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Effectiveness and Public Perception of Synthetic and Natural-Based Mosquito Repellents Against *Aedes aegypti* in Indonesia

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Abstract

Since 1968, dengue fever cases in Indonesia have persisted despite various vector control efforts. One of the most common and accessible methods of personal protection is the use of mosquito repellents. This study evaluated public perceptions of mosquitoes and repellents, their willingness to pay (WTP) for these products, and the efficacy of synthetic and natural-based repellents against *Aedes aegypti*, considering variations in mosquito strain and age. A Knowledge, Attitude, and Practices (KAP) analysis was conducted to assess public understanding and behaviors, utilizing the Analytical Hierarchy Process (AHP) and SWOT-AHP. Repellent efficacy was tested using the arm-in-cage method based on WHO guidelines, involving four mosquito strains (BORA, BDG, TSK, TGR) and three age groups (5, 10, 15 days).The KAP analysis revealed high public awareness but limited translation into effective practices due to differing perceptions and low personal responsibility for dengue prevention. Natural-based repellents were preferred, scoring 3.40 out of 5, with WTP ranging from IDR 20,000–40,000. However, only synthetic repellents containing DEET provided 90% protection for six hours, while natural-based repellents offered less than 60% protection in the first hour. Strain variation significantly affected repellency, with TSK showing the highest repellency, while BORA and BDG exhibited similar trends. Although 10-day-old mosquitoes were more sensitive to repellents, age variation did not consistently influence repellency. These findings highlight the need for improved education campaigns, tailored repellent formulations, and localized testing to enhance public protection against mosquito bites and dengue transmission.

Keywords: *Aedes aegypti, Strain, Vector Control Strategy, Repellent, Natural-based repellent, DEET*

1. Introduction

In Indonesia, dengue fever has persisted as a significant public health challenge since 1968, despite decades of vector control efforts. *Aedes aegypti* mosquitoes thrive in human environments, fueling recurrent outbreaks and posing a continuous threat to public health. Various control measures have been implemented, these include peri-focal adult spraying, mass larviciding, and community-focused education on disease prevention [1]. However, these strategies have proven insufficient to eliminate dengue transmission entirely, highlighting the need for complementary approaches, particularly at the individual level.

Mosquito repellents are among the simplest and most widely accessible tools for personal protection. These products, available in various forms and active ingredient compositions, help mitigate the risk of mosquito-borne diseases while offering relief from the discomfort of bites [2]. Their effectiveness, however, depends on factors such as active compounds, formulation, mosquito biology, and proper application. Synthetic repellents, especially those containing DEET (N,N-diethyl-3-methylbenzamide), are recognized as highly effective, providing long-lasting protection [3]. Conversely, natural-based repellents are often favored for their perceived safety and eco-friendliness, though they generally offer lower efficacy.

Despite the widespread preference for natural-based repellents due to their safety and environmental appeal, their limited efficacy poses a challenge to achieving optimal protection against mosquito bites and disease transmission. This mismatch between consumer preference and product performance underscores the importance of understanding public perceptions and willingness to pay (WTP), which are crucial for guiding education campaigns and improving

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repellent product development.

This study explores public perceptions, acceptance, and willingness to pay (WTP) for mosquito repellents in Indonesia, alongside an evaluation of the efficacy of synthetic and natural-based products against *Aedes aegypti* mosquitoes of varying strains and ages. Utilizing a Knowledge, Attitude, and Practices (KAP) survey in combination with Analytical Hierarchy Process (AHP) and the Strengths, Weaknesses, Opportunities, and Threats–Analytical Hierarchy Process (SWOT-AHP) methods, this research aims to bridge the gap between consumer preferences and product performance, providing critical insights for improving individual-level protection and supporting broader vector control efforts in Indonesia.

2. Methodology

2.1 Survey Design

This study utilized an online survey to analyzing Knowledge, Attitude, and Practices (KAP), product acceptance, and Willingness to Pay (WTP) for mosquito repellents. The survey, distributed via Google Forms, collected 250 responses predominantly from participants aged 20–29 years (62.4%), most of whom were graduate-level educated (79.6%). Respondents were primarily students (37.6%) or employees (24.8%) and predominantly resided on Java Island (85.2%). The survey included 46 questions divided into the following sections: Demographics: Age, education level, occupation, and location; Knowledge: Perceptions and understanding of mosquitoes, repellents, and vector control; Attitude: Experiences and attitudes toward mosquitoes; Practices: Methods of larval control and mosquito bite prevention. Additional sections addressed product acceptance and WTP for repellents: Repellent users, questions about usage reasons, preferred ingredients, and WTP levels; Non-repellent users, questions on non-usage reasons, ingredient acceptance, and WTP levels.

Questions about product acceptance were based on six parameters proposed by Debboun et al. [2]: protection time, safety, probability of side effects, accessibility, price, and ingredient performance. WTP was defined as the amount participants were willing to pay to reduce mosquito bites and associated disease risks. The sample size was calculated using the formula by Charan & Biswas [4], with a confidence interval of 95%, resulting in a minimum of 96 respondents.

$$n = \frac{(Z_{1-a/2})^2 \, p \, (1-p)}{d^2}$$

2.2 Vector Control Strategy Analysis using AHP & SWOT-AHP

Analytical Hierarchy Process (AHP) was employed to identify the primary problems through a logical weighting process. Prioritized aspects and alternative solutions were further developed using SWOT-AHP to determine strategic priorities. Modeling was conducted using the AHP Online System (AHP-OS) developed by Goepel [5].

2.3 Rearing of Aedes aegypti

Mosquito rearing was conducted at a field laboratory in Bandung, West Java. Female *Aedes aegypti* mosquitoes from four strains were used: BORA: A standard laboratory-susceptible strain obtained from National Chung Hsing University, Taiwan; BDG, TSK, TGR: Laboratory-maintained wild-type strains, collected in 2020, originating from Bandung, Tasikmalaya, and Tangerang, respectively.

Rearing conditions were maintained at 24–28°C with 70–80% relative humidity and a 12:12 light-dark photoperiod. Mosquitoes were provided with a 10% sucrose solution as their primary food source. Female mosquitoes were given blood meals via direct human forearm feeding to support egg production. Mosquitoes were housed in 30 × 30 × 30 cm metal-frame cages, covered with white observable nets, and equipped with sleeves to allow forearm access for feeding.

2.4 Repellent Efficacy Testing

The repellent efficacy test included three variables: repellent products, mosquito strains, and mosquito age. The repellents tested were: Product A (DEET-based, positive control): Claimed protection of 6–8 hours; Product K (lavender and geranium oil-based): Claimed protection of 8 hours; Product S (eucalyptus oil-based): Claimed protection of 4 hours; Product C (citronella, eucalyptus, and chamomile oil-based): Claimed protection of 8 hours. These products were chosen based on their popularity in Indonesia and variations in ingredients and application methods. The mosquito strains tested were BORA (standard strain), BDG, TSK, and TGR. Age groups included 5, 10, and 15-day-old nulliparous mosquitoes to explore correlations between age, host avidity [6], and repellency response.

2.5 Preparation for Repellent Efficacy Testing

Participants were selected based on low sensitivity to mosquito bites and/or repellent ingredients. Smoking, wearing perfume, or using repellent within 12 hours before testing was prohibited [7]. Test area preparation included washing with non-perfumed soap and sanitizing with 70% ethanol. The exposed forearm surface area was calculated using the formula 1:

$$Area = \left(\frac{C_W + C_E}{2}\right) \times D_{WE}$$

Where CW is wrist circumference, CE is *elbow-cubital fossa* circumference, and DWE is the distance between them. Mosquitoes were deprived of 10% sucrose solution and blood meals for 12 hours before the test. Testing was conducted with 25 female mosquitoes per 30 × 30 × 30 cm cage.

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2.6 Repellent Product Efficacy Testing

Efficacy Evaluation:

Repellent performance was evaluated following WHO Pesticide Evaluation Scheme (WHOPES) guidelines [7] using the arm-in-cage method. Observations measured: Repellency level (R%), Protection duration conformity with product claims, and Complete Protection Time (CPT). Procedure: Right arm: Used as a control (no repellent); Other arm: Treated with 1 mL of repellent. Arms were exposed in the cage for 3 minutes at 1-hour intervals to count mosquito landings/probings. Repellency level (R%) was calculated as:

$$R\ (\%) = \left(\frac{C - T}{C}\right) \times 100\%$$

Where C is the number of landings/probings on the control arm and T is the treated arm.

CPT was defined as the time elapsed between application and the first mosquito landing/probing. Testing continued at 10-minute intervals if no landings/probings occurred in the initial 3 minutes. According to the Ministry of Agriculture criteria, a repellent is deemed effective if it provides ≥90% protection for at least 6 hours [8].

3. Results

3.1 Respondent Demographic

The survey (Table 1) collected 250 responses between April and August 2020. The majority of participants resided on Java Island (85.2%), primarily in the West Java province. Among the respondents, 62.4% were between the ages of 20 and 29, and most had an income level between IDR 3,500,001 and 5,000,000 (22.6%). A considerable proportion of respondents held a graduate degree (79.6%), with the majority working as students (37.6%), employees (24.8%), or government employees (15.6%).

3.2 Knowledge, Attitude, and Practices (KAP) Score

The KAP scores (Table 2) indicate a high level of Knowledge (8.66 ± 2.11 out of 13), Attitude (2.38 ± 0.54 out of 3), and Practices (3.52 ± 0.58 out of 4). Knowledge: Higher scores were observed among males (8.71 ± 2.02), individuals aged over 50 years (9.43 ± 1.22), those with income levels above IDR 10,000,000, and participants with a doctoral degree (10.50 ± 2.08). Attitude: Higher scores were noted for males (2.46 ± 0.56), individuals aged 30–39 years (2.45 ± 0.55), and participants with income levels above IDR 10,000,000 (2.57 ± 0.50). Practices: Higher scores were observed among females (3.57 ± 0.56), individuals under 20 years of age (3.89 ± 0.33), and junior high school graduates (4 ± 0).

3.3 Correlation within KAP & KAP-WTP

Table 3 shows weak but positive correlations between Knowledge-Attitude (0.031) and Attitude-Practices (0.032), while Knowledge-Practices (-0.034) showed a small negative correlation. WTP for repellents showed a slight positive correlation with respondents' age and income level (0.21 and 0.21, respectively).

3.4 Repellent Acceptance Level & WTP

According to Table 4, users preferred natural-based repellents, scoring 3.40 out of 5, excelling in safety (3.79) and a low probability of side effects (3.63). DEET-based repellents scored slightly lower (3.32), performing well in protection duration and accessibility. Non-users also rated natural-based repellents higher (3 out of 5), despite their lower efficacy. WTP ranged between IDR 20,000 and 40,000 (USD 1.44-2.88).

Table 1. Respondent demographic

Information	**N**	**%**	**Income level**	**n**	**%**
Total Respondent	250	100	No income	52	20.8
			IDR 1,000,000-3,500,000	59	23.6
Gender	**n**	**%**	IDR 3,500,001-5,000,000	64	25.6
Male	94	37.6	IDR 5,000,001-10,000,000	47	18.8
Female	156	62.4	> IDR 10,000,000	28	11.2
Age	**n**	**%**	**Education level**	**n**	**%**
< 20 years old	9	3.6	Junior high school graduate	2	0.8
20-29 years old	156	62.4	High school graduate	22	8.8
30-39 years old	44	17.6	Graduate	199	79.6
40-49 years old	27	10.8	Master degree	23	9.2
≥ 50 years old	14	5.6	Doctoral degree	4	1.6
Province	**n**	**%**	**Jobs**	**n**	**%**
Sumatera	31	12.4	Student	94	37.6
Jawa	213	85.2	Entrepreneur	12	4.8
Kalimantan	2	0.8	Freelance	10	4
Sulawesi	1	0.4	Teacher/lecturer	20	8
Others	3	1.2	Housewives	9	3.6
			Employee	62	24.8
			Retired person	4	1.6
			Government employee	39	15.6

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3.5 Vector Control Strategy

The survey results informed the development of vector control strategies focused on repellent usage. The primary challenges were categorized into five aspects and prioritized using the Analytical Hierarchy Process (AHP), as shown in Table 5: 1) Social aspects (0.42): Addressing public awareness and engagement; 2) Economic aspects (0.34): Ensuring sufficient funding and affordability; 3) Regulatory aspects (0.11): Enhancing reporting systems and policy enforcement; 4) Technological aspects (0.09): Improving tools and resources for vector control. 5) Biological vector aspects (0.05): Addressing mosquito adaptation and resistance.

Based on these priorities, three key solutions were proposed in the following Table 6: 1) Micro-scale planning and implementation programs (0.16): Tailored to specific local needs; 2) Enhanced intra- and inter-sector collaboration (0.14): Aimed at aligning control efforts with community behaviors; 3) Informative, educative, and communicative strategies (0.13): Designed to improve societal perceptions and engagement.

The AHP-derived solutions were further analyzed using SWOT-AHP, with Strength (0.59) and Opportunity (0.28) emerging as the most significant components, followed by Weakness (0.08) and Threat (0.054). The highest-priority strategies included are summarized in Table 7. The SWOT-AHP results are shown in Table 7 and strategy formulations in Table 8. Strength (S3): "Interactive and engaging information to increase understanding and change behavior" (0.41); Opportunity (O2): "Innovation and collaboration opportunities to accelerate case handling and vector control" (0.19). Weakness (W1): "The need for good and uniform field officer competence" (0.06); Threat (T2): "Clarification is needed for regulations and management flow between sectors" (0.04). The recommended strategy prioritizing Strength-Opportunity (SO) as mentioned in Table 8 focuses on: 1) Enhancing community empowerment through tailored assistance programs; 2) Delivering information via engaging media campaigns; 3) Conducting outreach programs in community activity centers.

Table 2. KAP Score

Parameter	Score ± SD		
	Knowledge (8.66 ± 2.11 out of 13)	Attitude (2.38±0.54 out of 3)	Practices (3.52±0.58 out of 4)
Gender			
Male	8.71±2.02	2.46± 0.56	3.45±0.62
Female	8.63±2.17	2.34 ± 0.53	3.57±0.56
Age			
< 20 years old	7.33±1.73	2.11±0.60	3.89±0.33
20-29 years old	8.616±2.11	2.37±0.55	3.55±0.58
30-39 years old	8.68±2.32	2.45±0.55	3.45±0.63
40-49 years old	8.93±2.38	2.44±0.51	3.52±0.51
≥ 50 years old	9.43±1.22	2.43±0.51	3.29±0.61
Income level			
No income	8.5±1.87	2.31±0.54	3.73±0.53
IDR 1,000,000-3,500,000	8.36±2.16	2.37±0.61	3.44±0.65
IDR 3,500,001-5,000,000	8.28±2.13	2.33±0.47	3.45±0.56
IDR 5,000,001-10,000,000	9.17±2.09	2.45±0.54	3.57±0.54
> IDR 10,000,000	9.61±2.11	2.57±0.50	3.39±0.57
Education level			
Junior high school graduate	6±1.41	2±0	4±0
High school graduate	7.91±2.02	2.27±0.63	3.68±0.57
Graduate	8.73±2.03	2.37±0.53	3.49±0.58
Master degree	8.70±2.65	2.52±0.51	3.39±0.58
Doctoral degree	10.5±2.08	3±0	3.25±0.5

Table 3. KAP & WTP Correlation Analysis

	Gender	Age	Income level	Education level	Knowledge	Attitude	Practices
Knowledge	-0.003	0.139	0.167	0.144	1	0.031	-0.034
Attitude	-0.116	0.084	0.115	0.123	0.031	1	0.027
Practices	0.098	-0.118	-0.137	-0.129	-0.034	0.027	1
Willingness to Pay (WTP)	-0.061	0.210	0.213	0.036	0.007	-0.047	0.107

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Table 4. Repellent Acceptance Level by Repellent Users & Non-users

Type of users	Product acceptance parameter	Synthetic-repellent effectivity (out of 5)	Natural-repellent effectivity (out of 5)
Repellent users	Given duration of protection	3.36	3.15
	Safety and comfort in using product	3.00	3.79
	Side effect possibility	2.71	3.63
	Product accessibility in the market	3.92	3.13
	Product price	3.60	3.38
	Raw material performance	3.31	3.33
	Average effectivity	**3.32**	**3.40**
Non-repellent users	Given duration of protection	2.75	3.06
	Safety and comfort in using product	2.63	3.25
	Side effect possibility	2.56	2.81
	Product accessibility in the market	2.69	2.75
	Product price	2.69	3.06
	Raw material performance	2.44	3.06
	Average effectivity	**2.63**	**3.00**

3.6 Repellency Trends by product

As shown in Tables 9, 10, 11, and 12, the repellency trends for tested products are summarized as follows: Product A: DEET-based repellent provided ≥90% protection for up to 6 hours, aligning with product claims. Among the tested strains, the TSK strain exhibited the highest repellency (98.22 ± 3.08%), while the TGR strain showed the lowest (89.71 ± 4.27%); Product K: Lavender and geranium oil-based repellent demonstrated 60% initial repellency, which declined to 0–12.13% by the fourth hour, offering no protection beyond this duration; Product S: Eucalyptus oil-based repellent provided initial repellency ranging from 58.24% to 62%, which decreased substantially by the fourth hour; Product C: Citronella and eucalyptus-based repellent offered protection only during the first hour, with repellency ranging from 29.32% to 38.69%.

3.7 Repellent Product Effectiveness Based on Strain and Age Variations

Pearson correlation analysis revealed a significant relationship between strain variation and repellency level ($r = 0.58$; $p = 0.04 < 0.05$), indicating that strain variation in *Aedes aegypti* significantly affects repellency levels. In contrast, no significant correlation was found between mosquito age and repellency level ($r = 0.10$; $p = 0.74 > 0.05$).

The Pearson correlation value of 0.58 suggests a

Table 5. Summary of Significant AHP Category & Parameter

Aspect group	Group priority	Aspect factors	Consistency ratio	Priority within group	Overall priority
Social	**0.42**	Increase understanding in mosquito-borne disease	9.6%	0.27	0.12
		Understand the importance of larvae management within society		0.19	0.08
Economic	**0.34**	Funding intensification on vector prevention and management	9.7%	0.39	0.13
		Assess management cost based on the type of vector		0.27	0.09
Regulatory	**0.11**	Improve management on case reporting and disease handling scheme	9.4%	0.22	0.02
Technological	0.09	Grow and develop the usage of potential plants as repellent	9.2%	0.34	0.03
		Deliver information in an easy to understand & interactive method		0.33	0.03
Biological Vector	0.05	Manage areas with frequent cases of mosquito bites	9.6%	0.48	0.02
		Collect data and map areas of the disease cases and on-going programs		0.26	0.01

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Table 6. Alternative AHP Solutions

Aspect factors	Priority of solution	Rank
Micro-scale planning and implementation programs	**0.16**	**1**
Enhanced intra- and inter-sector collaboration	**0.14**	**2**
Informative, educative, and communicative strategies	**0.13**	**3**
Proper evaluation in the vector control based on location	0.11	4
Optimum budget allocation on disease management	0.09	5
Collaboration and research in vector data collection and potential repellent plant with research institute and university	0.09	6
Develop integrated database and reporting system for entomology, epidemiology, and vector control technology	0.09	7
Gather vector-related cases, information, and programs	0.08	8
Perform training and further education program for the expert	0.06	9
Government subsidy on larvae and mosquito control	0.06	10

moderately strong relationship between strain variation and repellency. Among the strains tested, the TSK strain was the most repelled by the product, showing 1.19 times higher repellency compared to the BORA strain (Table 13). Notably, the BORA and BDG strains exhibited similar trends, while the TSK and TGR strains displayed different tendencies. Regarding mosquito age, mosquitoes aged 10 days were the most sensitive to the repellent, demonstrating the highest repellency levels compared to other ages. However, TSK and TGR strains showed different responses to the repellent compared to the BDG strain (Table 13). While 10-day-old mosquitoes appeared more sensitive to repellents, overall age

4. Discussion

4.1 Knowledge, Attitude, and Practices (KAP) Score

As shown in Table 2, public knowledge about mosquitoes, mosquito-borne diseases, and repellents is relatively high (8.66 ± 2.11 out of 13). This can be attributed to the dissemination of information through social media, television, and discussions with family and co-workers. These findings align with studies conducted in Northern Iran [9] and India [10], where media is a primary source of information on mosquitoes and related diseases. However, the lack of in-depth coverage can leave gaps in understanding, underscoring the need for targeted education on the importance of mosquito control.

Table 7. SWOT-AHP Evaluation

Aspect group	Group priority	Aspect factors	Consistency ratio	Priority within group	Overall priority
Strength	**0.59**	S1 - Specific needs according to the location and vector type	8%	0.23	0.14
		S2 - Integrated reporting system (entomology, epidemiology, and vector control technology)		0.08	0.04
		S3 - Interactive and engaging information to increase understanding and behavioral changes		**0.70**	**0.41**
Weakness	**0.08**	**W1 - The need for competent field operator**	9.8%	**0.70**	**0.06**
		W2 - Development of reporting and data collecting		0.06	0.01
		W3 - Gap understanding between each society cluster and		0.24	0.02
Opportunity	**0.28**	O1 - Technology application for helping better data collecting and reporting system	9%	0.27	0.06
		O2 - Innovation and collaboration opportunity to accelerate case handling and vector control		0.67	0.19
		O3 - Ease of accessibility to informations		0.10	0.03
Threat	**0.05**	T1 - Difficult distribution and accessibility of field expert to suburban and remote area	5.6%	0.22	0.01
		T2 - Clarification is needed for regulations and management flow between sectors		0.71	0.04
		T3 - Maintaining the credibility of source of information		0.07	0.00

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Table 8. SWOT-AHP Strategy Formulation

Type	Strategy	Group priority
Strength-Opportunity (SO)	Enhancing community empowerment through tailored assistance programs	**0.43**
	Delivering information via engaging media campaigns	
	Conducting outreach programs in community activity centers	
Strength-Threat (ST)	Evaluation and observation on current circulating information within society for each related stakeholder	0.29
	Creating integrated and sychronized intersectoral report and data collection system	
	Optimizing public services management to be more updated and ease to be used	
Weakness - Opportunity (WO)	Providing training and further education program for increasing the expert's competency	0.17
	Innovation in on-site case and vector condition reporting system	
	Create workshop and basic training for early knowledge in society	
Weakness-Threat (WT)	Optimum budget allocation on vector control management according to the needs on each location	0.11
	Increasing government active participation in evaluating vector control performance on each sector	
	Intensification on vector observation by increasing intersectoral collaboration	

Data from the Indonesian Ministry of Health [11] shows that men (53.11%) are more likely to contract dengue fever than women (46.89%). This may explain why men have higher knowledge levels, a trend also observed in Pakistan [12], where individuals with prior dengue fever experience were more likely to seek information. Similarly, respondents with higher education levels (bachelor's degree or above) displayed better knowledge than those with only a high school education, a trend consistent with studies in Laos and Thailand [13]. Where people with a combination of both better access to information and higher education level confirmed to have better understanding and knowledge [14].

The Attitude score as shown in Table 2 (2.38 ± 0.54 out of 3) indicates that the community recognizes the impact of mosquitoes and engages in mosquito control strategies. Higher Attitude scores are associated with respondents who have higher education levels or previous experience with dengue fever, as observed in Laos [13].

As shown in Table 2, practices scored positively (3.52 ± 0.58 out of 4), with common strategies including controlling waterlogging (77.6%, with an effectiveness scale of 3.76 out of 5) to eliminate breeding sites. Interestingly, respondents with lower education levels had higher Practices scores, contrary to Knowledge trends. This mirrors findings from Northern Iran [9], suggesting that individuals with lower education levels may have greater exposure to practical mosquito control efforts through government programs.

4.2 Correlation within KAP & KAP-WTP

As shown in Table 3, the weak but positive correlations between Knowledge-Attitude (0.03) and Attitude-Practices (0.03) suggest limited relationships between public understanding, perception, and mosquito control behaviors. Meanwhile, the negative correlation between Knowledge-Practices (-0.03) highlights that knowledge does not consistently translate into action.

Similar discrepancies have been observed in Venezuela [15], where over 50% of households were identified as potential *Aedes aegypti* habitats despite high awareness levels. Contributing factors include low perceived benefits of mosquito control practices [16], lack of individual responsibility for dengue prevention [17], and persistent mosquito presence despite interventions. Many respondents prioritize convenient protective measures, such as repellent use (aerosol: 61.6%; topical: 50.8%), over sustainable actions like habitat elimination. Systemic challenges, including reliance on government interventions, irregular water supplies requiring storage, and perceived inefficacy of control measures, further hinder efforts.

Our findings align with Harapan et al. [18], who emphasize the importance of integrating knowledge and practices through effective planning and community engagement. In Indonesia, bridging these gaps requires education campaigns that emphasize the benefits of combining habitat management with repellent use, foster community ownership, and address

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Table 9. Product A Repellency

Strain	Product A, Percent protection (hour)						
	0	1	2	3	4	5	6
BORA	100	100	100	100	100	98.20	92.93
BDG	100	100	100	100	100	100	94.31
TSK	100	100	100	100	100	100	98.22
TGR	100	100	100	100	100	97.98	89.71

Table 10. Product K Repellency

Strain	Product K, Percent protection (hour)					
	0	1	2	3	4	5
BORA	58.24	29.81	14.22	3.64	0.00	
BDG	61.70	47.12	36.27	12.60	6.25	0.00
TSK	61.60	57.46	42.67	20.35	4.30	0.36
TGR	62.00	45.34	32.86	25.31	12.13	0.71

Table 11. Product S Repellency

Strain	Product S, Percent Protection (hour)					
	0	1	2	3	4	5
BORA	47.66	28.34	7.28	0.90		
BDG	74.49	53.33	30.07	2.73		
TSK	75.97	59.46	34.46	1.15		
TGR	71.28	51.70	34.69	15.22	8.33	0.00

Table 12. Product C Repellency

Strain	Product C, Percent Protection (hour)			
	0	1	2	3
BORA	54.50	37.82	14.79	2.80
BDG	48.79	29.32	12.06	0.99
TSK	55.84	35.68	9.98	1.48
TGR	53.78	38.69	18.73	1.52

systemic issues like waste and water management. Taiwan offers a compelling example: comprehensive mosquito control measures—including habitat elimination, vector control, and quarantine of infected individuals—led to a dramatic reduction in dengue cases in Kaohsiung City, from 14,999 and 19,723 suspected cases in 2014 and 2015 to just 3 and 11 cases in 2017 and 2018 [19].

The findings from our study, along with evidence from Venezuela [15], Harapan et al. [18], and Taiwan [19], underscore the need for multifaceted strategies that not only enhance public awareness but also ensure the translation of knowledge into consistent, community-wide practices, ultimately reducing mosquito populations and mitigating the risk of disease transmission.

The alignment between KAP and WTP highlights an opportunity to engage the public in adopting protective measures. While repellents are affordable (IDR 20,000–40,000 or USD 1.44–2.88), increasing awareness about their ingredients and efficacy can enhance informed decision-making and encourage consistent use.

Most respondents (93.6%) use repellents to prevent bites and disease transmission, while 6.4% avoid them due to concerns about active ingredients. This highlights the importance of raising public awareness about repellent safety. Additionally, 28% of respondents admitted to not considering active ingredients, further emphasizing the need for education.

Natural-based repellents are preferred for their perceived safety (3.40 out of 5), while synthetic repellents are valued for longer protection times (3.32 out of 5). Non-users also favor natural-based repellents (3 out of 5), despite evidence that synthetic repellents outperform them in efficacy. Bridging the gap between public perception and actual product performance is essential for improving protective measures.

Marketing campaigns should highlight the scientifically proven benefits of DEET-based products while addressing safety concerns. Pricing strategies could focus on making synthetic repellents more accessible, emphasizing their cost-effectiveness relative to protection duration. Additionally, public education campaigns should address misconceptions about synthetic repellents and promote informed choices.

4.3 Vector Control Strategy

The primary priorities for vector control are social (0.42), economic (0.34), and policy (0.11) aspects. Social strategies focus on educating communities about mosquito control, while economic strategies aim to ensure adequate funding for vector control initiatives. Policy strategies are designed to enhance reporting and management systems and secure

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Table 13. Repellency Level Comparison among Strain and Age Variation

Strain	Age			Variance level
	5	10	15	
BORA	46.02	44.09	45.40	Standard
BDG	51.98	48.16	51.33	1.118 times
TSK	47.48	59.22	54.62	1.190 times
TGR	50.40	55.02	49.01	1.140 times

government support for mosquito control activities. The demonstrated effectiveness of educational interventions at various community levels in controlling Aedes-borne diseases underscores the importance of multidisciplinary collaboration [20]. Proposed solutions include implementing micro-level programs tailored to local needs (0.16), fostering inter- and intra-sectoral collaboration (0.14), and delivering targeted educational campaigns (0.13). The Strength-Opportunity (SO) strategy (0.43) prioritizes community empowerment, engaging media campaigns, and outreach at high-risk community activity centers.

Examples like Mexico's Patio Limpio strategy [21] demonstrate the effectiveness of community participation in eliminating mosquito habitats. Similarly, border monitoring has proven effective in Taiwan, reducing dengue cases by targeting imported infections [19].

Wolbachia-based mosquito control offers a promising alternative, as trials in Yogyakarta have shown that Wolbachia-infected mosquitoes reduce dengue transmission through reproductive manipulation and shortened mosquito lifespans [22, 23]. Expanding such strategies could significantly impact mosquito populations and disease incidence in Indonesia.

Dengue fever cases in Indonesia are predominantly concentrated among children aged 5–14 years (33.97%) and productive-age adults aged 15–44 years (37.45%). Younger children aged 1–4 years (14.88%), the elderly (over 44 years; 11.57%), and infants under one year old (3.13%) represent smaller but still significant proportions. Mortality rates are highest in children aged 5–14 years (34.14%), followed by children aged 1–4 years (28.57%), productive-age adults (15.87%), the elderly (11.11%), and infants (10.32%) [11].

These patterns suggest a need for age-specific and context-sensitive approaches to dengue prevention using repellents:

1. High-risk/vulnerable groups (children aged 5–14 years): Children in this age group require repellents with long-lasting protection that are safe for use in high-activity settings such as schools and outdoor spaces. DEET-based synthetic repellents (Product A) are ideal, providing sustained protection for these environments.
2. Medium-risk group (children aged 1–4 years and adults aged 15–44 years): Comfort and aroma are key for this group. Natural-based repellents with lavender and geranium oils (Product K) are suitable for younger children, while products offering moderate-duration protection work well for adults engaged in outdoor activities.
3. Low-risk group (infants under one year and elderly adults over 44 years): Repellents for these groups should prioritize ease of application and comfort. Citronella and eucalyptus-based products with chamomile aromas (Product C) are appropriate for infants, while roll-on eucalyptus and cajuput-based repellents (Product S) are practical for elderly adults.

4.4 Repellent Protection Power Comparison

According to the criteria set by the Ministry of Agriculture, a repellent is considered effective if it provides at least 90% protection for at least 6 hours [8]. This study showed that out of the four products tested, only synthetic repellents containing DEET (product A) effectively provided this level of protection. None of the natural-based products could provide 90% protection for 6 hours. For the natural products, even in the first hour the range of protection provided was only around 29.81% (product A against BORA strain) 59.45% (product S against TSK). For the following hours, the protection provided is getting smaller. When compared to other studies, our findings align closely with previous research. For instance, Peng et al. [24] evaluated the efficacy of 26 commercial repellents against *Aedes albopictus* mosquitoes. Among these, only 17 products demonstrated repellent activity, with the best-performing product containing 15% DEET, which provided an average protection time of 5.63 ± 0.36 hours. In contrast, most plant-based repellents in the study showed limited efficacy, as mosquitoes began landing less than 2 hours after application. However, it is challenging to directly compare results across studies due to various factors that can influence repellent effectiveness. These factors include differences in chemical formulations, environmental conditions, application methods, and experimental designs [25].

4.5 Repellent Effectiveness by Strain and Age

The significant correlation between mosquito strain and repellency ($r = 0.58$; $p = 0.048$) indicates that strain variations influence repellent effectiveness. Among the strains tested, the TSK strain was the most repelled, showing 1.19 times higher repellency compared to the BORA strain. Notably, the BORA and BDG strains exhibited similar trends, while TSK and TGR strains displayed distinct tendencies. Additionally, mosquitoes aged 10 days were the most sensitive to the repellent, demonstrating the highest repellency levels compared to other age groups, though this trend was not consistent across all strains. This finding aligns with Deletre et al. [26], which highlighted the role of insecticide resistance alleles in altering

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mosquito behavior. Resistance in TSK and TGR strains may also explain these results, as suggested by Silalahi et al. [27], who reported resistance to pyrethroids and other insecticides in Indonesian *Aedes aegypti* populations. These results underscore the need for targeted testing of repellents on local mosquito strains to ensure efficacy. Products marketed in Indonesia should undergo strain-specific evaluations to account for regional variability, guiding product development and improving consumer confidence in repellent effectiveness.

Age variations had a negligible overall effect on repellency ($r = 0.11$; $p = 0.741$). While 10-day-old mosquitoes exhibited slightly higher sensitivity to repellents, no statistically consistent trends were observed across age groups or strains. This suggests that other biological factors, such as enzyme activity and antenna sensitivity, might have a stronger influence on repellent performance [28, 29]. Further research into age-related factors is warranted to refine product formulations.

5. Conclusion

The community demonstrates a strong understanding of mosquito control, but translating knowledge into effective practices remains a challenge. Natural-based repellents are preferred for their safety, while DEET-based repellents are necessary for achieving effective protection against *Aedes aegypti*. Social and economic factors are critical in guiding vector control strategies, emphasizing the need for community-focused educational programs and collaborations. Additionally, strain variations significantly influence repellent efficacy, highlighting the importance of localized testing for product development. These findings underline the need for a balanced approach that integrates public preferences with evidence-based practices to enhance mosquito bite prevention and dengue control.

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