EVALUATION OF THREE BATTERY- POWERED BACKPACK SPRAYERS TO APPLY ADULTICIDES AGANIST *AEDES AEGYPTI*

MUHAMMAD FAROOQ, STEVEN SMOLEROFF, KAI BLORE,
WHITNEY A. QUALLS, AND RUI-DE XUE

Anastasia Mosquito Control District, 120 EOC Drive, St. Augustine, FL 32092

Subject Editor: Alden Estep

ABSTRACT

Backpack mist sprayers have been used for control of adult mosquitoes on limited small scales. A study was conducted to evaluate three battery powered backpack sprayers to assess their suitability to apply adulticides. The three sprayers are the Field King 190515, the Ryobi One+, and the Tornado (model Spray Mate). The Field King operated at 276 kPa, the Ryobi One+ at 414 kPa, and the Tornado at 414kPa (option at 276 or 414 kPa) were used for this study. Due to higher flow rates of these sprayers compared to ULV sprayers, Aqualuer™ 20-20 was used as an adulticide by diluting with water. To achieve application rates of 9, 37, 74, and 148 mL/ha for different sprayers at their flow rates, the formulation was diluted 26 to 1,209 times. All dilutions were replicated three times and one application rate of all sprayers was tested in a day. Adult female *Aedes aegypti* mosquitoes at 25 /cage were used for the experiment. Caged mosquitoes were placed on the poles before spray and removed after the spray ended. Mortality was recorded at 24 -h after treatment. The Tornado backpack sprayer provided the highest mortality, better than or similar to Ryobi one+ and Field King provided the least mortality. The sprayers were effective up to 3.0 m from the spray line. By increasing application rate from 9 to 74 mL/ha, mortality increased but did not increase as the rate went from 74 to 148 mL/ha. Application with the Tornado at 74 mL/ha was the best option for short distance control.

Key Words: Alternate Technique, *space spray*, Aqualuer™ 20-20, mosquito control, permethrin

INTRODUCTION

In spite of global efforts to control vector borne diseases, they are still a threat to human health. The issue is critical in societies where hygienic conditions are bad and where economies cannot support the variety of vector control activities needed for an integrated vector control program. Some of these countries that are most impacted may not have any vector control activities. There may be instances where a few or no tools are available, and these programs must use whatever is available. Using backpack sprayers for application of adulticides can be ranked among such activities.

Backpack sprayers have been designed, manufactured, and marketed over the years as convenient means for application of liquid products (Kardatzke et. al. 1981). These sprayers have been in use for multiple approaches to control mosquitoes such as larviciding (Kurucz and Pettit 2018; Bohari et al. 2020; Jacups et al. 2013), barrier applications (Kurucz and Pettit 2018), applications to cryptic sites (Harwood et al. 2016; Jacups et al. 2013), and indoor residual sprays (Matthews et al. 2014; Obenauer et al. 2015). Some of these sprayers have even been used as blowers to clean after maintenance work and lawn mowing. Xue et al. (2012) evaluated two backpack sprayers developed for ULV applications for their effectiveness against *Ae. albopictus* Skuse and *Culex quinquefasciatus* Say. Few backpack sprayers have been developed exclusively for application of mosquito adulticides. One aspect which is common to all these sprayers is that they are made for small scale applications.

Studies have been conducted to investigate the use of backpack sprayers as non-traditional ways to control mosquito populations. Lloyd et al. (2017) used a backpack sprayer to apply the insect growth regulator pyriproxyfen to tire piles in a study to investigate the possibility of auto-dissemination. Xue and Fulcher (2021) used different backpack sprayers to study the efficacy of orange oil as an adulticide to control of *Aedes aegypti* (L). and *Cx. quinquefasciatus.* Conover et al. (2015) tested three back sprayers of which two were battery powered and one was a hand pump operated backpack sprayer to apply adulticides for mosquito control at distances of 1.8 m. Luo et al. (2019) evaluated the efficacy of a mixture of permethrin and methoprene applied with a backpack sprayer against larval and adult *Cx. quinquefaciatus.* Ponlawat et al. (2017) studied the efficacy of a hand-held thermal fogger and a backpack ULV sprayer using a combination of two

different adulticides and an insect growth regulator for reduction of indoor *Ae. aegypti* populations.

Until recently, these sprayers were either manual continuous pumping systems or motorized. The manual pumping systems require to pump every 1-3 seconds based on flow rate of the nozzles. For some of the nozzles, it must be pumped continuously to maintain pressure and spray quality. The motorized sprayers have removed pumping effort but have noise and vibration that may pose health issues to the operators using these sprayers on a regular basis. Due to these factors and with the development of high capacity but small sized batteries, battery powered versions of these sprayers are being introduced by manufacturers of the earlier backpack sprayer systems. Since the introduction of the battery powered sprayers, more interest is being generated in of these sprayers.

The use of backpack sprayers is a logistical compromise to conduct small scale adulticide applications. These have been considered as tools of convenience when treating small areas with adulticides (Kardatzke et al. 1981; Xue et al. 2012). This study compared three commercial battery powered backpack misting sprayers for adulticide applications and to expand their range up to full swath of 15 m, which is normally used for hand held/backpack sprayers.

MATERIALS AND METHODS

The three sprayers included in this study are Field King 190515 (The Fountainhead Group, New York Mills, NY), Ryobi One+ (Ryobi, Innovation Way, Anderson, SC), and Tornado (Spray Mate, China). The comparative specifications of the three sprayers as provided by manufacturers are in the Table 1.

The three sprayers were calibrated while spraying water by collecting the water sprayed in a jug and measuring the volume collected during a 30 min period. The flow rate was determined as mL/min. These flow rates for different settings of sprayers evaluated are presented in Table 2. The flow rates of 482, 530, and 1380 mL/min from Field King, Ryobi and Tornado sprayers were used during evaluations as listed in Table 2.

Droplet size characteristics for the three sprayers at the selected pressures and flow rates were determined with an Artium phase Doppler interferometer (Model TK-1, Artium Technologies, Inc. Sunnyvale, CA) spraying water as the spray liquid. The software associated with the laser system reports various droplet spectrum parameters of which $D_{V0.1}$, $D_{V0.5}$ and $D_{V0.9}$ for each test are reported. The $D_{V0.1}$, $D_{V0.5}$ and $D_{V0.9}$ are the droplet diameters (µm) where 10, 50, and 90 % of the spray volume is contained

Table 1. Summary of comparative specifications of the three commercial sprayers purchased from online

Specification Parameter	Field King 190515	Ryobi One+	Tornado
Power Source	18 V Battery	18 V Battery	18 V Battery
Spray Duration	4 hours	150 L	2 hours
Charge time	3.5 hours	Not provided	2.5 hours
Spray tank	15 L	15 L	15 L
Pressure	276 kPa	414 kPa	276 and 414 kPa
Nozzles	Adjustable	Adjustable	Yellow Flat fan
Hose Length	Not specified	1.2 m	1.5 m

Table 2. Mean flow rate ± standard error (SE) for different nozzles and settings of the sprayers

Sprayer	Nozzle	Pressure in Kpa	Mean flow ± SE, in mL/min
Field King	Adjustable, fully closed	276	482 ± 9
Ryobi	Adjustable, fully closed	414	530 ± 0
Tornado	Adjustable, fully closed	276	1573 ± 9
		414	1949 ± 24
Tornado	Yellow flat fan	276	1292 ± 3
		414	1380 ± 0

in droplets smaller than these diameters (ASTM Standard E1620, 2004). The droplet spectrum for three sprayers while spraying water at the conditions used for the field evaluations are summarized in Table 3.

Aqualuer 20-20 (AI: permethrin 20.6% and piperonyl butoxide 20.6%, Value Garden Supply, St. Joseph, MO) was used as an adulticide in these evaluations. The lowest label rate (9 mL/ha), the highest label rate (37 mL/ha), two-times highest label rate (74 mL/ha) and four-times the highest label rate (148 mL/ha) of Aqualuer 20-20 were tested. Using the swath width of 15 m and walking speed of 5 km/h, the flow rate required for each application rate was determined in mL/min. As required flow rates were quite low for each application rate than the measured flow rates for each sprayer through calibration, all five application rates for three sprayers were achieved by using appropriate dilution rates of the formulation for each combination. The features of the sprayers, the nozzles and pressures used with each sprayer, respective flow rates for these nozzles at the used pressure and dilution rates for all application rate and sprayer combination are listed in the Table 4.

The effectiveness of the sprayers was evaluated using cage bioassays and mosquito mortality as an indicator of effectiveness. For this evaluation, 8 bioassay cages were deployed 1.2 m above ground in two rows that were 8 m apart. Four cages in each row were placed at 1.5, 3.0, 9.0, and 15.0 m from spray line (Figure 1). Spray started 8 m before the first row and ended 8 m after the last row and the applicator covered 24 m in 17 seconds walking at 5 km/hr speed. Each cage had 25, 5-7 days old female laboratory reared Orlando 1952 strain *Ae. aegypti*. Mosquitoes were reared at Anastasia Mosquito Control District (AMCD) insectary maintained at 26.6 °C, 70% relative humidity and a 14:10 (L:D) photoperiod. Two cages in each run were treated as a control placed in a similar environment about 60 m upwind. Cages were placed on the poles before spray and removed 5 minutes after the spray ended. After removal, cages were provided with cotton balls soaked in 10 % sugar solution and were stored in incubators maintained at 26.6 °C, 70% relative humidity and a 14:10 (L:D) photoperiod until mortality was recorded at 24 hr after treatment. To protect mosquitoes from stress caused in the process of transfer into clean cages, mosquitoes

Table 3. Droplet spectrum for three different sprayers at the conditions used in evaluation.

Sprayer	Nozzle	Pressure, kPa	$D_{V0.1}$, µm	$D_{V0.5}$, µm	$D_{V0.9}$, µm
Field King	Adjustable	276	39.4	68.3	107.7
Ryobi	Adjustable	414	31.7	58.4	96.3
Tornado	Yellow	414	38.4	75.2	110.1

Table 4: Nozzles, application parameters and dilution rates used for all sprayers in the study.

Application Parameter	Field King 190515	Ryobi One+	Tornado
Nozzle	Adjustable, fully closed	Adjustable, fully closed	Yellow flat fan
Pressure	276 kPa	414 kPa	414 kPa
Flow rate	482 mL/min	530 mL/min	1380 mL/min
Walking speed	4.8 km/h	4.8 km/h	4.8 km/h
Swath width	15 m	15 m	15 m

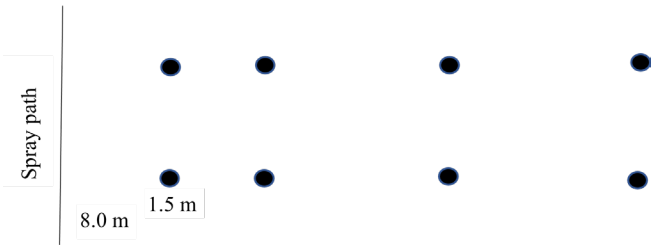

Figure 1. Layout of cages and spray path during the study.

were maintained in same cages. All treatments were replicated three times.

One application rate was evaluated in one day making 9 tests for a day and the study spanned over 4 days in four weeks carried out once a week. Each day, the sequence in which the sprayers were used was selected randomly. Applications started about an hour before sunset when inversion just started to occur and continued until all 9 tests were completed. Each day, the direction of the grid was adjusted based on the expected wind direction for spray path to be perpendicular to the rows of cages. During applications, temperature, relative humidity, wind speed and wind direction were recorded at 3 m above ground using AcuRite weather station (model 01512, Chansey Industrial Co. Lake Geneva, MI). The weather conditions during these experiments are presented in Table 5. During the study, the temperature ranged from 23.9 – 30.6 °C, relative humidity ranged from 57 - 83 %, wind speed ranged from 1.6 – 11.2 km/h, and wind direction varied during different days and ranged from west to east-southeast.

Due to non-normal distribution of data, Wilcoxon test of nonparametric analysis was performed to assess the significance of difference in adult mortality from different application rates, between different distances from the spray line, and between different sprayers using JMP Version 15 (SAS Institute Inc., Cary, NC). The means were compared using nonparametric multiple comparison Wilcoxon each pair test at 95% level of significance.

RESULTS

Table 5: Weather conditions on different days during the trials at Anastasia Mosquito Control District, 120 EOC Drive, St. Augustine, FL

Sprayer	Application Rate	Temperature, °C	Relative Humidity (%)	Wind Speed (km/h)	Wind Direction
Field King	9 mL/ha	27.8 – 30.6	56 – 65	3.2 – 6.4	W
Ryobi	9 mL/ha	28.9 – 30.6	58 – 61	3.2 – 11.2	W – SSW
Tornado	9 mL/ha	28.3 – 30.0	59 – 63	3.2 – 8.0	W – SWW
Field King	37 mL/ha	25.0 – 28.3	61 - 78	3.2 – 4.8	S – SSE
Ryobi	37 mL/ha	23.9 – 27.2	67 - 82	3.2 – 6.4	NE - SE
Tornado	37 mL/ha	25.6 – 27.8	62 - 76	3.2 – 6.4	NE - SE
Field King	74 mL/ha	26.1 – 27.8	67 - 81	3.2	SE - ESE
Ryobi	74 mL/ha	26.7 – 28.3	70 - 79	6.4 – 11.2	SE - ESE
Tornado	74 mL/ha	25.6 – 28.3	67 - 83	3.2	S - SE
Field King	148 mL/ha	26.7 – 28.9	61 - 75	3.2 – 8.0	SE - SSW
Ryobi	148 mL/ha	26.7 – 29.4	59 - 72	1.6 – 8.0	SE - ESE
Tornado	148 mL/ha	26.1 – 29.4	57 – 78	3.2 – 6.4	SE - SSE

Combining data for all the application rates and distances from the spray line, the overall mean mortality was significantly affected by the sprayer used. (x^2 = 21.03, df = 2, p<0.001). Tornado resulted in highest overall mean 24-hr mortality (43%), while the Field King had the lowest 24-hr mortality (19%). The Ryobi resulted in 24-hr mortality of 39%. Statistically, the mortality from Tornado and Ryobi was similar and both were more than Field King. The application rate also significantly affected overall mean 24-hr mortality (x^2 = 29.90, df = 3, p<0.001). The 74 mL/ha application rate resulted in the highest 24-hr mortality of 44% followed by 148 mL/ha (37%), 37 mL/ha (27%) and 9 mL/ha (26%). Statistically, 9 and 37 mL/ha rates produced similar mortality while 74 and 148 mL/ha produced similar mortality. As expected, 24-hr overall mortality decreased with increasing distance from the spray line (x^2 = 98.76, df = 3, p<0.001).

Figure 2 shows comparative 24-hr mortality from three sprayers for four application rates at four different distances from the spray line. The statistical comparison is shown between three sprayers at each combination of application rate and distance from spray line. The mortality from all three sprayers from all four application rates at distances of 9.0 and 15.0 m ranged from 0 to 41 % and the difference in mortality between sprayers at the two locations was not statistically significant and is not discussed further. For the application rate of 9 mL/ha, the mortality at distances of 1.5 and 3.0 m, from all sprayers ranged from 40 – 70%, which is not considered enough to control mosquito populations. For the application rate of 37 mL/ha from the Tornado sprayer resulted in 100 % mortality at 1.5 m followed by 86.7% from the Ryobi and 33.3% mortality from the Field King (Figure 2). At the 3.0 m distance, these sprayers produced 54.9%, 23.6%, and 16.7 % mortality, respectively. For the application rate of 74 mL/ha, the Tornado sprayer resulted in 100 % mortality at 1.5 m followed by 79.3%

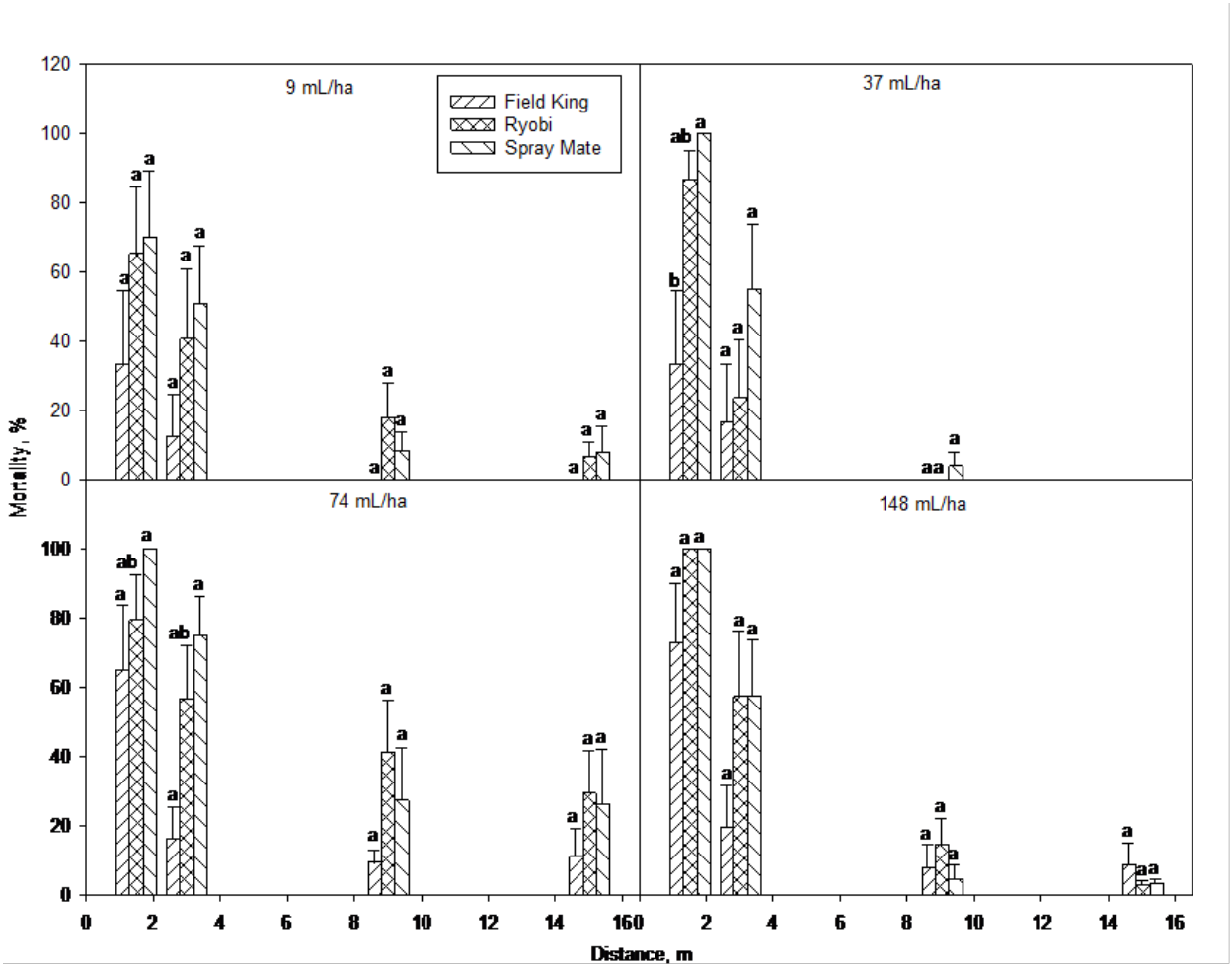

Figure 2. Comparison of adult mortality between sprayers at four application rates at each location. Similar letters for each rate and location indicate that the difference between mortality between sprayers is not significant at 95% level of confidence.

from Ryobi and 65.0% from the Field King (Figure 2). At 3.0 m distance, these sprayers produced 74.7%, 56.7%, and 16.0 % mortality, respectively. For the application rate of 148 mL/ha, both Tornado and Ryobi sprayers resulted in 100 % mortality at 1.5 m followed by 72.7% from the Field King (Figure 2). At 3.0 m distance, the Tornado, Ryobi, and the Field King resulted in 57.3%, 57.3%, and 19.3 % mortality, respectively. Based on these results, Ryobi sprayer can be used with the application rate of 148 mL/ha and Tornado can be used with the application rate of 74 mL/ha for control at a short distance when other means of controlling mosquitoes are not available.

DISCUSSION

Backpack sprayers are designed to apply pesticides as misters mainly for applications where deposition is needed. However, some portion of their spray is comprised of droplets smaller than 30 µm which are not suitable for deposition. Applications of mosquito control adulticides mainly have droplets which are not suitable for deposition, instead remain afloat and interact with flying mosquitoes. Mosquito control adulticiding is a specialized way of using insecticides and equipment is specifically designed to apply these products.

However, what can be done in situations where this specialized equipment is not available? Also, it is not logistically appropriate to make this equipment available due to the limited area to be treated. There are communities which cannot afford the specialized equipment for each type of application but control of mosquitoes in those communities is still urgently needed. For this situation, it is important to investigate the use of non-traditional tools to achieve a task beyond the capabilities of a system. This study was an effort in that direction.

As stated earlier, a small portion of spray from backpack mister sprayers is in the range to control mosquitoes. To study their possible use for adulticiding, higher application rates were tested to verify if the increase in the rate can increase the volume of spray in smaller droplets to control flying insects. However, the users are cautioned not to use these rates if not permitted by the product label. At other places these rates should be used as an absolute necessity.

The results of this study have shown that Tornado can be used for adulticide applications on a limited scale to control mosquitoes up to 3.0 m from the spray using maximum label rate. Ryobi also joins the rank of usable sprayers but only at 4 times the label rate. However, that high rate may not be sustainable for a longer period and should only be used in extreme situations, in the absence of other alternatives. This type of use would not be possible within the continental United States as it would be in violation of the approved label. The Field King has a low flow rate and lower maximum pressure it can produce making the droplets larger than with the similar flow rate for Ryobi. This means it produces lesser number of droplets per unit of flow rate compared to Ryobi. Also, it has a smaller proportion of floating droplets resulting in lower mortality compared to Ryobi. When Tornado is compared with other two, it has about 4 times the flow rate of the other two sprayers. The larger droplets generated by this sprayer are due to higher flow rate. This means that this sprayer produces significantly more number of droplets including proportion of floating droplets causing more mortality than the other two sprayers.

All three sprayers took similar time to charge the batteries and lasted for the time as claimed by manufacturers. In conclusion, to have a short distance control, Tornado applying at maximum label rate of Aqualuer™ 20-20 is the best option based on our study results.

ACKNOWLEDGEMENTS

This is a research report only and specific mention of any commercial products does not imply endorsement by the Anastasia Mosquito Control District. The authors acknowledge the help from Olivia Sypes of AMCD for providing all the mosquitoes for testing.

REFERENCES CITED

Bohari R, Hin JC, Matusop A, Abdullah MR, Ney TG, Benjamin S, Lim LH. 2020. Wide area spray of bacterial larvicide, *Bacillus thuringiensis israelensis* strain AM65-52, integrated in the national vector control program impacts dengue transmission in an urban township in Sibu district, Sarawak, Malaysia. *PLoS ONE* 15(4): e0230910. https://doi.org/10.1371/journal.pone.0230910

Conover D, Fulcher A, Smith ML, Farooq M, Gaines MK, Xue RD. 2015. Evaluation of three commercial backpack sprayers with Aqualuer™ 20-20 against caged adult *Aedes aegypti*. *J Am Mosq Control Assoc.* 31:190-192.

Harwood JF, Helmey WL, Turnwall BB, Justice KD, Farooq M, Richardson AG. 2016. Controlling *Aedes aegypti* in cryptic environments with manually carried ultra-low volume and mist blower pesticide applications. *J Am Mosq Control Assoc.* 32:217 – 223.

Jacups SP, Rapley LP, Johnson PH, Benjamin S, and Ritchie SA. 2013. *Bacillus thuringiensis* var. *israelensis* misting for control of *Aedes* in cryptic ground containers in North Queensland, Australia. *Am J Trop Med Hyg* 88:490 – 496.

Kardatzke JT, Gula PR, Nelson JH. 1981. Engineering evaluation of commercial backpack sprayer/dusters. *Mosq News* 41:327 – 330.

Kurucz N, Pettit W. 2018. Dengue mosquito detection at HMAS

Coonawara, Darwin. *Negl Trop Dis Control Bull* 25:20 – 22.
Lei L, Xue RD, Bibbs CS. 2019. Efficacy evaluation of the mixture of permethrin and S-methoprene applied by a backpack sprayer against larval and adult *Culex quinquefaciatus. Acta Parasitol Med Entomol Sin* 26:92 – 98.
Lloyd AM, Farooq M, Estep AS, Xue RD, and Kline DL. 2017. Evaluation of pyriproxyfen dissemination via Aedes albopictus from a point-source larvicide application in northeast Florida. *J Am Mosq Control Assoc* 33:151–155.
Matthews GA, Morgan W, Bateman R, Clayton JS, Sides M. 2014. Mosquito control by electrostatic spray application. *Aspects of Applied Biology* 122, *International Advances in Pesticide Application*, pp. 1–7.
Obenauer PJ, Farooq M, Knap JA, Yans MW, Santana LA, Richardson AG, Nador NN, Diclaro JW. 2015. Comparison of indoor residual spray equipment for malaria control in Liberia. *J Am Mosq Control Assoc* 31:388 – 391.
Ponlawat A, Harwood JF, Putnam JL, Nitatsukprasert C, Pongsiri A, Kijchalao U, Linthicum KJ, Kline DL, Clark GG, Obenauer PJ, Doud CW, Mccardle PW, Richardson AG, Szumlas DE, Richardson JH. 2017. Field evaluation of indoor thermal fog and ultra-low volume applications for control of *Aedes aegypti* in Thailand. *J Am Mosq Control Assoc* 33:116-127.
Xue RD, Fulcher A. 2021. Evaluation of orange oil applied by three backpack sprayers against A*edes aegypti* and *Culex quinquefasciatus. J Florida Mosq Control Assoc.* 68:101 – 104.
Xue RD, Qualls WA, Smith ML, Zhao TY, Brown JR. 2012. Evaluation of Pioneer Eco-backpack™ sprayer and Twister XL™ backpack sprayer using Aqualuer® against caged adult *Aedes albopictus* and *Culex quinquefasciatus. J Am Mosq Control Assoc* 28:341 – 342.

Submitted date: October 1, 2023. Accepted date: January 31, 2024. Published date: June 30, 2024.