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FIELD EVALUATION OF COLORED LIGHT-EMITTING DIODES AS ATTRACTANTS FOR WOODLAND MOSQUITOES AND OTHER DIPTERA IN NORTH CENTRAL FLORIDA

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ABSTRACT. The attraction of mosquitoes to transmitted light from colored super-bright light-emitting diodes (LEDs) (100-nm bandwidth) was evaluated by comparison of capture numbers with and without carbon dioxide-baited (200 ml/min) Centers for Disease Control (CDC) traps. Traps with either colored LEDs or control lights were arranged in Latin square designs at 2 north central Florida woodland locations and checked daily during July and August 1996. When data were analyzed by species, a significant difference in attractivity of lights was found in some species. *Aedes atlanticus, Aedes dupreei, Aedes infirmatus, Anopheles crucians* s.l., *Culiseta melanura, Culex nigripalpus, Psorophora columbiae,* and *Uranotaenia sapphirina* showed significant color preferences. These results will have potential for use by ecologists, epidemiologists, and mosquito control personnel for improving collection efficiency of certain species of mosquitoes.

KEY WORDS Trap, color, vision, visual ecology, light traps, attractants

INTRODUCTION

Light-emitting diodes (LEDs) were evaluated as an alternative light source for use as an adult mosquito attractant. Much of the research on dipteran color preference is based on reflected light (Brett 1938; Bracken et al. 1962; O'Gower 1963; Granger 1970; Bradbury and Bennett 1974; Browne and Bennett 1980, 1981; Allan and Stoffolano 1986). Many authors have shown that mosquitoes are attracted to transmitted light (Headlee 1937, Weiss 1943, Williams et al. 1955, Bargren and Nibley 1956, Breyev 1963, Wilton and Fay 1972, Gjullin et al. 1973, Browne and Bennett 1981). Few reports detail the response of individual species. Several colors (100 nm width) of highly efficient, low cost, super-bright LEDs have recently been developed. These colored LEDs when used in Centers for Disease Control (CDC) traps have a greater intensity and require significantly lower amounts of energy (ca. 0.125 ma/h vs. 150 ma/h for standard CM-47 bulb). We evaluated the use of LEDs as an inexpensive light source and examined the relationship between transmitted light color and its attractiveness to woodland mosquito and other dipteran species.

MATERIALS AND METHODS

Three field trials were conducted using standard CDC-type traps (John W. Hock Co., model 512, Gainesville, FL) modified by replacing the standard bulbs with the LEDs. The LED was secured into a piece of 2 × 2-cm plexiglass and fastened to the screen atop the lid assembly 3 cm below the aluminum trap lid (Fig. 1). Trial 1 used 9-kg compressed-gas (carbon dioxide [CO_2]) cylinders equipped with double-stage regulators (Victor Equipment Co., model VTS453B-320, Denton, TX) and microregulators (Series M, Nupro, Wiloughby, OH) to maintain a constant gas flow of 200 ml/min. Carbon dioxide was delivered to the trap through a 3-m length of 8-mm Tygon® (Norton Performance Plastics Corp., Akron, OH) tubing secured with a rubber band so the top of the tubing was even with the top of the trap opening. Gas flow was checked each morning and evening using an in-line flowmeter (No. 12, Gilmont Instruments, Great Neck NY). Mosquitoes attracted near the trap intake were drawn in by the trap fan and blown through a screen funnel and into a 1-quart polypropylene jar containing a 3 × 6-cm piece of dichlorvos-impregnated vinyl strip used as a killing agent. Powersonic® (PowerSonic Corp., San Diego, CA) 6-V, 10-amp-h rechargeable gel cell batteries were used to run the fan motor and standard incandescent light.

Six colors with and without CO_2 (trials 1 and 2): From July 15 to 20 (trial 1) and July 22 to 27 (trial 2), 1996, different colored lights were used as attractants in standard CDC-type surveillance traps using a 6 × 6 Latin square design. Light, day, and position effects were evaluated using a 3-way analysis of variance (SAS Institute 1985) for the total number and most common species represented in the traps. Multiple comparisons were made using the Ryan–Einot–Gabriel–Welsh multiple range test ($\alpha = 0.05$). Trial 1 used CO_2 as an additional attractant and trial 2 used the same randomization, but did not use CO_2. Four different colored super-bright Toshiba Tosbright® (Martech Optoelectronics, Latham, NY) Ultrabright LEDs were compared to no light and a standard GE® (John W. Hock Co., Gainesville, FL, CM-47, 6.3 V, 520 millicandela [mcd]) miniature lamp incandescent bulb used as controls. The diodes tested were red (613 ± 50 nm,

Fig. 1. Modified Centers for Disease Control (CDC)-type trap equipped with light-emitting diode (LED) (shown with arrow).

1,600 mcd, 22°); orange (605 ± 50 nm, 2,000 mcd, 22°); yellow (587 ± 50 nm, 2,300 mcd, 22°), and green (567 ± 50 nm, 2,400 mcd, 8°). Each LED was powered by 2 alkaline D-cell batteries at 2.8 ± 0.2 V and 18 ± 2 ma. A 10-Ω resistor was placed in series to prevent overdriving the LED.

Trials 1 and 2 were conducted at the University of Florida's Austin Cary Memorial Forest, a research area located north of Gainesville, FL. The habitat consisted of a cypress swamp surrounded by pine flatwoods. Traps were hung 165 cm above ground level and placed every 30 m near the banks of a seasonal forest stream that runs through the middle of the swamp. Because of the thick vegetation, none of the traps were visible to each other. The trapping period followed a 24.5- and 6.83-cm rainfall on July 5 and 9, respectively.

These trials ran from 1800 to 0800 h for 6 days in a row using a 6 × 6 Latin square design. The trap and motor assembly remained stationary, but the lights or diodes were changed nightly so each light would occupy each position during the 6-day period. After each trap night, the captured mosquito adults were identified and counted. All *Culex* (*Melanoconion*) Theobald, *Anopheles quadrimaculatus* s.l., *Anopheles crucians* s.l., and *Aedes atlanticus* Dyar and Knab/*Aedes tormenter* Dyar and Knab species were pooled, as these taxa could not be distinguished with confidence.

Eight colors with CO_2 (trial 3): Trial 3 was con-

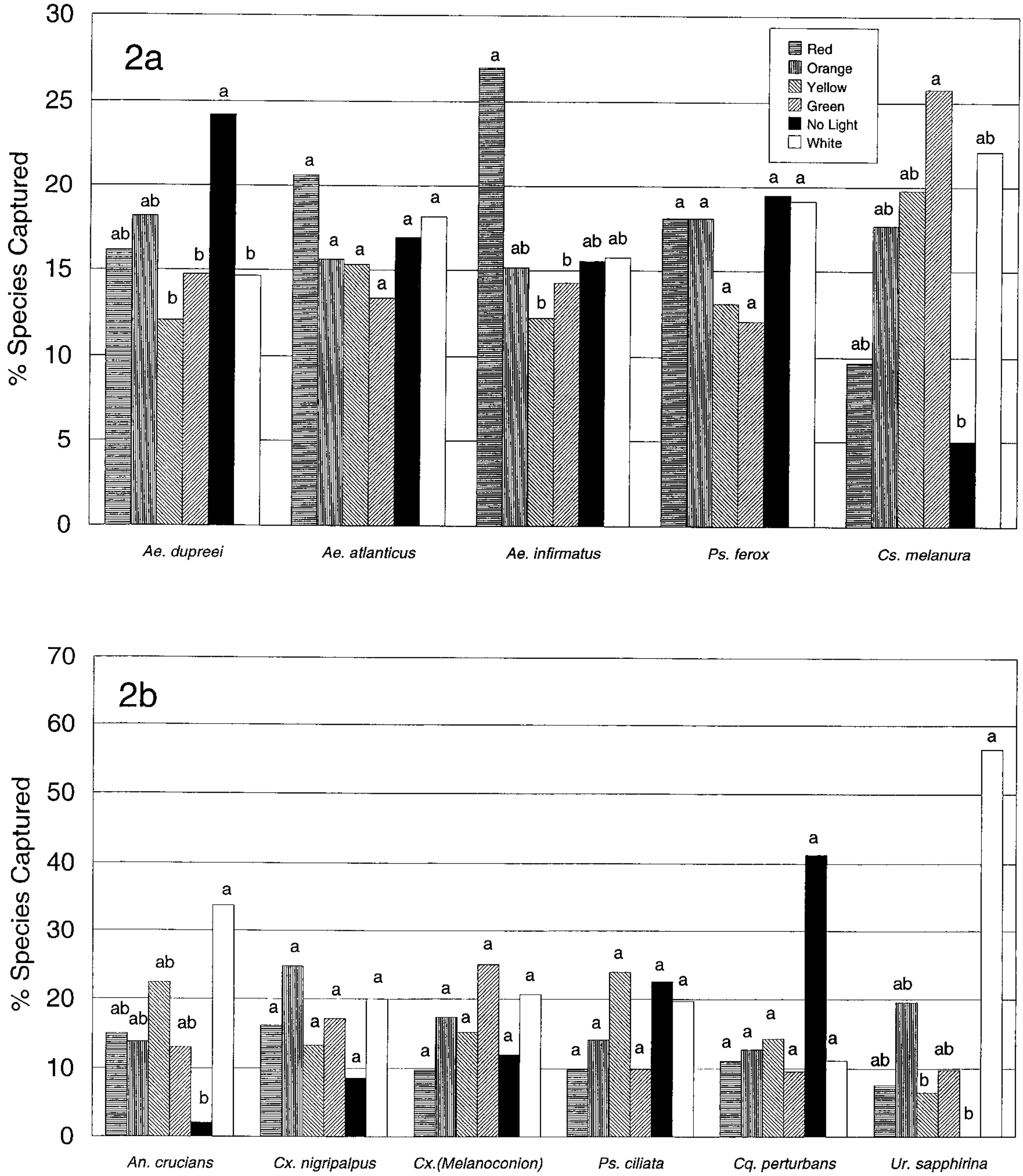

Fig. 2. Relative percent composition of mosquito species captured in CO_2-baited Centers for Disease Control (CDC)-type traps using colored light-emitting diodes or incandescent light only. Means within each species group having the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh multiple range test). $\alpha = 0.05$, $n = 6$ nights.

ducted from August 12 to 21, 1996. Because of fluctuating water levels and mosquito populations at the Austin Cary Forest site, a similar, but more permanent cypress swamp habitat was chosen north of Gainesville, FL. In addition to the 4 LED colors and 2 controls previously discussed, 2 additional LED wavelengths, infrared (940 ± 50 nm, 22° [Martech Optoelectronics, Latham, NY, model MTE1080]) and blue (450 ± 50 nm, 800 mcd, 22° [Panasonic®, Panasonic Technologies, Inc., Princeton, NJ]) were evaluated also. Using an 8 × 8 Latin square design, traps were placed around the perimeter of the swamp. Each trap

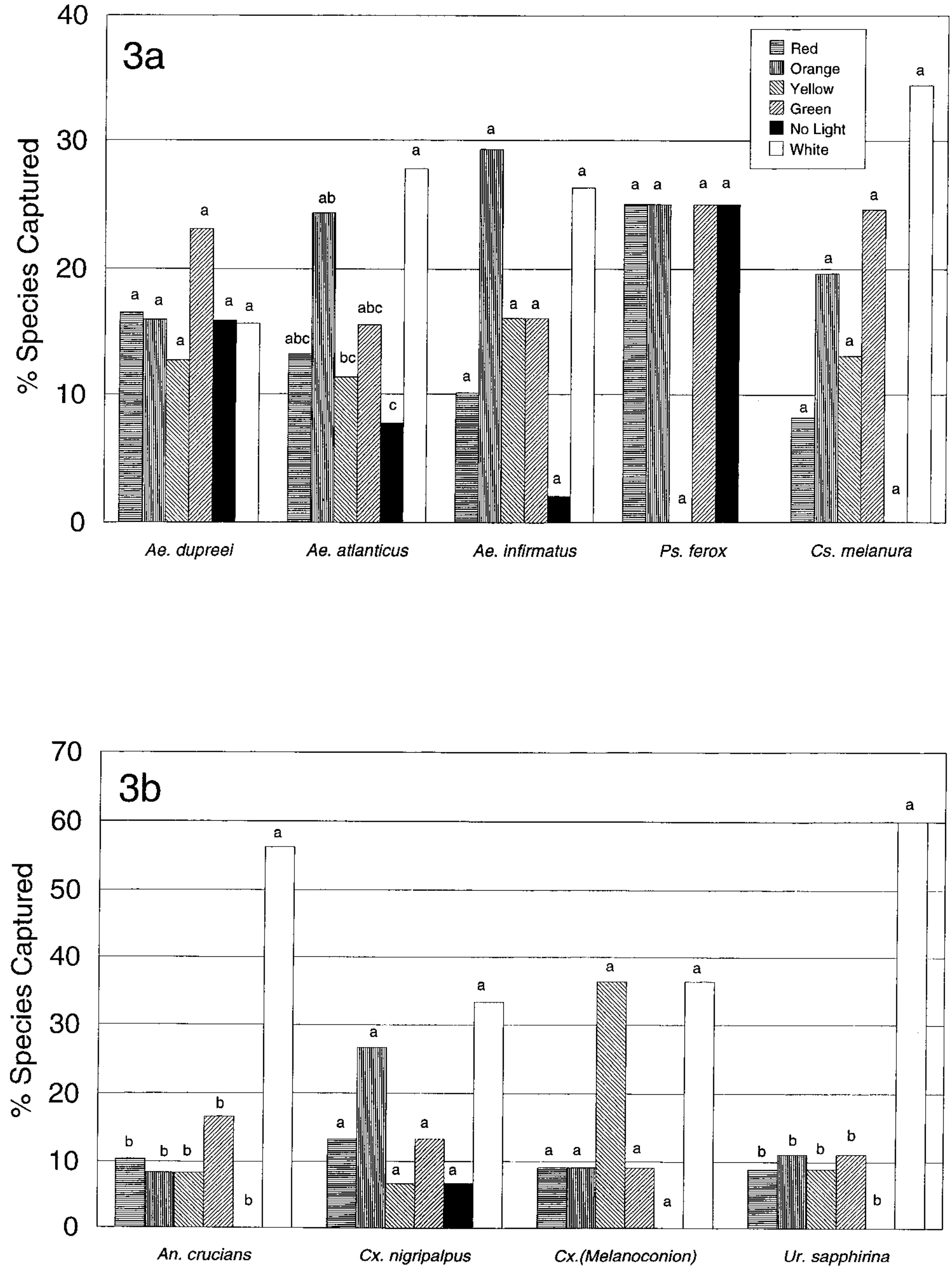

Fig. 3. Relative percent composition of mosquitoes captured in Centers for Disease Control (CDC)-type traps using colored light-emitting diodes or incandescent light only. Means within each species group having the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh multiple range test). $\alpha = 0.05$, $n = 6$ nights.

was baited with 200 ml/min CO_2 as in trial 1 and otherwise treated as before.

RESULTS

Six colors with and without CO_2 (trials 1 and 2)

During the 6 trap-nights of trials 1 and 2, 32,059 and 1,916 specimens of mosquitoes were collected from traps enhanced with CO_2 and those without CO_2, respectively. The mosquito species compositions attracted to the incandescent light trap agree with those found by Mann (1993). Responses of the most numerous mosquito species are shown in Fig. 2a, 2b, and 3a, 3b. Means, standard errors, P values, and significant differences for species represented in large enough numbers are shown in Ta-

Table 1. Centers for Disease Control (CDC) trap counts using colored light-emitting diodes or incandescent light with 200 ml/min CO_2 (means ± SEM). Means within each row having the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh multiple range test) (n = 6 nights).

Species	Red	Orange	Yellow	Green	No light	Incandescent	*P* value
Aedes dupreei[1,2]	549.7 ± 108.9 ab	619.7 ± 163.1 ab	411.7 ± 98.5 b	502.5 ± 117.1 b	825.8 ± 205.9 a	499.8 ± 112.5 b	0.02
Ae. fulvus pallens	0.3 ± 0.03 a	0.2 ± 0.2 a	0.5 ± 0.3 a	0.0 ± 0.0 a	0.5 ± 0.3 a	0.7 ± 0.2 a	0.57
Ae. atlanticus[1,2,3]	306.2 ± 64.0 a	232.0 ± 31.4 a	227.5 ± 57.8 a	198.7 ± 40.2 a	251.2 ± 51.2 a	269.7 ± 64.9 a	0.34
Ae. canadensis	1.2 ± 1.0 a	0.2 ± 0.2 a	0.2 ± 0.2 a	0.5 ± 0.5 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.37
Ae. infirmatus[1,2]	60.2 ± 15.1 a	33.8 ± 5.2 ab	27.3 ± 4.8 b	31.8 ± 5.4 b	34.7 ± 9.0 ab	35.2 ± 7.8 ab	0.01
Anopheles crucians s.l.	6.2 ± 1.2 ab	5.7 ± 2.1 ab	9.2 ± 2.4 ab	5.3 ± 1.4 ab	0.8 ± 0.4 b	13.8 ± 4.8 a	0.03
An. quadrimaculatus s.l.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	—
Culex nigripalpus[1,2]	5.7 ± 2.0 a	8.7 ± 4.4 a	4.7 ± 1.0 a	6.0 ± 1.6 a	3.0 ± 1.3 a	7.0 ± 2.0 a	0.19
Cx. (*Melanoconion*) spp.	1.5 ± 0.0 a	3.3 ± 1.8 a	2.8 ± 1.1 a	4.3 ± 1.2 a	2.3 ± 1.1 a	3.2 ± 1.3 a	0.65
Cx. quinquifaciatus	0.0 ± 0.0	0.2 ± 0.2	0.3 ± 0.3	0.3 ± 0.3	0.0 ± 0.0	0.5 ± 0.3	—
Psorophora ciliata[1]	1.2 ± 0.7 a	1.7 ± 0.8 a	2.8 ± 1.5 a	1.2 ± 0.7 a	2.7 ± 1.1 a	2.3 ± 1.2 a	0.54
Ps. columbiae	0.7 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	—
Ps. ferox[1,2]	26.0 ± 4.9 a	26.0 ± 5.8 a	18.8 ± 6.5 a	17.3 ± 3.6 a	28.0 ± 12.0 a	27.5 ± 4.9 a	0.47
Ps. howardii	0.3 ± 0.3 a	0.2 ± 0.2 a	0.3 ± 0.2 a	0.2 ± 0.2 a	0.0 ± 0.0 a	0.2 ± 0.2 a	0.88
Coquillettidia perturbans	1.2 ± 1.0 a	1.3 ± 1.1 a	1.5 ± 0.5 a	1.0 ± 0.5 a	4.3 ± 2.8 a	1.2 ± 0.7 a	0.51
Culiseta melanura	9.2 ± 3.8 ab	18.7 ± 5.7 ab	16.7 ± 5.6 ab	24.3 ± 5.2 a	4.7 ± 2.2 b	20.8 ± 6.3 ab	0.03
Uranotaenia sapphirina	1.2 ± 0.6 ab	3.0 ± 2.6 ab	1.0 ± 0.4 b	1.5 ± 0.8 ab	0.0 ± 0.0 b	8.7 ± 3.9 a	0.04
Toxorhynchites rutilus	0.0 ± 0.0	0.5 ± 0.3	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	—
Total no. mosquitoes[1]	940.2 ± 104.0 a	952.0 ± 163.1 a	725.0 ± 113.6 a	793.7 ± 119.1 a	1,157 ± 190.8 a	759.7 ± 122.1 a	0.08

[1] Significant day effect ($P < 0.05$).
[2] Significant position effect ($P < 0.05$).
[3] Adults could not be distinguished from *Ae. tormenter*.

Table 2. Centers for Disease Control (CDC) trap counts using colored light-emitting diodes or incandescent light only (means ± SEM). Means within each row having the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh multiple range test) (n = 6 nights).

Species	Red	Orange	Yellow	Green	No light	Incandescent	P value
Aedes dupreei[1,2]	34.5 ± 10.8 a	33.3 ± 13.7 a	26.5 ± 7.2 a	48.2 ± 24.2 a	33.2 ± 8.6 a	32.7 ± 11.6 a	0.51
Ae. fulvus pallens	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—
Ae. atlanticus[1,2,3]	8.3 ± 1.3 abc	15.3 ± 6.9 ab	7.2 ± 2.2 bc	9.8 ± 3.6 abc	4.8 ± 1.2 c	17.5 ± 5.1 a	0.009
Ae. canadensis	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—
Ae. infirmatus[1]	1.7 ± 0.7 a	4.8 ± 2.9 a	2.7 ± 1.0 a	2.7 ± 0.8 a	0.3 ± 0.2 a	4.3 ± 1.3 a	0.1
Anopheles crucians s.l.[1]	0.8 ± 0.5 b	0.7 ± 0.3 b	0.7 ± 0.4 b	1.3 ± 1.1 b	0.0 ± 0.0 b	4.5 ± 1.4 a	0.004
An. quadrimaculatus s.l.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	—
Culiseta melanura	0.8 ± 0.5 a	2.0 ± 1.3 a	1.3 ± 0.9 a	2.5 ± 1.0 a	0.0 ± 0.0 a	3.5 ± 0.8 a	0.13
Culex nigripalpus[1,2]	0.3 ± 0.2 a	0.7 ± 0.7 a	0.2 ± 0.2 a	0.3 ± 0.2 a	0.2 ± 0.2 a	0.8 ± 0.4 a	0.68
Cx. (*Melanoconion*) spp.	0.2 ± 0.2 a	0.2 ± 0.2 a	0.7 ± 0.3 a	0.2 ± 0.2 a	0.0 ± 0.0 a	0.7 ± 0.3 a	0.25
Psorophora ciliata	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	—
Ps. ferox[2]	0.2 ± 0.2 a	0.2 ± 0.2 a	0.0 ± 0.0 a	0.2 ± 0.2 a	0.2 ± 0.2 a	0.0 ± 0.0 a	0.72
Uranotaenia sapphirina	0.7 ± 0.3 b	0.8 ± 0.3 b	0.7 ± 0.3 b	0.8 ± 0.3 b	0.0 ± 0.0 b	4.5 ± 1.0 a	0.001
Total no. mosquitoes[1,2]	47.8 ± 11.8 a	58.2 ± 23.4 a	39.8 ± 9.2 a	66.2 ± 30.5 a	38.7 ± 9.0 a	68.7 ± 16.1 a	0.24

[1] Significant day effect ($P < 0.05$).
[2] Significant position effect ($P < 0.05$).
[3] Adults could not be distinguished from *Ae. tormenter*.

bles 1 and 2. As noted in the tables, trap-position and day effects were significant for some species.

No significant differences were observed for the total number of mosquitoes captured at different colors in either the CO_2-baited or unbaited trials (P = 0.08, P = 0.24, respectively). However, differences were observed for individual species. In trial 1, *Aedes dupreei* (Coquillett), *Aedes infirmatus* (Dyar and Knab), *An. crucians* s.l., *Culiseta melanura* (Coquillett), and *Uranotaenia sapphirina* (Osten Sacken) showed significant color preferences. In trial 2, only *Ae. atlanticus, An. crucians* s.l., and *Ur. sapphirina* showed significant preferences. *Aedes dupreei* was the predominant species and was the only species preferring the CO_2-baited trap using no light. This species was also abundant in the no light control. Three female *Lutzomyia shannoni* (Dyar) and one *Lutzomyia vexator* (Coquillett) were collected during trial 1. None were collected in trial 2.

Eight colors with CO_2 (trial 3)

During the 8 trap-nights, 4,668 specimens of mosquitoes, 1,189 tabanids (*Diachlorus ferrugatus* Osten Sacken), 3,667 chaoborids (*Corethrella* spp.), and 3 phlebotomine sand fly specimens were collected. Responses of the most numerous mosquito species are shown in Figs. 4a, 4b. A highly significant difference was found in the total numbers of mosquitoes captured for the different colors (P = 0.0001). Means, standard errors, P values, and significant differences for species represented in large enough numbers are shown in Table 3. As seen in trials 1 and 2, trap-position and day effects were significant for some species. Overall capture of mosquitoes was significantly greatest with the standard white broad-spectrum incandescent, followed by blue, green, orange, yellow, red, no light control, and infrared, respectively. When collections were classified by mosquito species, clear preferences were seen between species. *Anopheles crucians* s.l., *Cs. melanura, Culex nigripalpus* Theobald, *Psorophora columbiae* (Dyar and Knab), and *Ur. sapphirina* showed significant color preferences. White light captured the most *An. crucians* s.l.. The greatest numbers of *Cs. melanura* were captured in traps with white, green, and orange. The most *Ps. columbiae* were collected in traps with blue, and significantly more *Ur. sapphirina* were captured in traps with standard white or blue. No colors were found to be repellent to mosquitoes when compared to the no light controls. No significant difference (P = 0.26) for color attraction were obtained for the tabanid *D. ferrugatus*. Conversely, the chaoborids (*Corethrella* spp.), showed significant color attraction (P = 0.002), preferring white and blue over the other colors.

DISCUSSION

Many common Florida woodland mosquitoes are medically important. Although one of the primary

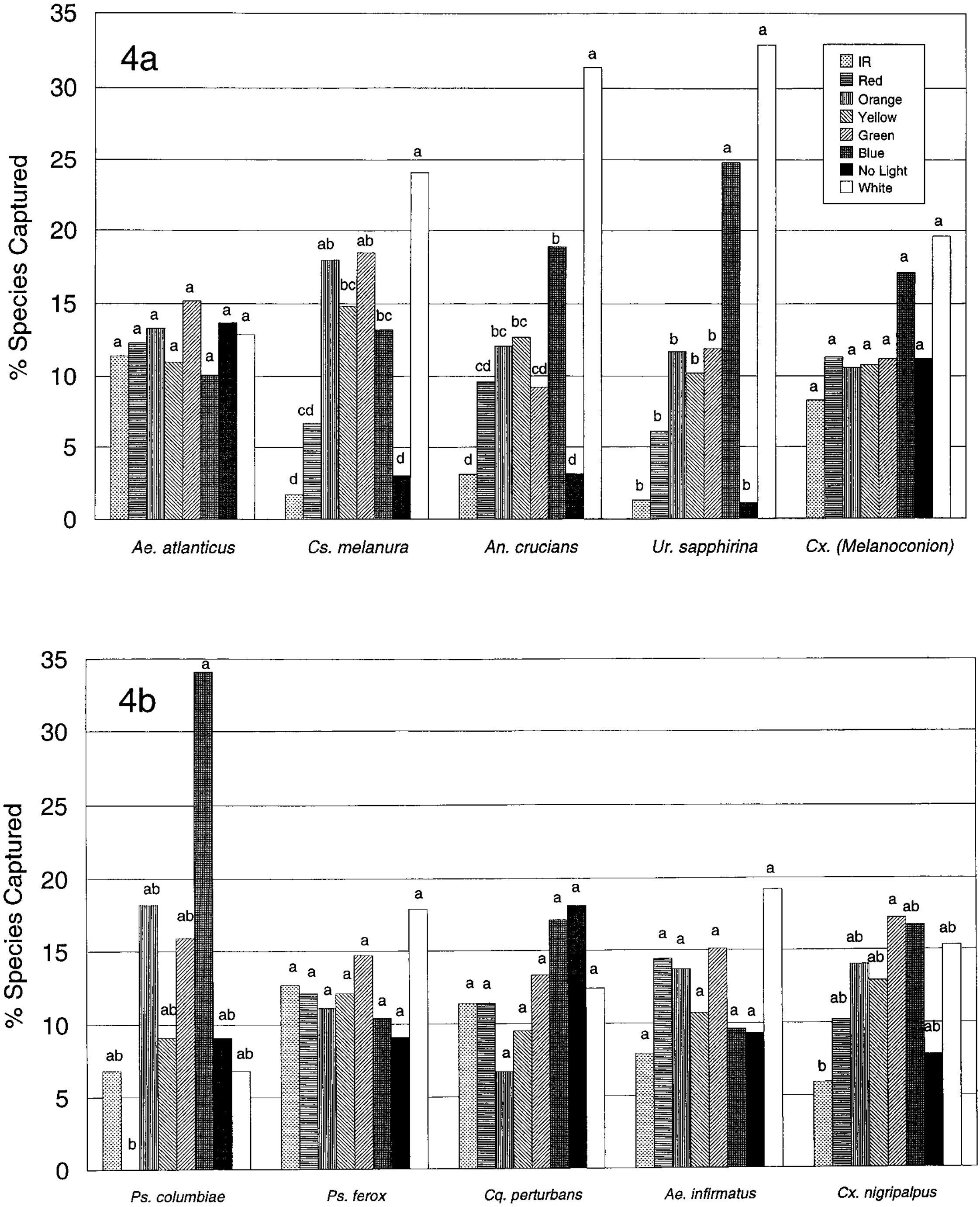

Fig. 4. Relative percent composition of mosquitoes captured in CO_2-baited Centers for Disease Control (CDC)-type traps using colored light-emitting diodes or incandescent light only. Means within each species group having the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh multiple range test). $\alpha = 0.05$, $n = 8$ nights.

means of evaluating the presence or absence and relative abundance of certain mosquitoes is through the use of light traps, few studies have evaluated mosquito response to different wavelengths of transmitted monochromatic light. Even fewer studies have detailed the response of individual species. Browne and Bennett (1981) tested filtered light of known wavelengths to equate host preference with landing rates for *Coquillettidia perturbans* (Walker). They found shorter wavelengths (400–600 nm

Table 3. Centers for Disease Control (CDC) trap counts using colored light-emitting diodes or incandescent light with 200 ml/min CO_2 (means ± SEM). Means within each row having the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh multiple range test) (n = 8 nights).

Species	Infrared	Red	Orange	Yellow	Green	Blue	No light	Incandescent	P value
Diachlorus ferrugatus[1,2]	19.6 ± 4.5 a	16.9 ± 3.2 a	18.1 ± 4.1 a	15.5 ± 2.7 a	21.5 ± 5.0 a	25.8 ± 4.4 a	20.9 ± 5.3 a	15.5 ± 5.2 a	0.26
Corethrella spp.[2]	2.6 ± 0.8 c	21.1 ± 4.2 c	45.0 ± 9.9 c	43.5 ± 7.3 c	54.1 ± 12.3 c	119.3 ± 28.9 b	6.9 ± 2.0 c	211.9 ± 30.1 a	0.002
Aedes dupreei[1,2]	1.0 ± 0.4 a	0.6 ± 0.3 a	0.6 ± 0.5 a	0.6 ± 0.5 a	0.6 ± 0.3 a	0.3 ± 0.2 a	0.3 ± 0.2 a	0.4 ± 0.2 a	0.52
Ae. fulvus pallens	0.4 ± 0.2 a	0.4 ± 0.2 a	0.6 ± 0.3 a	0.3 ± 0.2 a	0.3 ± 0.2 a	0.5 ± 0.4 a	0.6 ± 0.3 a	0.4 ± 0.2	0.89
Ae. atlanticus[1,2,3]	13.1 ± 3.1 a	14.1 ± 3.4 a	15.3 ± 3.9 a	12.6 ± 4.1 a	17.5 ± 5.5 a	11.6 ± 3.4 a	15.8 ± 5.7 a	14.9 ± 5.0 a	0.43
Ae. canadensis	1.1 ± 0.4 a	0.8 ± 0.3 a	0.8 ± 0.4 a	0.0 ± 0.0 a	0.4 ± 0.2 a	0.4 ± 0.4 a	0.6 ± 0.4 a	1.0 ± 0.4 a	0.38
Ae. infirmatus[1]	2.9 ± 0.4 a	5.3 ± 0.7 a	5.0 ± 1.8 a	3.9 ± 1.1 a	5.5 ± 1.7 a	3.5 ± 0.7 a	3.4 ± 1.1 a	7.0 ± 3.5 a	0.42
Anopheles crucians s.l.[1,2]	2.0 ± 0.4 d	6.1 ± 1.7 cd	7.8 ± 1.9 bc	8.1 ± 1.7 bc	5.9 ± 0.9 cd	12.1 ± 3.3 b	2.0 ± 0.5 d	20.1 ± 2.9 a	0.0001
An. quadrimaculatus s.l.	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	—
Coquillettidia perturbans	1.5 ± 0.6 a	1.5 ± 0.4 a	0.9 ± 0.3 a	1.3 ± 0.3 a	1.8 ± 0.5 a	2.3 ± 0.8 a	2.4 ± 0.7 a	1.6 ± 0.7 a	0.58
Culiseta melanura	2.4 ± 0.8 d	9.4 ± 2.3 cd	25.1 ± 4.2 ab	20.6 ± 2.7 cb	25.9 ± 2.7 ab	18.5 ± 2.9 bc	4.3 ± 1.4 d	33.6 ± 4.7 a	0.0001
Culex nigripalpus[1,2]	2.8 ± 0.25 b	4.8 ± 1.1 ab	6.5 ± 1.1 ab	6.0 ± 1.1 ab	8.0 ± 1.2 a	7.8 ± 1.7 ab	3.6 ± 0.7 ab	7.1 ± 1.6 ab	0.02
Cx. (*Melanoconion*) spp.[1]	8.5 ± 1.3 a	11.5 ± 2.0 a	10.8 ± 3.0 a	11.0 ± 2.8 a	11.4 ± 2.6 a	17.4 ± 2.9 a	11.4 ± 4.0 a	20.0 ± 7.6 a	0.07
Cx. salinarius	0.3 ± 0.2	0.3 ± 0.2	0.4 ± 0.3	0.4 ± 0.2	0.5 ± 0.3	0.5 ± 0.3	0.1 ± 0.1	0.5 ± 0.2	—
Mansonia dyari	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—
Psorophora ciliata	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	—
Ps. columbiae[1]	0.4 ± 0.3 ab	0.0 ± 0.0 b	1.0 ± 0.8 ab	0.5 ± 0.4 ab	0.9 ± 0.5 ab	1.9 ± 1.1 a	0.5 ± 0.4 ab	0.4 ± 0.4 ab	0.08
Ps. ferox[1]	4.9 ± 1.3 a	4.6 ± 1.3 a	4.3 ± 1.6 a	4.6 ± 1.8 a	5.6 ± 2.1 a	4.0 ± 0.8 a	3.5 ± 1.4 a	6.9 ± 3.1 a	0.47
Uranotaenia sapphirina[1,2]	2.8 ± 1.3 b	13.4 ± 3.3 b	25.5 ± 6.1 b	22.3 ± 4.1 b	25.9 ± 6.2 b	53.9 ± 13.4 a	2.4 ± 1.1 b	71.5 ± 16.7 a	0.0001
Total no. mosquitoes[1,2]	44.0 ± 5.1 e	72.6 ± 9.5 cde	104.8 ± 11.7 bc	92.3 ± 11.4 bcd	110.1 ± 10.9 bc	134.6 ± 20.3 b	50.8 ± 10.4 ed	185.6 ± 26.8 a	0.001

[1] Significant day effect ($P < 0.05$).
[2] Significant position effect ($P < 0.05$).
[3] Adults could not be distinguished from *Ae. tormenter*.

or blue-green) attracted significantly more mosquitoes than did longer wavelengths. Their results correspond well to ours in trial 3. In Georgia, Bargren and Nibley (1956) found *Aedes vexans* (Meigen), *Culex salinarius* (Coquillett), and *Culex quinquefasciatus* (Say) to have varying levels of attraction to New Jersey traps using different colored bulbs of similar intensities. Other species, such as *Cx. nigripalpus,* showed no preference for any of the 4 color bandwidths (447, 570, 659, 670 nm) tested. This finding agrees with ours in trials 1 and 2, but differs from those of trial 3, which found significant color preferences (blue, green, white) for *Cx. nigripalpus.* Vavra et al. (1974) tested several types and colors of light and found no significant differences in the total numbers of mosquitoes attracted to each of the colors. Attraction of individual species of mosquitoes was not examined. In a laboratory test using *Culex tarsalis* (Coquillett), *Cx. quinquefasciatus* (Say), and *Anopheles sierrenis* (Ludlow), Gjullin et al. (1973) tested New Jersey light traps equipped with either ultraviolet light, or ceramic-dipped bulbs colored red, green, blue, orange, and white. They found no significant differences in attraction between any of the colors tested. Wilton and Fay (1972) tested *Anopheles stephensi* (Liston) against a clear incandescent bulb and monochromatic light of various wavelengths. They found this mosquito highly attracted to bandwidths of 290 and 365 nm in the ultraviolet region and 690 nm, but blues, greens, and yellows (bandwidths of 490, 540, and 590 nm, respectively) were not as attractive as the clear bulb.

Allan et al. (1987) stated that crepuscular and nocturnal biting flies are unlikely to have well-developed color vision, but their abilities to detect differences in intensity contrast are likely to be well developed. Spectral sensitivity (i.e., relative sensitivity of the retina to light of different wavelengths) studies consistently showed that most flies possess a bimodal spectral response with peaks around 340 and 525 nm (White 1985). Considering the variation in mosquito species' attraction to light traps (Huffaker and Back 1943, Bidlingmayer 1967), it is not unreasonable to expect differences in color preference based on variations in their spectral sensitivities.

Alternatively, attractiveness may not be due to color per se. Different wavelengths may be physiologically perceived as more intense and subsequently more attractive. Barr et al. (1963) concluded that more intense light (up to a point) is more attractive than less intense light. Electroretinographs (ERGs) conducted by Muir et al. (1992) showed *Aedes aegypti* (L.) to have spectral sensitivities ranging from ultraviolet (323 nm) to orange-red (621 nm) with sensitivity peaks in both the ultraviolet (345 nm) and green (523 nm) wavelengths. By studying the relationship between illumination and suitability of an oviposition site for *Ae. aegypti,* Snow (1971) found a similar bimodal response. Unfortunately, all mosquito spectral sensitivity studies have focused on *Ae. aegypti*; none have been conducted on nocturnal or other species commonly attracted to artificial light.

Unlike standard bulbs that radiate light in a 360° pattern, the diodes emit a narrow beam (8 or 22°), which in these tests was oriented upwards and reflected off the shiny surface of the aluminum pan covering the CDC trap. If the mosquitoes are responding to differences in perceived intensity, an assortment of several of the most promising LED colors (e.g., blues and greens) could be arranged to produce a 360° pattern and perhaps greatly increase the efficiency of the trap. Several LEDs in series would be many times brighter and still use significantly less battery power than a single incandescent bulb. Several of the ERG studies previously mentioned have shown peak dipteran spectral activity from bandwidths ranging from 450 to 550 nm. Based on the numbers of certain mosquito species that were attracted to the blue and green wavelengths, LED wavelengths between 450 and 550 nm may produce excellent results. Currently, technology limits production of LEDs producing these wavelengths. Super-bright blues (450 nm) have only recently become available, and perhaps future technology will produce a blue-green diode peaking at about 500 nm.

Light-emitting diodes run on significantly lower amounts of energy (ca. 1 ma/8 h) than incandescent bulbs, resulting in substantial savings in battery life and expense. Hours of use (means ± SEM) with the no light control (69 ± 7.5), blue (63 ± 9), and green (63 ± 5.7) were found to last significantly more hours (n = 4, P = 0.02) than the standard white bulb (36 ± 0). For convenient use, LEDs can be soldered in series directly into the existing trap circuitry. Best results for all colored LEDs except blue (100 Ω) were obtained using 200-Ω resistors connected to the light motor assembly. Future studies should focus on combinations of colors oriented in different directions. The use of super-bright LEDs warrants serious consideration as a replacement for standard incandescent bulbs used in light traps. These results have potential for use in population dynamics studies or for enhancing the attractivity for certain species.

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