43.5	1.000	82
1.3,2	31.0	29.4 – 32.6	41.4	39.0 – 44.9	10.2 ± 1.1	73.9	0.726	82
1,3,3	24.7	23.2 – 26.1	32.7	30.6 – 35.7	10.5 ± 1.2	53.3	0.994	82
2,3,1	45.4	42.7 – 47.9	61.5	57.7 – 67.1	9.7 ± 0.8	120.4	0.004	82
2,3,2	24.4	15.5 – 33.2	47.0	34.5 – 84.1	4.5 ± 0.3	1129.0	0.000	82
2,3,3	31.2	29.4 – 32.9	43.1	40.5 – 46.8	9.1 ± 0.9	60.8	0.962	82
3,3,1	52.5	50.2 – 54.6	64.8	61.6 – 69.5	14.0 ± 1.3	116.0	0.008	82
3,3,2	44.5	42.4 – 46.5	60.3	57.1 – 64.6	9.7 ± 0.9	62.6	0.946	82
3,3,3	37.0	34.4 – 40.0	51.1	47.3 – 57.0	9.2 ± 0.8	149.1	0.000	82

Table 17. Knockdown speed of test products

Type	Test product	Heated	Average KT_{50}	Average KT_{90}	Fastest KT_{90}	position	Latest KT_{90}	Position
Liquid	F-killer®	1 d	23.9 ± 1.5	37.8 ± 2.5	17.8 (14.9 – 24.5)	(1,1,3)	69.4 (53.7 – 118.2)	(1,2,1)
		35 d	27.7 ± 1.1	37.1 ± 1.4	17.7 (16.4 – 20.0)	(1,1,3)	46.0 (40.5 – 58.5)	(3,3,2)
	Happyhome®	1 d	32.0 ± 1.7	55.9 ± 3.0	32.2 (25.8 – 44.6)	(1,1,2)	106 (77.6 – 192.5)	(2,2,1)
		45 d	25.0 ± 1.8	34.5 ± 2.4	12.7 (11.3 – 15.3)	(1,1,2)	54.9 (51.5 – 59.9)	(2,1,1)
	Homemat®	1 d	20.1 ± 0.9	33.4 ± 1.8	16.6 (14.4 – 20.4)	(1,1,2)	57.1 (45.9 – 87.2)	(2,3,1)
		45 d	21.3 ± 1.3	32.2 ± 2.0	13.3 (11.8 – 15.8)	(1,2,3)	53.1 (39.5 – 103.3)	(1,3,1)
	Homemat Home Solution®	1 d	21.1 ± 1.0	29.3 ± 1.5	14.5 (12.8 – 17.2)	(1,1,2)	49.4 (39.2 – 86.7)	(1,2,1)
		45 d	30.7 ± 1.6	52.0 ± 2.9	15.7 (14.1 – 18.4)	(1,1,2)	70.8 (50.1 – 260.0)	(2,2,3)
Mat	F-killer®	0 h	22.9 ± 1.3	33.6 ± 2.2	18.6 (16.1 – 23.3)	(1,1,3)	64.1 (45.0 – 197.3)	(1,1,1)
		12 h	40.1 ± 2.0	64.6 ± 3.2	31.8 (29.8 – 34.9)	(1,3,2)	94.1 (71.0 – 155.3)	(1,2,1)
	Happyhome®	0 h	25.2 ± 1.1	37.2 ± 2.3	24.1 (22.1 – 27.1)	(1,1,3)	68.9 (49.7 – 181.5)	(2,1,2)
		15 h	39.7 ± 2.2	58.1 ± 3.6	32.7 (30.6 – 35.7)	(1,3,3)	111.5 (100.6 – 128.6)	(2,1,1)
	Homemat®	0 h	25.1 ± 1.1	37.1 ± 2.0	20.3 (18.5 -23.5)	(1,1,3)	59.3 (55.1 – 65.3)	(2,1,1)
		15 h	36.4 ± 1.5	52.5 ± 2.5	24.4 (22.8 – 27.2)	(1,1,2)	78.7 (70.0 – 94.7)	(2,3,1

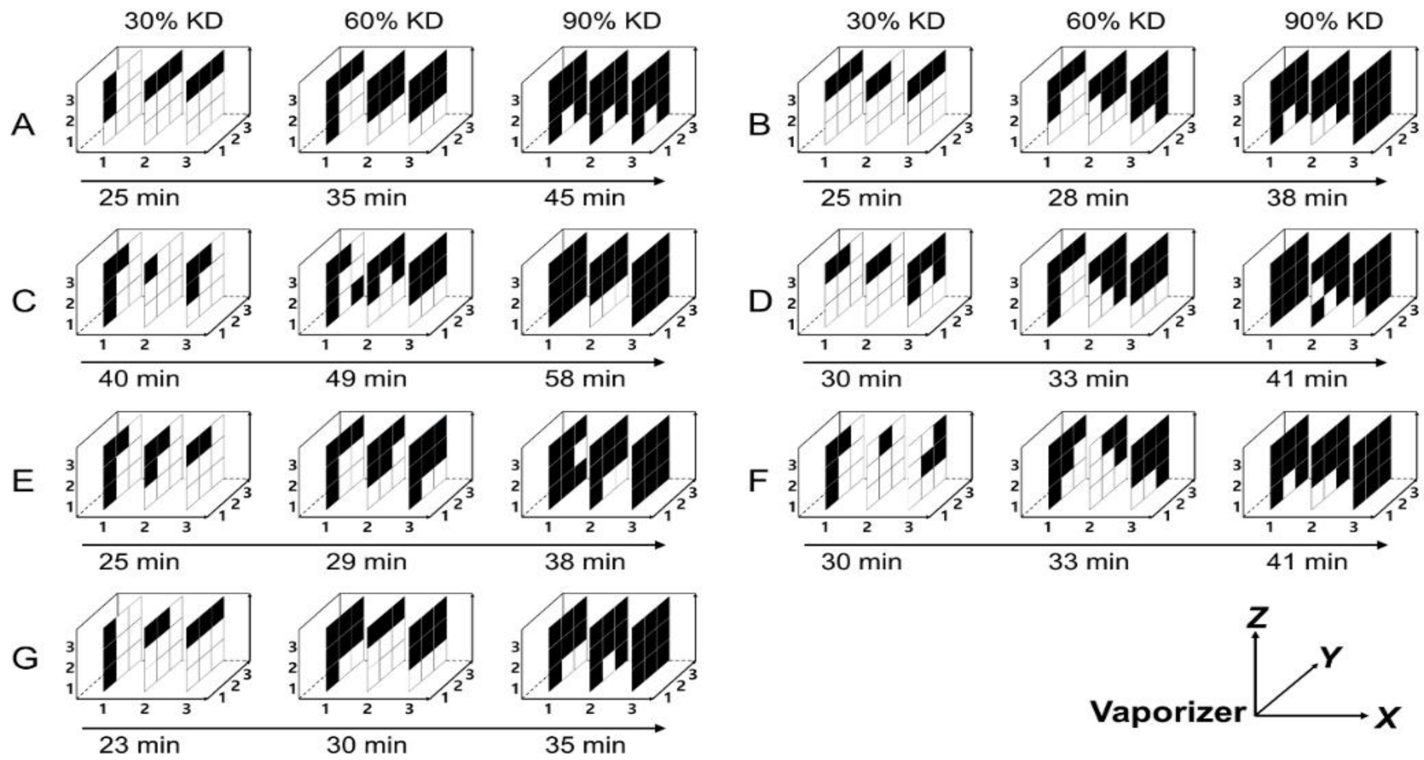

Figure 7. Comparisons of knock-down speed and spatial distribution of two different vaporizers applied [JT6]in a Peet-Grady chamber; (A)F-killer® liquid vaporizer (active ingredient: prallethrin), (B)F-killer® mat vaporizer (allethrin), (C)Happyhome® liquid (prallethrin), (D)Happyhome® mat (prallethrin), (E)Homemat® liquid (prallethrin), (F)Homemat® mat (prallethrin), and (G)Homemat Home Solution® liquid (metofluthrin). Black sections indicate that mosquitoes in the corresponding net show > 90% of knock-down effect (based on the average KD_{90} values). See

Supplementary Information Tables for the full data.

4. Efficacy of mat and liquid vaporizers in a field-simulation test

To examine the knock-down and insecticidal activity of liquid and mat vaporizers (Homemat® products) in the actual field condition, a field-simulation test in a 62 m^3 room was conducted (Fig. 8). Up to two hours after operating the heaters, neither liquid nor mat type insecticides display knock-down activity to the mosquitoes, and the toxic response was observed at 3 h observation in both vaporizers. In the knock-down activity, mat type vaporizer showed relatively greater activity than liquid vaporizer did (72.8 ± 11.7% and 56.7 ± 7.3%, respectively), but no statistical difference was found ($P = 0.270$). On the other hand, in mortality, mat type was significantly less active than liquid type (57.2 ± 6.7% and 79.2 ± 2.7%, respectively, $P = 0.013$), indicating better efficacy in liquid type vaporizer than mat type product.

As for the spatial distribution in toxicity, when mat type insecticide was used, mosquitoes positioned in upper netting cages (N2, M2, and F2) showed significantly greater knock-down activity and 24 h mortality (97.8 ± 2.2% and 70.0 ± 6.7% in average, respectively) than mosquitoes in under cages (N1, M1, and F1, 47.8 ± 7.3% and 44.4 ± 4.4% in average, $P = 0.003$ and 0.033, respectively), whereas liquid vaporizers did not show any vertical difference in knock-down and insecticidal activity ($P = 0.219$ and 0.150, respectively). Based on the distance from the insecticides, there were no statistical difference in knock-down and insecticidal activity among near (N), middle (M), and far (F) nets both in the liquid ($P = 0.269$ and 0.867) and mat ($P = 0.950$ and 0.622) vaporizers.

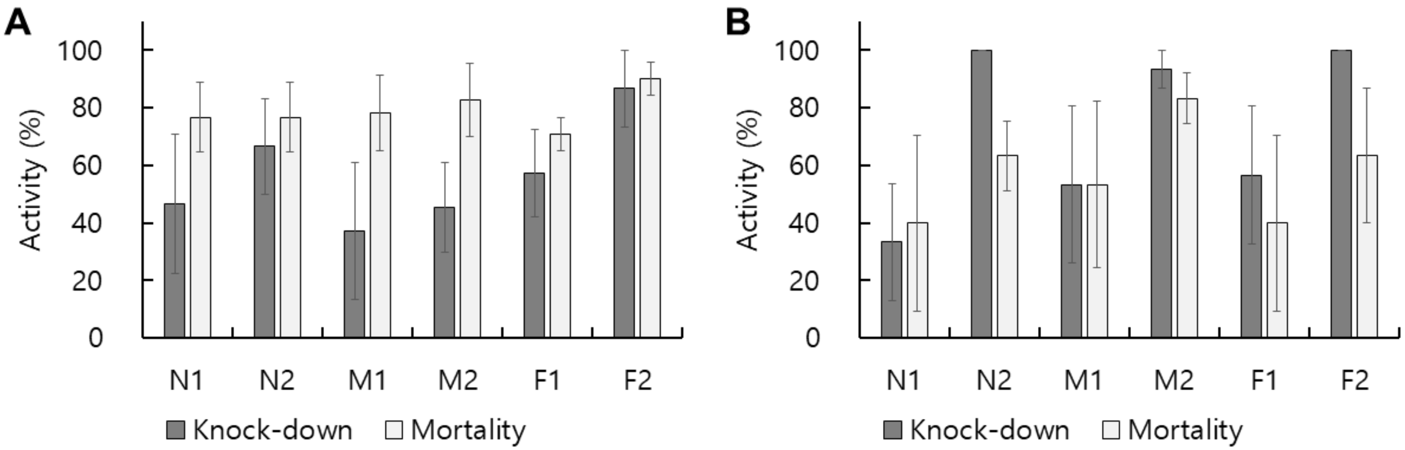

Figure. 8. Knock-down and insecticidal activity of insecticide vaporizers in a field test area (62 m^3). (A) Homemat® liquid-type vaporizer, and (B) Homemat® mat-type vaporizer (Tukey HSD test, $P < 0.05$).

Discussion

In the present study, mosquitoes located in the upper position of the test chamber and the field-simulated room displayed faster knock-down activity, indicating the accumulation of active ingredients at the ceiling area of insecticides-treated space. Previous studies in modeling simulations and chemical analyses showed the same patterns (Matoba et al. 1994, Ramesh and Vijayalakshmi 2001, Vesin et al. 2013), that the heated particles of the vaporizers moved upward with the rising flow then deposited on the ceiling. The evaporation can be directly influenced by the temperature settings of heating devices. As shown in Figs. 5 and 6, heaters with higher temperatures resulted in faster evaporation speed of F-killer® liquid vaporizer than the other ones, although the chemical analyses showed the prallethrin concentration in the remaining liquid content was constant. Likewise, a previous study in mat vaporizers showed that the difference in temperature of the heaters affected the release of the active ingredient into the air significantly, also contribute to the difference in the knock-down and insecticidal activity (Amalraj et al. 1992). On the other hand, the three heaters of Happyhome® liquid vaporizers had no difference in temperature, but the evaporation patterns in daily monitoring showed a wide difference in evaporation speed in different heating devices. This may indicate that not only the temperature of heaters but also the internal structure or chemical composition of insecticidal products may affect the evaporation profiles as well. In most cases, only the insecticidal products are to be subjected to the legal regulation or examination for the registration of household insecticides, but it always requires the heaters to operate the electric vaporizers, therefore the test guidelines ought to expand their boundaries to cover the heating devices as well.

Several test guidelines for the efficacy of household insecticides may either not clearly represent the real use of insecticides, or some important formulation-specific features are not fully considered. For example, as shown in Table 18, [JT7]test guidelines from WHO Pesticide Evaluation Scheme (WHOPES 2009) require testing in relatively larger settings than the guidelines of other countries, that 1.8 × 1.8 × 1.8 m Peet-Grady chamber for a lab-scale test and at least a 30 m^3 size room for a field test are recommended for the efficacy test. However, it does not specify to monitor how evaporation affects the composition or stability of active ingredients, which is crucial for the products with multi-day usage. US Environmental Protection Agency does not specify the test area but suggests to test in an actual application site, and the efficacy must be > 95% when the product is applied as following the manufacture's instruction (EPA 1998). In the meanwhile, other countries give more detailed guidelines for vaporizers. Malaysian test guidelines suggest testing the efficacy at 0, 50, and 90% of evaporation periods (based on the label) for the liquid vaporizers as well as at 2, 4, 6, and 8 h of heating time for mat vaporizers. Although only the lab-scale test areas (0.7 × 0.7 × 0.7 m or 1.8 × 1.8 × 1.8 m) are recommended, the efficacy of test products must ensure to be equivalent or better than that of Malaysian Standard reference products. However, unlike the test guideline for aerosol insecticides, liquid and mat vaporizers only require the 40 min knock-down activity result, not the 24 h mortality, which cannot examine the recovery from the knock-down activity or slow insecticidal action of the test products (Pesticides Board Malaysia 2009). Compared to the test guidelines from other countries or organization, Chinese guidelines seems more comprehensive. For example, for liquid and mat vaporizers, it recommends testing the efficacy at five points of evaporation periods (0, 20, 40, 60, 80, and 100%) in lab-scale as well as field test areas with at least of 28 m^3 size room (SAC 2009a, 2009b, 2009c). As of 2019, the registration for household insecticides in South Korea is being regulated by the Ministry of Environment under the Act on consumer chemical products and biocides safety (ME 2020), which was used to be the Ministry of Food and Drug Safety under Pharmaceutical affairs act (MFDS 2016). The present test guideline was originally proposed by MFDS, which is currently under an amendment to represent the actual usage in household environments better since the test guidelines only recommend testing in a lab-scale setting (MFDS 2014).

Table 18. Comparison of test guidelines for liquid and mat-type vaporizers

Country/ Organization	Regulatory body	Test area	Note
WHO	-	Lab scale: 1.8×1.8×1.8 m Field test: minimum of 30 m^3	- WHO does not involve in registration and only provide test guidelines
USA	EPA	Not specified (field condition)	- At least 95% of efficacy must be confirmed when followed the label's instruction
Malaysia	DOA[a]	0.7×0.7×0.7 m, 1.8×1.8×1.8 m, or ϕ0.2×0.8 m cylinder	- Efficacy equivalent or better than MS reference products - Liquid: 0, 50, and 90% evaporation periods - Mat: 2, 4, 6, and 8 h evaporation periods
China	MARA[b]	Lab scale: 0.7×0.7×0.7 m or ϕ0.2×0.7 m cylinder Field test: minimum of 28 m^3	- 0, 20, 40, 60, 80, and 100% evaporation periods should be tested for efficacy
South Korea	ME (MFDS)[c]	0.6×0.6×1.3 m, 1.8×1.8×1.8 m, or ϕ0.2×0.8 m cylinder	

[a]Department of Agriculture

[b]Ministry of Agriculture and Rural Affairs

[c]As of 1 Jan 2019, legal body in South Korea for household insecticides is shifted to Ministry of Environment from Ministry of Food and Drug Safety.

Based on the evaporation test result as well as chemical analyses, the theoretical vaporization of the active ingredient, prallethrin, in liquid and mat vaporizers were 47.2 ± 5.7 and 37.4 ± 5.7 μg/ m3, respectively, during the test period (3 h) in the field-simulated test room. Meanwhile, bioassay results in the 62 m3 room showed that the mat type insecticide exhibited a better knock-down effect than the liquid vaporizer did, especially to the mosquitoes locating in the upper position of the netting cages in the room (Fig. 6). This result may come from the difference in the delivery methods of heat to the vaporizers. Whereas the heat energy from the heating plate (84.9 ± 1.4℃, Fig. 4) is transferred to the wick using air as a medium in the liquid vaporizers, the heat in higher temperature (120.1 ± 2.4℃) is directly transmitted to the mat products via direct contact, which may result in rapid evaporation with higher vapor pressure. Nonetheless, the liquid vaporizer seemed to perform better than the mat type in the insecticidal activity. One of the possible explanations would be the difference in formulation, that in the liquid vaporizer, not only the active ingredient but also the isoparaffinic hydrocarbon solvents [JT8][p9]are evaporated together into the air in the treated area. The fumigated hydrocarbon may assist better attachment or penetration of the insecticide into the cuticular layer of mosquitoes. In the previous study in our laboratory, solvent-based aerosol insecticides exhibited significantly greater effect than water-based ones, presumably due to the lowered surface tension of hydrocarbon (Yoon et al. 2020), and another study showed that surface tension of insecticide solution and insecticidal activity seem to be inversely proportional (Tak and Isman 2017).

As for the volume of the test spaces, most electric vaporizers showed < 60 min of average KT_{90} values as well as complete mortality when tested in the Peet-Grady chamber against female adults of *Ae. albopictus* when the insecticides were operated for 1 h. However, in the field-simulated test, no toxic response was observed up to 2 h of application, and liquid and mat vaporizers showed 79.2 ± 3.9% and 57.2 ± 9.0% of 24 h mortality in average, respectively, when the insecticides were operated for 3 h (Fig. 8). This limited efficacy indicates that it might not be easy to satisfy the public and consumers' expectations for an insecticide, although it can meet the legal standards. Similar results were found in previous studies, that in a field test on mosquito coils using metofluthrin and esbiothrin as active ingredients, the coils showed 84% and 83% of mortality, respectively, against female Anopheles gambiae sensu lato mosquitoes when tested in huts built with bricks and cement, which were lower than the standard criteria (> 95%) proposed by WHOPES (Lukwa and Chiwade 2008). Katsuda et al. (2008) also observed allethrin-based mosquito coils to be effective against the Southern house mosquito, *Culex pipiens quinquefasciatus*, and *Anopheles dirus* only at a high concentration (0.5%) that is 2 times the conventional dosage, but it still exhibited poor efficacy against *Ae. aegypti* even at the high concentration when the bioassay was conducted in a 25 m^3 room. Due to their small test volume in the conventional test guidelines including the cylinder method, glass container, or Peet-Grady chamber method which generally can yield a higher aerial concentration of test substances, it can cause a great deal of deviation in activity from the actual application. For those vaporizing insecticides whose efficacy depends on the aerial concentration of active ingredients, a more realistic approach should be adopted (i.e., larger test space) which can give good reproductivity and reliability in data. For example, a previous study showed that when the chamber size was increased from 6 m^3 to 40 m^3, the KT_{90} values also increased 5.8-fold (80.17 min to 217.49 min) when tested with a 0.88% (w/v) of transfrluthrin-containing liquid vaporizer (Jeyalakshmi T et al. 2014). Since it is impossible to define a 'typical' size of a room for insecticide treatment, a mathematical approach in developing the conversion dynamics of insecticides based on the different sizes of the test area would be further studied.

Recently, new types of formulations including passive emanators, candles, motorized fans, or wearable devices using conventional and newly developed insecticides as well as botanicals, especially plant essential oils, have been developed and tested (Norris and Coats 2017, Rodriguez et al. 2017, Hazarika et al. 2020). Amongst those active ingredients, metofluthrin and transfluthrin have lesser polarity and low vapor pressure than traditional pyrethroids hence can evaporate at ambient temperature without using an external energy source (Ogoma et al. 2012), which provides unique sub-lethal effects of spatial repellency (Ogoma et al. 2012, Buhagiar et al. 2017, Bibbs et al. 2019). Since most of the current test guidelines only focus on testing acute toxicity including knock-down activity and mortality, efforts in the development of new test methodologies that can incorporate those new formulations and sub-lethal effects should also be given in regulatory agencies while they are trying to set up more realistic and comprehensive test guidelines for the conventional insecticides.

To summarize, the evaporation of seven commercial electric vaporizers were examined in the present study, and there were differences in evaporation speed, presumably due to the difference in temperature settings as well as internal structures. When the knock-down and insecticidal activity were examined according to the conventional test guidelines, all products seemed to perform acceptable efficacy until the end of their evaporation periods, satisfying the regulatory standards. However, the knock-down and insecticidal activity of electric vaporizers significantly decreased when tested in a field-simulated space, suggesting the need to establish more realistic test guidelines.

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Abstract in Korean

액체 및 매트 전자모기향의 흰줄숲모기에 대한 시공간적 살충활성 연구

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초록

전자 모기 훈증기들은 살충성분을 연속적으로 공기 중에 방출하기 때문에, 처리 공간 내에서의 침적과 공간적 분포를 이해하여 적절히 관측해야 한다. 해당 연구에서, 시판되는 7종의 액상과 매트 전자 모기 훈증기의 흰줄숲모기, *Aedes albopictus* 에 대한 녹다운 및 살충효과를 평가했다. 3개 회사에서 만들어진 살충제품들은 기기 형태나 살충성분의 농도 등 차이가 있으며, 시간별 그리고 일별 모니터링에서 대체로 꾸준한 휘산량을 보이는 경향이 있었다. 피트-그래디 챔버와 모의 실공간 상부에 위치한 모기들이 가장 빠른 녹다운을 보여주었고, 이는 살충성분들이 급격히 천장부로 훈증되는 경향이 있음을 보인 증거이다. 훈증기들이 피트-그래디 챔버 내에서 KT_{90}값을 60분 이내에 나타냈으나, 모의 실공간 실험 2시간 내에 어떤

녹다운이나 살충효과도 보이지 않았으며, 3시간 실험했을 때 매트에서 72.8 ± 11.7%, 액상에서 56.7 ± 7.3%의 녹다운 결과를 각각 보여줬다. 모의 실공간 실험에서 전자 모기 훈증기들의 효과가 제한적으로 나타난 것은 좀 더 현실적이고 엄격한 가정용 살충제 평가 기준이 필요하다는 것을 제시한다.

검색어: 흰줄숲모기, 전자모기향, 효능, 실험 가이드라인, 살충제, 피트-그래디 챔버

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