

## Differential response to plant- and human-derived odorants in field surveillance of the dengue vector, *Aedes aegypti*

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### ABSTRACT

Linalool oxide (LO) and hexanoic acid (HA) represent plant- and human-derived odorants, respectively, previously found as attractants for the dengue vector *Aedes aegypti*. Here, we investigated if a blend of both compounds can improve captures of this mosquito species in field trials in two dengue endemic sites, Kilifi and Busia Counties in Kenya. *Ae. aegypti* captures were significantly higher in Kilifi than Busia ( $\chi^2_{1,142} = 170.63$ ,  $P < 0.0001$ ) and varied by treatments ( $\chi^2_{5,137} = 151.19$ ,  $P = 0.002$ ). We found that CO<sub>2</sub>-baited BG Sentinel traps combined with a blend of both odorants decreased *Ae. aegypti* captures about 2- to 4-fold compared to captures with the individual compounds (LO or HA) used as positive controls. This was the case for all blends of LO and HA, irrespective of the doses tested. Our findings indicate that combining plant- and human-derived odors may elicit a masking effect in trapping *Ae. aegypti*. These results partly corroborate previous findings for malaria mosquitoes which showed that combining lures from both host sources either decreases or increases trap catches depending on the dose. Further investigations in the usefulness of combining plant and animal odorants in mosquito trapping are therefore necessary.

### 1. Introduction

Effective surveillance is an integral part of disease epidemiologic risk assessments. For improved surveillance of arboviral diseases, effective trapping tools are required to increase vector collections to maximize virus detection rates (Gu et al., 2008; Tchouassi et al., 2013). Such tools can also reveal accurate trends in vector population abundance to ensure appropriate and timely interventions and to evaluate vector control impact (Tchouassi et al., 2013; Owino et al., 2014; Eiras et al., 2018; Wilke et al., 2019). Effective monitoring and control of vector populations can be achieved through application of behavior-modifying chemicals.

The mosquito *Aedes aegypti* (Linnaeus, 1762) is a key vector of the arboviral pathogens dengue, chikungunya, yellow fever and Zika viruses (Owino et al., 2015; Weetman et al., 2018). Frequent disease outbreaks attributed to these agents have occurred recently in various parts of the world, thereby posing a significant health threat (Chepkorir et al., 2018; Braack et al., 2018). Thus, surveillance for this vector is a critical component of assessing risk of transmission and outbreak occurrence. Improved monitoring of adult *Ae. aegypti* populations using

host-derived odorants mainly of human origin have been exploited (Bernier et al., 2000; Bernier et al., 2002; Owino et al., 2015). However, only limited field assessment has been carried out on most of the identified semiochemicals.

It is known that a complex bouquet of host derived chemicals is needed to elicit vector attraction (Syed, 2015; Chan et al., 2018). For instance, ammonia has been reported to increase the attractiveness of lactic acid to *Ae. aegypti* (Geier and Boeckh, 1999). Additionally, blends of acetone and carboxylic acids also elicit increased attractiveness to this mosquito species (Bosch et al., 2000; Bernier et al., 2003). Recently, efforts to combine odorants from plant- and mammalian-derived sources to develop improved lures have been attempted (Jacob et al., 2018). As observed for the malaria vectors, combining lures from both sources either decreases or increases trap catches depending on the dose (Jacob et al., 2018).

Previously, in a field study, hexanoic acid (HA) representing a human-derived odorant was found to exhibit superior attraction to *Ae. aegypti* compared to the commercial BG lure (Owino et al., 2015). Also, linalool oxide (LO), identified from plants, a sugar feeding substrate for various mosquito species, was reported as an effective lure for *Ae.*

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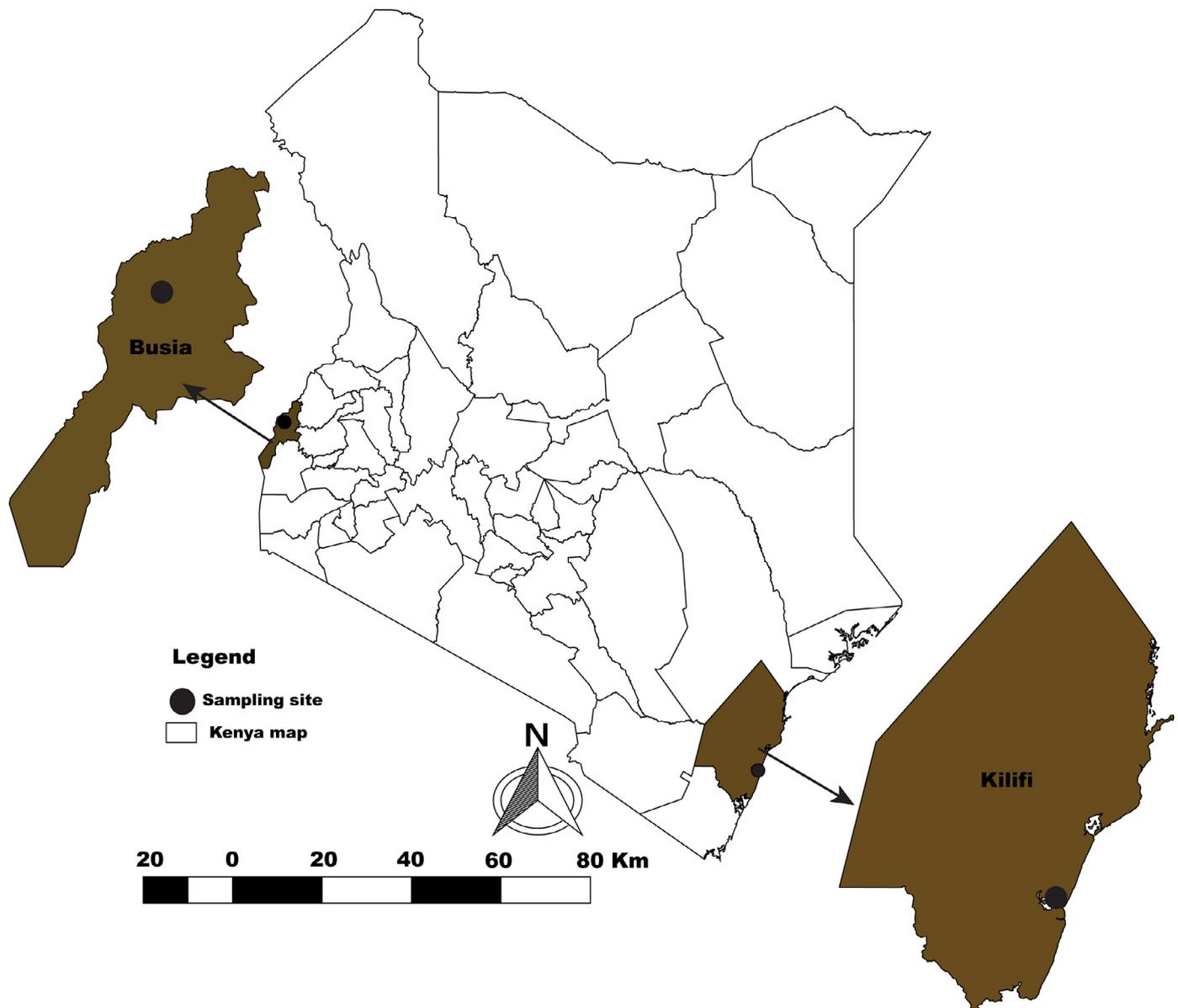


Fig. 1. Map of Kenya showing trapping sites in the two counties, Kilifi and Busia.

*aegypti* in field trials (Nyasembe et al., 2015). In the present study, we tested the hypothesis that a combination of hexanoic acid and linalool oxide improves attractiveness of *Ae. aegypti* in the field. As objective of the study, we evaluated the captures of *Ae. aegypti* in conventional BG Sentinel traps baited with different combinations of these compounds and compared to those in traps with the single compounds.

## 2. Materials and methods

### 2.1. Chemicals

Authentic commercial standards of (*E*-) linalool oxide and hexanoic acid were purchased from Sigma-Aldrich, and purities were  $\geq 99\%$ .

### 2.2. Study sites

Field experiments were conducted in Busia County (Kamosing) and Kilifi town in western and coastal Kenya, respectively (Fig. 1). *Aedes aegypti* is prevalent in these sites especially coastal Kenya where the *Aedes*-borne viral diseases, dengue and chikungunya are endemic

(Owino et al., 2014; Ngoi et al., 2016).

The average temperature and annual rainfall in Busia range between 17–30°C and 900–1500 mm, respectively. Long rains occur between March and June with short rains from between September and October. Small scale farming of maize, beans, groundnuts, cassava, sorghum and vegetables is dominant. Livestock farming of cattle, goats, sheep, pigs and chickens is practiced in the area. In the morning and evening, cattle, goats and sheep are tethered around homesteads with chicken and pigs mainly reared within the homesteads.

Kilifi County is generally warm throughout the year with temperatures ranging between 21 °C during the coldest months (June and July) and 32 °C during the hottest months (January and February). Rainfall ranges between 900 mm and 1000 mm annually. Two rainy seasons were observed; April to June (long rains) and October to December (short rains), although there could be year to year variations in the timing of rainfall.

### 2.3. Field evaluation of LO and HA on *Aedes aegypti* catches

Field evaluation was carried out in two experiments. In experiment

I, we evaluated the effect of combining LO and HA on trap catches of *Ae. aegypti* in Busia and Kilifi. The compounds were each evaluated using established optimum doses- LO, 20 ng/ $\mu$ l (Nyasembe et al., 2015) and HA at 0.5 mg/ $\mu$ l (Owino et al., 2015) both prepared in hexane, in BG-1 Sentinel Trap (Bioquip, Rancho Dominguez, California, USA). The treatments evaluated in a 6  $\times$  6 Latin Square designed experiment included (i) blend of LO + HA + CO<sub>2</sub>, dispensed together (mixture in a single dispenser) and (ii) separately (individual dispensers), against (iii) LO + CO<sub>2</sub>, (iv) HA + CO<sub>2</sub>, (v) BG lure + CO<sub>2</sub> and (vi) CO<sub>2</sub> alone (positive controls). The compounds were dispensed using rubber septa (17.5 mm diameter, Sigma-Aldrich). Each trap was baited with approximately 1 kg of dry ice dispensed using Thermos Igloos (Bioquip, Rancho Dominguez, California, USA). Daily, traps were set around selected homesteads, about 50 m from each other at 08:00 a.m. and retrieved after 24 h the following day.

Experiment II was limited to Kilifi County only where we investigated the effect of combining HA and LO on mosquito catches in dose response assays. We evaluated 10-fold lower and higher doses of the established optimal doses of LO and HA prepared in the same way already described in experiment I. These, together with the established optimum doses of LO and HA were blended resulting in 9 different blend combinations (Table 1). Each blend or compound evaluated separately was baited with CO<sub>2</sub> and compared to control traps having CO<sub>2</sub> only. The resulting 12 trap-treatments (Table 1) were evaluated in a complete randomized design with days as replicates. CO<sub>2</sub> was supplied as dry ice as described previously; however, traps were set at 7:00 a.m. and retrieved at 18:30 the same day.

#### 2.4. Mosquito processing and identification

Trapped mosquitoes were anesthetized by exposure to triethyl amine for 2 min, sorted and identified to species level on-site using available taxonomic keys (Huang, 2004). Daily counts of mosquitoes were recorded by species for each trap and site. After sorting, the mosquitoes were preserved in Eppendorf tubes in liquid N<sub>2</sub> and later transported to the Behavioral and Chemical Ecology Unit (BCEU), icipe, Duvuville Campus, Nairobi, for storage at -80 °C.

#### 2.5. Ethical considerations

We sought oral consent from village elders and home owners to set up traps around homesteads at both sites prior to the experiments, in addition to study approval from the KEMRI Scientific Ethics Review Unit (Protocol 3312).

#### 2.6. Statistical analysis

Daily counts or abundance of *Ae. aegypti* and by sex in the different treatments served as the response variable in separate generalized linear models (GLM) with a negative binomial error structure. Treatment and site were the main predictor variables in the model for

experiment I, while only treatment was included in the model for experiment II. All analyses were implemented in R version 3.3.1 (Team, 2013) at  $\alpha = 0.05$  level of significance. Each treatment was compared to the control (CO<sub>2</sub> alone) as the reference and incidence rate ratio (IRR) estimated, as a likelihood measure that mosquitoes chose other treatments other than the control. For the control, the IRR is 1 with values above this indicative of treatments with better performance and values below underperformance relative to the control (Tchouassi et al., 2012). Further, pair-wise comparison in *Ae. aegypti* catches between the treatments was performed by Tukey's HSD test.

### 3. Results

In experiment I, *Ae. aegypti* comprised 97% of total mosquito catches in Busia ( $n = 977$ ) and 86% ( $n = 9097$ ) in Kilifi. Other mosquitoes recorded in low numbers included anopheline ( $n = 1$ ) and culicines mainly *Culex* spp. ( $n = 31$ ) in Busia, and *Culex* spp. ( $n = 1314$ ) in Kilifi. Of the total 8728 *Ae. aegypti* trapped 945 was caught in Busia (303 males, 642 females) and 7783 (1803 males, 5980 females) in Kilifi. *Aedes aegypti* captures were significantly higher in Kilifi than Busia ( $\chi^2_{1,142} = 170.63, P < 0.0001$ ) and varied between the treatments ( $\chi^2_{5,137} = 151.19, P = 0.002$ ) (Table 2). An analogous pattern was seen in catches of females [site:  $\chi^2_{1,142} = 163.99, P < 0.0001$ ; treatment:  $\chi^2_{5,137} = 150.64, P = 0.02$ ] and males [site:  $\chi^2_{1,142} = 191.96, P < 0.0001$ ; treatment:  $\chi^2_{5,137} = 145.30, P < 0.0001$ ] (Table 2). Relative to the reference control (CO<sub>2</sub> alone), *Ae. aegypti* abundance increased about two-fold in CO<sub>2</sub>-traps baited with LO (IRR = 2.2; 95%CI (1.42–3.56) or HA (IRR = 2.4; 95%CI (1.53–3.83) (Table 2), with similar pattern observed for females and males (Table 2). Between treatment effect in *Ae. aegypti* catches was evident between HA and BG-Lure (BGL) (IRR = 1.7; 95%CI (1.07–2.65;  $P = 0.024$ ) and between LO and BGL (IRR = 1.6; 95%CI (1.00–2.47;  $P = 0.05$ ). About a two-fold significant increase in abundance of females was found in HA than BGL (IRR = 1.7; 95%CI (1.06–2.79;  $P = 0.028$ ), and about 3-fold higher catches of males in LO than BGL (IRR = 2.8; 95%CI (1.72–4.53);  $P < 0.0001$ ). After controlling for study site, we found an overall variation in *Ae. aegypti* captures by sex largely influenced by the effect of HA and LO (Table 3). A significantly higher proportion of males was captured in traps with LO than HA in Kilifi ( $\chi^2 = 200.48, df = 1, P < 0.0001$ ) and in Busia (87/173 vs 57/197;  $\chi^2 = 16.783, df = 1, P < 0.0001$ ) (Table 3).

Experiment II limited to Kilifi involved 12 replicate trials. Total *Ae. aegypti* trap catches was 3667 (2344 females, 1323 males), comprising 90% of the total mosquitoes trapped ( $n = 4073$ ). The remaining 10% ( $n = 406$ ) were culicines mainly *Culex* spp. We found significant treatment variations in *Ae. aegypti* abundance ( $\chi^2_{11,132} = 158.99, P < 0.0001$ ), as well as females ( $\chi^2_{11,132} = 155.90, P < 0.0001$ ) and males ( $\chi^2_{11,132} = 163.36, P < 0.0001$ ). A dot plot of the trap catches across the different treatments is presented in Fig. 2. In the presence of CO<sub>2</sub>, only the individual lure LO or HA used as positive controls in this experiment significantly increased captures of *Ae. aegypti* (total and

**Table 1**

List of blends tested in Kilifi, Kenya, July 2018.

Lure type	Treatment tested	Blend abbreviation and dose
Binary	(E)-Linalool oxide + hexanoic acid	LH1
Binary	(E)-Linalool oxide + hexanoic acid	LH2
Binary	(E)-Linalool oxide + hexanoic acid	LH3
Binary	(E)-Linalool oxide + hexanoic acid	LH4
Binary	(E)-Linalool oxide + hexanoic acid	LH5
Binary	(E)-Linalool oxide + hexanoic acid	LH6
Binary	(E)-Linalool oxide + hexanoic acid	LH7
Binary	(E)-Linalool oxide + hexanoic acid	LH8
Binary	(E)-Linalool oxide + hexanoic acid	LH9
Single	Hexanoic acid	HA
Single	(E)-Linalool oxide	LO

**Table 2**  
Site and treatment comparison in *Ae. aegypti* trap catches in Busia and Kilifi, Kenya.

Factor		Total catches/captures		Female		Male	
		IRR (95%CI)	P-value	IRR (95%CI)	P-value	IRR (95%CI)	P-value
<b>Site (8728)</b>	Kilifi (7783)	7.7(5.89–10.01)	<0.0001	8.7 (6.58–11.62)	<0.0001	5.5 (4.12–7.35)	<0.0001
	Busia (945)	1 (reference)		1 (reference)		1 (reference)	
<b>Treatment (n)</b>	BGHALO (1083)	1.4 (0.89–2.24)ab	0.14	1.36 (0.83–2.23)bc	0.22	1.6 (0.97–2.75)bc	0.06
	BGL (1193)	1.4 (0.90–2.28)b	0.12	1.37 (0.84–2.25)bc	0.21	1.7 (1.03–2.92)b	0.04
	BGLOHA (1236)	1.6 (0.98–2.47)ab	0.06	1.37 (0.84–2.25)bc	0.21	2.3 (1.36–3.80)ab	0.002
	HA (2278)	2.4 (1.53–3.83)a	0.0001	2.4 (1.44–3.84)a	0.001	2.6 (1.57–4.35)ab	0.0002
	LO (2176)	2.2 (1.42–3.56)a	0.0005	1.6 (1.0–2.68)ab	0.048	4.9 (2.94–8.02)a	<0.0001
	CO <sub>2</sub> (762)	1b		1c		1c	

Columns followed by different letters indicate significant difference between the treatments at  $\alpha = 0.05$ . Analysis was by generalized linear models using negative binomial error structure. Each experiment was replicated 12 times. Blend abbreviations are defined as in Table 1. LO, linalool oxide; HA, hexanoic acid; BGL, commercial BG-Lure; BGHALO indicates blend of LO and HA dispensed on a single rubber septa as a mixture; BGLOHA indicates blend of LO and HA dispensed in separate rubber septa.

**Table 3**  
Sex comparisons in captures of *Ae. aegypti* between Busia and Kilifi in the different treatments.

Treatment	Busia-M	Busia-F	Kilifi-M	Kilifi-F	$\chi^2$ -test	P-value
CO <sub>2</sub>	25	87	114	536	1.16	0.281
BGHALO	41	115	183	744	3.1	0.08
BGL	37	106	221	829	1.46	0.23
BGLOHA	56	108	257	815	7.25	0.007
HA	57	140	327	1754	21.51	<0.0001
LO	87	86	701	1302	15.47	<0.0001
Total	303	642	1803	5980	35.96	<0.0001

Comparisons was by chi-square good-of-fit at  $\alpha = 0.05$ . All traps were baited with CO<sub>2</sub>; LO, linalool oxide; HA, hexanoic acid; BGL, commercial BG-Lure; BGHALO indicates blend of LO and HA dispensed on a single rubber septa as a mixture; BGLOHA indicates blend of LO and HA dispensed in separate rubber septa.

respective sexes) compared to the control (Table 4). Almost all the blends of LO and HA reduced catches of *Ae. aegypti* relative to the control. In fact, a 2- to 4-fold decrease in the abundance of *Ae. aegypti* was observed for most of the blends compared LO or HA in the presence of CO<sub>2</sub>. A higher proportion of females compared to males was caught in traps baited with HA ( $\chi^2 = 91.81$ ,  $df = 1$ ,  $P < 0.0001$ ) and LO ( $\chi^2 = 3.27$ ,  $df = 1$ ,  $P = 0.07$ ).

#### 4. Discussion

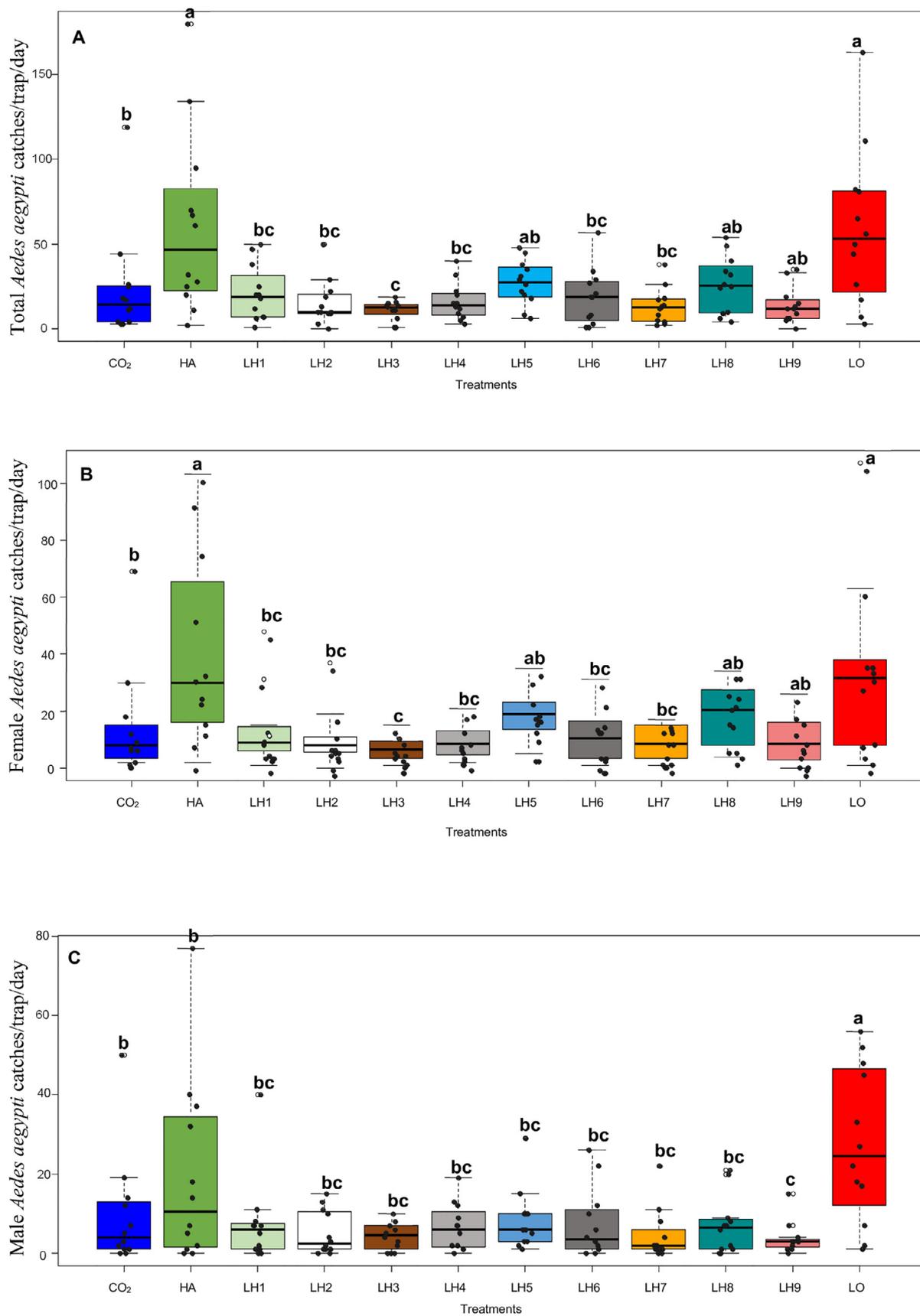
These results show that combining LO and HA reduces captures of *Ae. aegypti* and even in both sexes. This implies that when combined, each compound masks the attractive effect of the other. Previously, such interactive effect has been reported in the malaria vectors for blends of compounds albeit in a dose-dependent manner (Jacob et al., 2018). Here, irrespective of the doses tested, we found overall decreased *Ae. aegypti* catches in blends of HA and LO compared to the individual compounds in the presence of CO<sub>2</sub>. Dispenser types can affect effectiveness of vector catches to semiochemicals (Torr et al., 1997; Mweresa et al., 2014); thus, further research employing different dispensers are needed to confirm our findings. Nonetheless, the results underscore the importance of a detailed knowledge of interactive effect of odorants for improved lure formulation. On the other hand, knowledge of compounds with masking effects (otherwise known as attractant-inhibitors (Bernier et al., 2006), can be exploited in disease control. e.g., to mask attractiveness of humans, thereby limit mosquito bites and hence, pathogen transmission risk. For instance, ethyl pyruvate was found as an antagonist that masks attraction of *Ae. aegypti* to CO<sub>2</sub> and human skin odor (Tauxe et al., 2013).

Based on the trap catches, LO used as one of the positive controls lured both male and female *Ae. aegypti*. Generally, adult male

mosquitoes depend exclusively on plants for exogenous sources of energy, whereas females derive energy both from vertebrate blood and plant sugars (Foster, 1995; Nyasembe and Torto, 2014). *Aedes aegypti* females have recently been found to feed on plant tissue in nature (Nyasembe et al., 2018). Thus, it is not unexpected that both sexes were attracted to LO which serves as a cue for sugar sources as previously reported (Nyasembe et al., 2015). More intriguing was the finding that males were generally more attracted to traps with host odors, especially to the human-derived odorant HA, another positive control in our study (Tables 2,3,4). The reasons for this observation however, are unclear although it could be related to their bioecology. Male *Ae. aegypti* commonly seeks females for mating around a human host (Hartberg, 1971), a behavior which possibly involves olfactory cues (Grant, 1969). Perhaps males may detect and respond to human host-derived cues to locate and mate with females and this could explain their response to the host odors. Thus, studies that constitute evaluating male responses to host odors (plant and animal sources) may be explored in the development of improved lures that can maximize their catches in traps. This could be rewarding for the sterile insect technique where improved monitoring of male populations is crucial to assess success. Notably, trap catches with HA were higher for females than males. This could be attributed to HA signifying host attraction for a blood meal that only females indulge in.

Odor-dispensing is very important in improving odor-baited trapping systems (Torr et al., 1997; Mweresa et al., 2014). We found comparable *Ae. aegypti* caught in traps when the blends of HA and LO were dispensed either separately or as a mixture (Table 2). Possibly both dispensing modules did not affect the adsorption and slow-release of the odorant compounds. Further research is however, warranted to measure the release rates of each component in the different blends to confirm this suggestion.

The decreased *Ae. aegypti* abundance as a result of combining LO and HA was very striking. Whether the observed decrease is associated with the mosquito's peripheral coding of these odorants needs further study. Olfactory receptors (ORs) are involved in reception of odorants and mediate decoding of specific behavioral responses in insects such as mosquitoes (e.g. how they find food be it blood or sugars) (Ray, 2015; Bohbot and Pitts, 2015). The overall few ORs repertoires in most insects has led to the hypothesis that a majority of ORs are broadly tuned to a range of odorants (Bohbot et al., 2007). In the *Drosophila* fruit fly, large parts of the peripheral coding for odors appears to be functionally conserved (Linz et al., 2013; Goldman-Huertas et al., 2015). Narrow range tuning has been posited for odorants involved in reproduction, mate selection and food selection (Bohbot and Pitts, 2015). A possible explanation for the reduced catches to the blends include peripheral coding of both odorants by functionally conserved receptors to facilitate broad detectability of plants or animal sources. It is worth noting however, that ORs vary in their degree of specificity, from narrowly to



**Fig. 2.** A dot-plot of daily trap catches (a) total (b) female and (c) male *Ae. aegypti*. Statistical significance of pairwise differences between treatments was determined by Tukey's HSD test. Letters above the graph denote statistical significance in which treatments with a different letter are significantly different from each other. The boundaries of the dot plot whiskers represent the minimum and maximum of all the count data. The dots represent data points and those outside the boundaries are outliers. Black bars represent the median number of catches. HA, hexanoic acid; LO, linalool oxide; LH1–LH9, blends of linalool oxide and hexanoic acid with the doses as defined in Table 1.

**Table 4**

Trap comparisons in blends of linolool oxide and hexanoic acid and the individual compounds in Kilifi.

Treatment (n)	<i>Ae. aegypti</i>		Female <i>Ae. aegypti</i>		Male <i>Ae. aegypti</i>	
	IRR (95%CI)	P-value	IRR (95%CI)	P-value	IRR (95%CI)	P-value
HA (725)	2.5 (1.33–4.84)a	0.005	2.9 (1.52–5.38)a	0.001	2.0 (0.84–4.99)b	0.11
LH1 (251)	0.9 (0.46–1.69)bc	0.69	0.9 (0.49–1.79)bc	0.85	0.8 (0.31–1.93)bc	0.59
LH2 (184)	0.6 (0.33–1.24)bc	0.19	0.7 (0.37–1.37)bc	0.31	0.5 (0.21–1.34)bc	0.18
LH3 (133)	0.6 (0.24–0.90)c	0.02	0.5 (0.24–0.91)c	0.02	0.5 (0.18–1.15)bc	0.09
LH4 (193)	0.7 (0.35–1.30)bc	0.24	0.7 (0.35–1.28)bc	0.22	0.7 (0.28–1.70)bc	0.41
LH5 (326)	1.1 (0.59–2.19)ab	0.69	1.3 (0.69–2.49)ab	0.4	0.9 (0.35–2.17)bc	0.77
LH6 (226)	0.8 (0.41–1.52)bc	0.48	0.9 (0.42–1.54)bc	0.52	0.8 (0.31–1.89)bc	0.55
LH7 (160)	0.6 (0.29–1.08)bc	0.08	0.6 (0.32–1.18)bc	0.14	0.5 (0.19–1.19)bc	0.11
LH8 (313)	1.1 (0.57–2.10)ab	0.78	1.3 (0.71–2.54)ab	0.36	0.7 (0.29–1.79)bc	0.47
LH9 (165)	0.6 (0.30–1.12)ab	0.1	0.7 (0.36–1.34)ab	0.27	0.4 (0.16–0.99)c	0.047
LO (705)	2.5 (1.29–4.71)a	0.006	2.2 (1.16–4.13)a	0.01	2.9 (1.18–7.01)a	0.02
CO <sub>2</sub> (286)	1b		1b		1b	

All traps were baited with CO<sub>2</sub>; CO<sub>2</sub> only traps served as the reference control; n, total *Aedes aegypti* catches per treatment; Columns followed by different letters indicate significant difference between the treatments at  $\alpha = 0.05$ ; number of replicate trials, 12; HA, hexanoic acid; LO, linalool oxide; LH1–LH9, blends of linalool oxide and hexanoic acid with the doses as defined in Table 1.

very broadly tuned (Bohbot and Pitts, 2015). Future research should focus on the molecular mechanisms underlying HA and LO attractancy and to identify which receptors determine behavior toward them.

Previous studies have shown that the response of mosquitoes is affected by the feeding status. For instance, *Ae. aegypti*, expresses inhibition of host seeking following a blood meal until oviposition (Klowden and Lea, 1979; Davis, 1984). Similar behavior has been noted in the malaria vector *Anopheles gambiae*, showing reduced responses to hexanoic acid, after blood feeding (Takken et al., 2001). In the present study, we did not determine the feeding status of the mosquitoes caught in the different treatments. Thus, we could not establish whether the mosquitoes caught in each odor-baited trap reflects their resource need. Wild caught mosquitoes in traps generally consist of a mixed population of unfed, pre-gravid and gravid cohorts (Gillies, 1954; Lyimo and Takken, 1993). Nonetheless, it may be helpful in future studies to correlate trap catches and physiological status by examining the proportion of blood fed, gravid or half-gravid, plant-fed in the different trap treatments.

We conclude that blends of the individually attractive odorants HA and LO, regardless of the dose tested reduced trap catches of *Ae. aegypti* in the presence of CO<sub>2</sub>. i.e., both odorants are competitive attractants. The compounds signify different resource needs to the mosquito-LO for a sugar source and HA for a blood source, and could be peripherally encoded by functionally conserved receptors to facilitate broad detectability of plants or animal sources. Future studies should investigate different dispensers on the trapping efficiency of these odorants. Also, the molecular mechanisms underlying HA and LO attractancy should be pursued to identify which receptors determine behavior toward these odorants.

#### CRedit authorship contribution statement

Wyckliff P. Omondi: Conceptualization, Formal analysis, Writing - original draft. Eunice A. Owino: Conceptualization, Writing - original draft. David Odongo: Conceptualization, Writing - original draft. Joseph M. Mwangangi: Conceptualization. Baldwyn Torto: Conceptualization, Writing - original draft. David P. Tchouassi: Conceptualization, Formal analysis, Writing - original draft.

#### Declaration of Competing Interest

The authors do not have any conflict of interest.

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