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Efficacy of household *Aedes* larval control practices in a peri-urban township, Yangon, Myanmar: Implication for entomological surveillance

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A R T I C L E I N F O

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A B S T R A C T

Dengue is a major public health concern in Myanmar. We carried out a cross-sectional study to investigate the efficacy of larval control practices in household water containers, such as the use of the larvicide, temephos, covering the containers with lids and weekly cleaning. We surveyed 300 households in Kaw Hmu Township, a peri-urban community in the Yangon region. We inspected 1,892 water storage containers and 342 non-water storage/household waste containers during the rainy season and 1,866 water storage containers and 287 non-water storage/household waste containers during the dry season. The presence of *Aedes* larvae and larval control measures were recorded for each container. Results revealed that larval indices were higher than World Health Organization standard indices, and infestations in water storage containers were more common in the rainy season (6.6%) than in the dry season (5.7%). Infestations were also more likely in containers of non-potable water (9.1%–9.9%) than in containers of potable water (0.1%–0.7%). Two thirds of water storage containers were treated with temephos. Containers most likely to contain *Aedes* larvae were cement basins and barrels. Temephos was effective in controlling infestations in cement basins, while weekly cleaning was effective in controlling infestations in barrels. Combinations of control methods were more effective at larval control than the use of a single method. Larval infestations were high (18.4% in the rainy season) in unused containers and in containers which were household waste. Overall, we found a complex interaction between household water use, container characteristics, and larval control practices. Larval control strategies in Myanmar will require ongoing entomological surveillance and the identification of key breeding sources and optimal control methods.

1. Introduction

Dengue is a vector-borne disease that affects more than one third of the global population [1]. The primary vector is *Aedes aegypti*, and since 2000, WHO reported an increased number of dengue cases from 505,430 cases in 2000, to over 2.4 million in 2010, and 5.2

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million in 2019 [1,2]. It is estimated that 1.8 billion individuals are currently at risk of dengue infection in Southeast Asia and the Western Pacific region. In Southeast Asia, dengue emerged as a public health concern after World War II and the annual number of cases has gradually increased [2–4]. Myanmar bears a high burden of dengue and outbreaks have occurred in cycles of 3–5 years since the first record of an outbreak in the country in 1970 [3–5]. Of all vector-borne diseases, severe dengue is the leading cause of hospitalization in Myanmar, with an average number of 17,400 cases per year (maximum recorded: 42,913 cases in 2015) [4]. The disease mainly affects individuals under 14 years and the mortality rate is 40.5% in patients aged 5–9 years [6].

The National Strategic Plan for Dengue Prevention and Control (2016–2020) published by the Ministry of Health of Myanmar called for implementation of prompt case management and integrated vector control approaches. Dengue vector control efforts have included *Aedes* larval control, insecticide fogging with malathion, entomological surveillance, and the production and distribution of information and education materials [4]. *Aedes* mosquitoes breed mostly in artificial water containers in Myanmar, and household water containers are the main breeding sites [7]. Larval control measures have included treating the water with temephos, covering containers with lids, weekly cleaning, and the addition of larvivorous fish to the water containers. The success of dengue larval control depends largely on consistent control activities at the household level [8]. The efficacy of *Aedes* larval control has been shown to vary by type of household water container, the frequency of water use, and the control measures used [9,10].

Urbanization dynamics and population migration have complicated dengue control efforts in Myanmar, and treatment of the most infested water containers should be prioritized for efficiency, cost-effectiveness, and reductions in chemical use [7,11–13]. Identifying these key containers in household settings, the primary sources of *Aedes* larvae, and determining the efficacy of larval control activities are crucial activities for dengue control, but have not previously been studied in household water containers in Myanmar. The objective of the present study was to identify key containers for *Aedes* larval infestation in household water storage containers and evaluate the efficacy of larval control activities in these key containers so as to improve entomological surveillance under the current dengue control program in Myanmar.

2. Material and methods

2.1. Study design and location

We conducted a cross-sectional study in August 2018 (rainy season) and February 2019 (dry season) in Kaw Hmu Township (16°30′0″N 96°10′0″E), a peri-urban township in Yangon Region, Myanmar (Fig. 1) [14]. Climate in Yangon, August is in the rainy season, with an average temperature ranging from 23.2 °C to 30.0 °C with an average rainfall of 568 mm. While February is as the dry season, an average temperature ranges from 18.5 °C to 34.5 °C with an average of 3 mm rainfall [15].

The study area was selected because the highest incidence of dengue illness in Myanmar was previously recorded in Yangon and

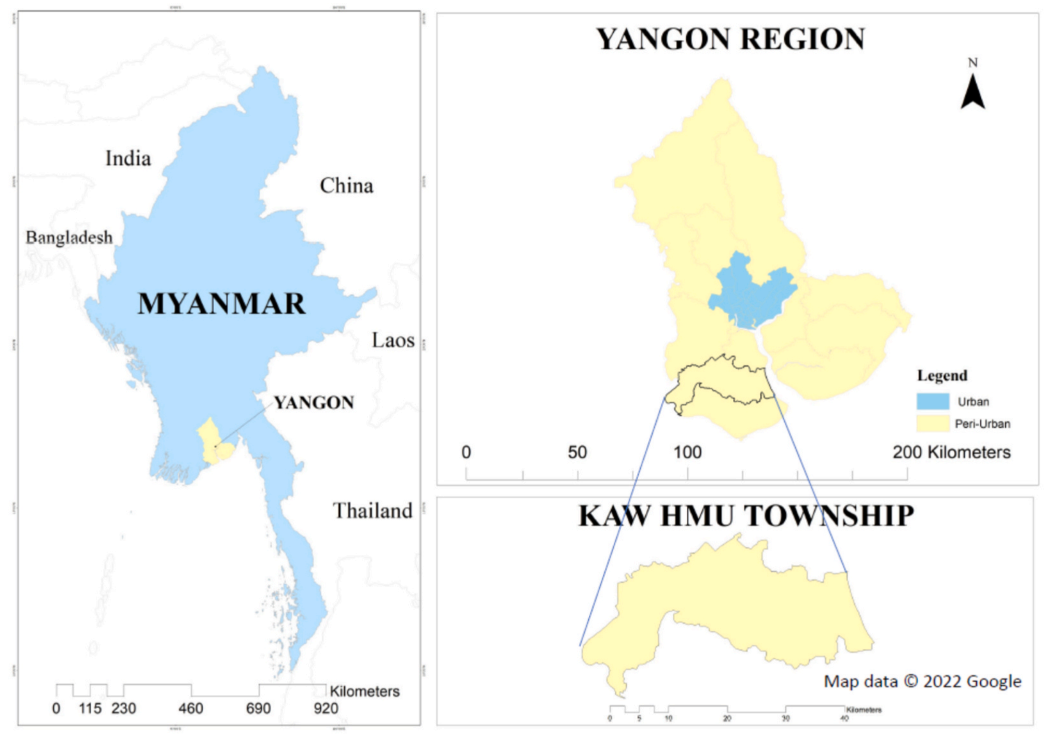

Fig. 1. Map of Yangon Region and the study area, Myanmar.

because the prevalence of dengue is higher in peri-urban areas than in urban areas [4]. Moreover, the larval indices in peri-urban areas were higher than those of an urban township; house index (the percentage of houses infested with *Aedes* larvae): peri-urban = 25.7% vs urban = 6.4% container index (the percentage of containers infested): peri-urban = 15.5% vs urban = 8.4%, Breteau index (the number of positive containers per 100 inspected houses): peri-urban = 48.0% vs urban = 7.2%) [7]. According to the 2014 census, Kaw Hmu Township comprised 29,792 households and 119,050 inhabitants [16]. In Kaw Hmu, 42.2% of individuals were self-employed or skilled agricultural, forestry, and fishery workers and 21% were labourers in these industries. The main water sources for household use in this area were pools, ponds, and lakes (41.4%), tube wells (boreholes) (24.6%), protected wells or springs (16.1%), and un-protected wells, springs, water fall, canals and river (17.9%). All households fetched water and stored it in containers [16]. The routine vector control activities in the study area were temephos treatment and fogging. Temephos (Abate® 1% sand granules) is nonsystemic organophosphorus insecticide, used as a larvicide which has a low mammalian toxicity and safe to use at recommended doses in drinking water [17]. Routine entomological survey has been carried out twice a year around June and September. Temephos is distributed and added to water containers in each household twice a year (prior to the rainy season in June and 3 months after that or around September or October) by health officers from the Rural Health Clinic [18]. Fogging in communities and schools was conducted by the Township Health Department once a year, mainly in September [4]. No information on larvicide and insecticide resistance in the study area was available.

2.2. Sampling

The required size of the sample was calculated as $n = \frac{z^2pq}{d^2}$, where n was sample size, z was level of significance at 95% CI, which was 1.96; p was proportion of households with *Aedes* larval-positive containers, determined as 0.25 [19]; q was 1–p or 0.75 and d was the precision set at 5%. Study households were selected using a two-stage sampling technique [20]. The required number of households for this study was 289. After Kaw Hmu Township was selected, the systematic random sampling was used to select 300 households by housing registration records from seven wards in the township. The same households were surveyed in both seasons. A total of 4,387 containers were inspected: 2,234 containers in the rainy season (1,892 water storage containers and 342 containers used for other purposes) and 2,153 containers in the dry season (1,866 water storage containers and 287 containers used for other purposes).

2.3. Study protocol

The protocol used in this study was developed at the Faculty of Tropical Medicine, Mahidol University, Thailand. The first part involved inspection of all man-made water containers according to World Health Organization guidelines [21]. The containers were inspected for the presence of larvae of *Aedes* genus mosquito and a flashlight was used to inspect water containers located in dark areas. Three larval indices, House index, Container index, and Breteau index [21] were calculated as follows:

- House index (HI): percentage of houses infested with larvae and/or pupae.
- Container index (CI): percentage of water-holding containers infested with larvae or pupae.
- Breteau index (BI): number of positive containers per 100 houses inspected.

In the second part, we collected information on the use of each water container (potable water, non-potable water, or no water; in the latter case, the containers were empty or served as flower pots or storage or waste receptacles). We also collected information on larval control practices as recommended by the national dengue control program, such as weekly cleaning, temephos treatment, covering the containers with lids. The information was collected by interviewing the participants who were the head of the household or his/her representative. The study team visited every selected household and gave information about the study and invited the potential participants to participate in this study. All 300 households agreed to join the study. Once obtaining signed consent from the participants, the questionnaire survey and larval inspections were carried out by a study team consisting of the study lead investigator (SHA), local entomologists and trained health staff from the Township disease control office.

2.4. Data analysis

We used STATA version 14.2 (College Station, TX, USA) for data analysis. The presence of *Aedes* larvae in water containers in households that employed control measures was described and compared with the categorical data by using the $\chi 2$ test. To determine the efficacy of each control measure, univariate and multivariate logistic regressions were used to calculate the crude odds ratio (COR) and adjusted odds ratio (AOR) and 95% confidence intervals (CIs). A p-value <0.05 was considered statistically significant.

2.5. Ethical considerations

The study was approved by the Ethics Committee of the Faculty of Tropical Medicine, Mahidol University, Thailand (MUTM 2019-025-01) and the Defense Services Medical Research Centers, Myanmar (IRB/2018/26).

2.6. Limitation of this study

We did not collect data on the actual quantities of temephos added to each water container and the actual volume of water stored in each container. As adding temephos was a responsibility of the health officers, the participants were unable to give this information. We therefore could not evaluate whether temephos was over- or under-diluted, influencing its efficacy. Furthermore, we only differentiated between *Aedes* and non-*Aedes* larvae and did not identify different *Aedes* larval species and did not count numbers of larvae found in water containers. We thus could not quantify the proportion of *A. aegypti* and *A. albopictus*, which have similar morphology as well as non-*Aedes* species in the water containers to determine larval composition and proportion in the study areas.

3. Results

The percentage of containers infested by *Aedes* larvae was higher in the rainy season (8.4%) than in the dry season (5.0%, $p = 0.000$; Table 1). Nonetheless, number of water storage containers contained *Aedes* larvae was of 6.6% in the rainy season slightly higher than 5.7% in the dry season ($p = 0.296$). We recorded 342 containers in the rainy season and 287 containers in the dry season that were not used for storing water. Of the unused containers, 63 were larval-positive during the rainy season (18.4% larval infestation rate), accounting for 33.7% of all larval-positive containers (63 of 187; the other 124 containers were larval-positive water storage containers). However, during the dry season, only one container was positive for larvae (0.3% of total larval-positive containers; Table 1).

Each larval index was higher in the rainy season than in the dry season (all $p = 0.000$; Table 1). The containers treated by larval control measures had lower indices than untreated containers in both the rainy season (house index: 15.7 vs. 22.2, $p = 0.081$; container index: 3.9 vs. 24.1, $p = 0.000$; Breteau index: 21.7 vs. 33.5, $p = 0.000$) and the dry season (house index: 14.3 vs. 17.3, $p = 0.369$; container index: 4.1 vs. 16.1, $p = 0.000$; Breteau index: 22.9 vs. 23.2, $p = 0.937$; Table 1).

3.1. Larval control practices in household water storage containers

Table 2 shows that at least one controlling measure has been used in 87.0% of water storage containers during the rainy season and the dry season. During both seasons, two thirds of water containers were used for storing non-potable water for washing, bathing, and flushing toilets (rainy season: 63.0%; dry season: 62.4%) and the larval infestation rates were 6.6% during the rainy season and 5.7% during the dry season. The percentage of larval-positive untreated containers was higher than that of larval-positive treated containers in both the rainy season (24.1% vs. 3.9%, $p = 0.000$) and the dry season (16.1% vs. 4.2%, $p = 0.000$). Similarly, among non-potable water containers, the percentages of larval-positive untreated containers were higher than those of larval-positive treated containers in both rainy season (23.6% vs 6.5% $p = 0.000$) and dry season (16.1% vs 7.3% $p = 0.000$). Few potable water containers contained *Aedes* larvae (rainy season: 0.7%; dry season: 0.1%; Table 2).

Almost all (95%) of households participated in the study had added temephos to at least one water container. Temephos was the sole control measure or one of several control measures in 77.2% of water containers (1,272 of 1,647) during the rainy season and 77.0% (1,251 of 1,624) during the dry season. The percentage of water containers treated with a single control measure that contained larvae (rainy season: 6.5%, 43 of 663; dry season: 8.0%, 50 of 635, $p = 0.283$) was higher than the percentage of containers treated with a combination of control measures (rainy season: 2.2%, 22 of 984; dry season: 1.7%, 17 of 989; $p = 0.000$). The highest percentage of water containers that had been treated with a control measure and still harbored larvae was that of containers containing non-potable and covered with lids (rainy season: 11.3%; dry season: 14.8%, $p = 0.592$) (Table 3). The reason could be that lids used were mostly improvised lids and not those of the respective containers; therefore, these lids did not close the containers properly.

For containers of potable water, the most common control practice was a combination of temephos and covering containers with lids (rainy season: 411 of 697, 58.9%; dry season: 419 of 701, 59.8%) and a combination of weekly cleaning and covering containers with lids (rainy season: 246 of 697, 35.3%; dry season: 216 of 701, 30.8%).

Table 1
Total number of containers surveyed and larval indices in 2018–2019 in Kaw Hmu Township, Yangon, Myanmar.

	Rainy			Dry		*P*-value
Total number of all containers	2234			2153		<0.001
Total number of larval positive containers	187 (8.4%)			108 (5.0%)		
Number of water storage containers	1892			1866		0.296
Number of larval positive containers	124 (6.6%)			107 (5.7%)		
Number of non-water activity containers	342			287		<0.001
Number of larval positive containers	63 (18.4%)			1 (0.3%)		
Larval Indices						
House Index (HI)	23.6			17.0		<0.001
Container Index (CI)	8.4			5.0		<0.001
Breteau Index (BI)	62.3			36.0		<0.001
Larval Indices	Control	Without control	*P*- value	Control	Without control	*P*- value
House Index (HI)	15.7	22.2	0.081	14.3	17.3	0.369
Container Index (CI)	3.9	24.1	<0.001	4.1	16.1	<0.001
Breteau Index (BI)	21.7	33.5	<0.001	22.9	23.2	0.937

Table 2
The larval control and larval positivity in household water containers in 2018–2019 in Kaw Hmu Township, Yangon, Myanmar.

	Total N (%)	With larvae N (%)	Non-potable water N (%)	With larvae N (%)	Potable water N (%)	With larvae N (%)
Rainy	1892	124 (6.6)	1192 (63.0)	119 (9.9)	700 (37.0)	5 (0.7)
Control	1647 (87.0)	65 (3.9)[a]	950 (79.7)	62 (6.5)[a]	697 (99.5)	3 (0.4)[a]
No control	245 (13.0)	59 (24.1)	242 (20.3)	57 (23.6)	3 (0.5)	2 (66.7)
Dry	1866	107 (5.7)	1165 (62.4)	106 (9.1)	701 (37.6)	1 (0.1)
Control	1624 (87.0)	68 (4.2)[a]	923 (79.2)	67 (7.3)[a]	701 (100.0)	1 (0.1)
No control	242 (13.0)	39 (16.1)	242 (20.8)	39 (16.1)	0 (0.0)	0 (0.0)

[a] p-value< 0.001 between containers with control and with no control measure.

Table 3
The larval control methods in household water containers in 2018–2019 in Kaw Hmu Township, Yangon, Myanmar.

Seasons	Control measures in water containers	Total N (%)	With larvae N (%)	Non-potable water (N)	With larvae N (%)	Potable water (N)	With larvae N (%)
Rainy N=1647	**Total single method**	**663 (40.2)**	**43 (6.5)**	**640**	**43 (6.7)**	**23**	**0 (0.0)**
	Temephos	549 (33.3)	35 (6.4)	547	35 (6.4)	2	0 (0.0)
	Lids	53 (3.2)	6 (11.3)	43	6 (13.9)	10	0 (0.0)
	Weekly cleaning	61 (3.7)	2 (3.3)	50	2 (4.0)	11	0 (0.0)
	Total combined methods	**984 (59.7)**	**22 (2.2)***	**310**	**19 (6.1)**	**674**	**3 (0.4)**
	Temephos and lids	548 (33.3)	14 (2.6)	137	11 (8.0)	411	3 (0.7)
	Temephos and cleaning	118 (7.2)	2 (1.7)	117	2 (1.7)	1	0 (0.0)
	Lids and weekly cleaning	261 (15.8)	3 (1.2)	15	3 (20.0)	246	0 (0.0)
	All three methods	57 (3.4)	3 (5.2)	41	3 (7.3)	16	0 (0.0)
Dry N=1624	**Total single method**	**635 (39.1)**	**51 (8.0)**	**614**	**50 (8.1)**	**21**	**1 (4.8)**
	Temephos	532 (32.8)	38 (7.1)	529	38 (7.2)	3	0 (0.0)
	Lids	54 (3.3)	8 (14.8)	40	7 (17.5)	14	1 (7.1)
	Weekly cleaning	49 (3.0)	5 (10.2)	45	5 (11.1)	4	0 (0.0)
	Total combined methods	**989 (60.9)**	**17 (1.7)**	**309**	**17 (5.5)**	**635**	**0 (0.0)**
	Temephos and lids	587 (36.1)	15 (2.6)	168	15 (8.9)	419	0 (0.0)
	Temephos and cleaning	97 (6.0)	2 (2.1)	97	2 (2.1)	0	0 (0.0)
	Lids and weekly cleaning	270 (16.6)	0 (0.0)	9	0 (0.0)	216	0 (0.0)
	All three methods	35 (2.2)	0 (0.0)	35	0 (0.0)	0	0 (0.0)

N = number of containers with any control measure.
*p-value< 0.001 values compared between rainy and dry seasons.
Others[#]
Mean either lids or weekly cleaning, or both lids and cleaning.

3.2. *Unused for water storage containers*

Containers not used for water storage were flower vases, plant pots, tires, and household waste. Majority of these containers was flower vases (rainy, n = 263; dry, n = 264) and placed in front of the Buddha shrines. None of these vases contained larvae, as the water in these vases was changed almost daily. Containers holding household waste were not treated with temephos against infestations.

Table 4
The types of household water containers and larval positivity in 2018–2019 in Kaw Hmu Township, Yangon, Myanmar.

Water container types	Rainy N (%)	With larvae N (%)	Dry N (%)	With larvae N (%)
	1892	124 (6.6)	1866	107 (5.7)
Dragon jars	846 (44.7)	46 (5.4)	835 (44.7)	36 (4.3)
Cement containers	440 (23.3)	41 (9.3)	437 (23.4)	49 (11.2)
Barrels	344 (18.2)	35 (10.2)	324 (17.4)	22 (6.8)
Clay pots	262 (13.8)	2 (0.8)	270 (14.5)	0 (0.0)

3.3. Efficacy of larval control measures in key containers

We found 10 types of potential breeding containers in which four types were water storage containers and the other six were not used for water storage. For water storage containers, *Aedes* infestations were typically found in cement basins and in barrels (Table 4). Cement basins have been widely used in Myanmar to store non-potable water, accounting for 23.4% of all water storage containers in the study; the percentage of cement basins infested with larvae was 10.3% (90 of 877), 9.3% in rainy season, and 11.2% in dry season, Table 5). This container has a capacity of 50–200 L and is round, rectangular, or square. No commercially available lids are a perfect fit for covering cement basins, which are sometimes covered by plastic sheets, cardboard, wood planks, or tin or plastic lids designed to cover other types of containers.

Barrels or drums are made of steel, fiber, or plastics with a capacity of 50–200 L and are commonly used for transporting and storing non-potable water. Barrels accounted for 18.1% (344 of 1,892) of water storage containers in the rainy season and 17.4% (324 of 1,866) in the dry season. The percentage of larval-positive barrels was 8.5% and the percentage in the rainy season was higher (10.1%, 35 of 344) than one in the dry season (6.8%, 22 of 324; $p = 0.118$). Table 5 lists the rates of treated and larval-positive cement basins and barrels. In cement basins, use of temephos (temephos alone and temephos combining with other methods) appeared to be effective at controlling larval infestations. In barrels, only weekly cleaning alone appeared to reduce larval infestations but did not differ statistically from the rate of infestations in untreated barrels.

4. Discussion

Dengue is the leading vector-borne disease in Myanmar [5,6,22]. Despite the household control measures promoted by the dengue control program, the larval indices in the study area were higher than World Health Organization standard indices [8,21]. There are no water pipes in the study area, requiring residents to fetch and store water in containers that can become mosquito breeding sites [23,24]. We found more larval-positive containers in the rainy (warm) season, likely attributable to high rainfall, high humidity, and a temperature suitable for fostering larval development [23,24]. We also found that the containers for storing non-potable water were the main breeding sites, but the infestation rates (9.1%–9.9%) were lower than those recorded by studies in Ethiopia (16.04%–24.2%) [25] and Thailand (34.3%–37.2%) [10].

Temephos was the most common control measure in this study, in use by 95% of study households. This is higher than the 60% of rural households and 25% of urban households reported in Thailand [10] and 42.0% of households reported in a study in Mexico [26].

Table 5
Larval control effectiveness in two key containers in the 2018–2019 in Kaw Hmu Township, Yangon, Myanmar.

	N	N with larvae (%)	COR (95% CI)	P - value	AOR (95% CI)	P - value
Cement containers (N = 877)						
Control						
No control	73	27 (37)	Ref		Ref	
Temephos alone	459	35 (7.6)	0.14 (0.08–0.25)	<0.001	0.13 (0.07–0.24)	<0.001
Cleaning alone	15	5 (33.3)	0.85 (0.26–2.76)	0.789	0.82 (0.25–2.66)	0.740
Lid alone	10	5 (50)	1.7 (0.45–6.43)	0.432	1.72 (0.45–6.52)	0.428
Temephos + Cleaning	172	3 (1.7)	0.03 (0.01–0.1)	<0.001	0.03 (0.01–0.1)	<0.001
Temephos + Lids	87	12 (13.8)	0.27 (0.13–0.59)	0.001	0.25 (0.11–0.55)	0.001
Cleaning + Lids	5	1 (20)	0.43 (0.05–4.01)	0.456	0.43 (0.04–4.09)	0.461
All	56	2 (3.6)	0.06 (0.01–0.28)	<0.001	0.06 (0.01–0.26)	<0.001
Place						
Outdoor	822	86 (10.5)	Ref		Ref	
Indoor	55	4 (7.3)	0.67 (0.24–1.9)	0.453	0.52 (0.17–1.58)	0.249
Season						
Rainy season	440	41 (9.3)	Ref		Ref	
Dry season	437	49 (11.2)	1.23 (0.79–1.9)	0.356	0.84 (0.52–1.36)	0.480
Barrels (N=668)						
Control						
No control	252	24 (9.5)	Ref		Ref	
Temephos alone	111	14 (12.6)	1.37 (0.68–2.76)	0.377	1.31 (0.65–2.65)	0.449
Cleaning alone	72	2 (2.8)	0.27 (0.06–1.18)	0.081	0.27 (0.06–1.16)	0.077
Lid alone	33	4 (12.1)	1.31 (0.42–4.04)	0.638	1.23 (0.4–3.8)	0.724
Temephos + Cleaning	39	1 (2.6)	0.25 (0.03–1.9)	0.181	0.23 (0.03–1.79)	0.163
Temephos + Lids	127	9 (7.1)	0.72 (0.33–1.61)	0.429	0.74 (0.33–1.64)	0.458
Cleaning + Lids	18	2 (11.1)	1.19 (0.26–5.48)	0.826	1.21 (0.26–5.68)	0.810
All	16	1 (6.3)	0.63 (0.08–5.01)	0.665	0.66 (0.08–5.23)	0.693
Place						
Outdoor	590	52 (8.8)	Ref		Ref	
Indoor	78	5 (6.4)	0.71 (0.27–1.83)	0.477	0.72 (0.27–1.9)	0.509
Season						
Rainy season	344	35 (10.2)	Ref		Ref	
Dry season	324	22 (6.8)	0.64 (0.37–1.12)	0.120	0.65 (0.37–1.15)	0.141

COR = Crude Odds ratio, AOR = Adjusted Odds Ratio.

Temephos alone was effective in controlling larvae, but adding a second control measure improved efficacy, in accordance with the findings from Thailand [10,27]. Combining a larvicide with environmental management protocols such as cleaning and use of lids is generally effective in lowering larval indices [10,26,28,29]. Several studies have reported a low community acceptance of temephos use in potable water because of an unpleasant odor and the perception of temephos as a harmful chemical [29–31]. However, for potable water containers in our study area, the combination of adding temephos, and covering the containers with lids or/and weekly cleaning was common practices, which proved to be an effective control approach [10,27].

Identifying containers that are likely to be infested can efficiently and cost-effectively prioritize prevention and control activities to reduce the mosquito density below the critical threshold [32]. In our study, these key containers, the most productive containers for *Aedes* larvae, were cement basins and barrels, similar to findings from another study in Yangon [22] and studies in Thailand [10], Indonesia [33], and Laos [34].

Cement basins are difficult to clean or cover with tight-fitting lids, and can therefore foster *Aedes* infestation. The use of temephos should be prioritized in cement basins to provide effective control, and the quantity used should depend on the volume of the cement basin [10] and the season of application [34,35]. In barrels, only weekly cleaning appeared to be somewhat protective against larvae, requiring research into more effective control measures for barrels. Although weekly cleaning may be effective, it requires work and the fetching of more water.

Non-water storage containers in this study accounted for one third of all breeding sites during the rainy season, similar to findings in Bangladesh [36] and Thailand [9]. No larval control measures were taken in containers that were not used for storing water in this study and the result indicated the need to control larvae in unused containers especially in rainy season. Rapid industrialization and urbanization are major problems in Yangon and have strained the capacity of solid waste management services [37]. *Aedes* productivity in household waste increases the risk of dengue outbreaks [38], and Myanmar should implement source reduction, especially during the rainy season when the larval infestation rate is high. Community education and waste management have been shown to reduce vector densities through source reduction interventions such as clean-up campaigns [18,38,39]. The proper disposal or recycling of discarded containers should be promoted with monetary incentives and expanding the capacity of regular collection of solid waste.

Temephos is regularly distributed in Myanmar by local health departments [18]. We found that combining temephos with other control measures was a common practice, indicating that temephos use alone may not reflect the true picture of the efficacy of the dengue control program. Moreover, effective control measures are the product of the complex interaction of household water use and larval control practices [10]. Therefore, the findings in this study clearly illustrate the need for better surveillance, recording all control methods used as well as the types and sizes of containers and the quantity of temephos added. If the supply of temephos is limited, prioritizing containers could achieve optimal efficacy. To implement an effective larval control program requires continuous community engagement with social marketing to reinforce consistent control practices as well as proper waste management including recycling schemes. Such efforts require investment and supports shared among key stakeholders [40,41]. Government and non-government stakeholders should collaborate to promote a sense of ownership and responsibility in conducting larval control activities in residences [42]. In summary, this study provides guidance on how to use entomological surveillance to improve household dengue control outcomes, in particular to the identification of key breeding water containers and their effective control methods. In rainy season, the waste management scheme in the study area should dispose of the un-used containers, a high percentage of which were infested with larvae. For further research, we suggest the development of a user-friendly tool or application for local health officers, to identify key containers as well as further research on improving temephos application and efficacy.

Author contribution statement

Soe Htet Aung: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Aye Mon Mon Kyaw: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Podjanee Jittamala; Suparat Phuanukoonnon: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Saranath Lawpoolsri: Conceived and designed the experiments; Wrote the paper.

Ngamphol Soonthornworasiri: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Patchara Sriwichai: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Suparat Phuanukoonnon reports article publishing charges and writing assistance were provided by Faculty of Tropical Medicine. Suparat Phuanukoonnon reports a relationship with Mahidol University Faculty of Tropical Medicine that includes: employment, funding grants, and non-financial support.

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