FACTORS AFFECTING LABORATORY PROCEDURES for EVALUATING EFFICACY of INSECT LIGHT TRAPS for HOUSE FLIES

Eric Snell
B&G Equipment Company, Plumsteadville PA 18949

Abstract Insect light traps are an important aspect of modern fly control in commercial food handling establishments. Many design factors of light traps are evaluated in a paired laboratory testing method. The influence variables have on the results of paired laboratory testing methods is evaluated to illustrate the need for industry-wide standards for testing. The negative effects of black background colors and grill on light traps are presented to show that there are design features that influence effectiveness. Design features are tested with different amounts of bulb wattage in two paired traps to demonstrate that total wattage in a room can influence the results of laboratory tests. It is also shown that age of the flies and number of flies in a room can affects on the results of rotated tests. Perhaps the largest factor that should be considered in the future is the balance of two paired locations in a laboratory test arena.

Key Words Light traps Ultra violet light UV light *Musca domestica* fly traps

INTRODUCTION

Insect light traps have been one of the most commonly used tools by professional pest control companies for nearly 50 years. During that time light traps and research-based information about them has changed little, and basic trap designs have changed little. Three distinct modifications in light traps can be recognized: glueboards have become design options for electrocution traps, traps have become small, and there are decorative models for use in public areas. But the literature in this field shows that these changes were made with little use of published research. For example, there is limited research data that show the difference in efficiencies of glueboard-based light traps compared to electrocution traps, and professional pest control companies are often unaware that electrocution traps are generally more effective than small glueboard traps. No research into the design elements of decorative traps for public areas has been published.

Only limited information has been published on the procedures for laboratory testing of the efficacy of light traps for house fly control. The influence of fly age has been measured by Pickens et al. (1969) and Bucher et al. (1948). The feeding history of flies has been documented as a test variable by Pickens et al. (1969), Keiding (1965), and Hecht (1963). Different degrees of attraction to UV light that are linked to the sex of the adult fly were reported by Pickens et al. (1969) and Morgan and Pickens (1968). Air temperature has been reported to influence the attraction of house flies to light traps (Pickens et al.,1969; Morgan and Pickens,1968; Dakshinamurty, 1948).

Laboratory methods and procedures for evaluating lights need improvement if the research data are to lead to improvements in light trap efficacy. Procedures that evaluate small and large design modifications can provide guidelines for overall improvement of light traps. Tests on the efficacy of light traps reported here were designed to measure the influence of variables such as trap position on a wall, total wattage of the trap, and the number of flies and age of flies used in tests. The variables that may affect paired testing methods include trap positions, age of flies, number of flies per square foot of laboratory space, length of time of test, time of day of test, and

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total amount of wattage per square meter of laboratory space. This research analysis evaluates each of these variables and reviews some of the design elements of light traps that make a difference in trap efficiency.

MATERIALS and METHODS

House Flies

A laboratory, normal strain of *Musca domestica* L. was used in all evaluations. Flies were obtained as pupae (Carolina Biological Supply Co., Burlington, N.C.), and adult flies emerged at the test site, Plumsteadville, Pa., and were maintained with adequate humidity and water until used. Adults were transferred to the evaluation room in a mesh container and released about 10 minutes before the start of the test and the light traps turned on. Flies unable to fly from the container at the start of each test were removed and are not considered in the evaluation.

Evaluation Laboratory

The evaluation laboratory was divided into two rooms: Room A, 2 meters wide and 5.3 meters long, with a total of 26.5 cubic meters; Room B, 1.5 meters wide and 2 meters long, with a total of 7.5 cubic meters. The walls and ceiling were plasterboard and painted white; the floor was concrete painted gray. Room A and B are separated by a door (Figure 1). Conditions in the evaluation laboratory were maintained at approximately 26°C and 75% RH during all tests. Four ceiling mounted fluorescent lights remained on during testing; no other light was in the rooms during evaluations.

Light Traps

The UV-light trap used in all evaluations was Model FM-4 Matrix (B&G Equipment Company, Plumsteadville, Pa.). The black, metal, rectangular trap is 53.3 cm long, 35.5 cm high, and 12.7 cm wide. The FM-4 model is designed to operate four 25 watt bulbs (F25T8) positioned horizontally; the bulbs are visible only from the front and top when mounted to the walls. Bulbs were either Sylvania F25T8/350BL or Sylvania F15T8/350BL (Osram Sylvania, Danvers, Mass.)

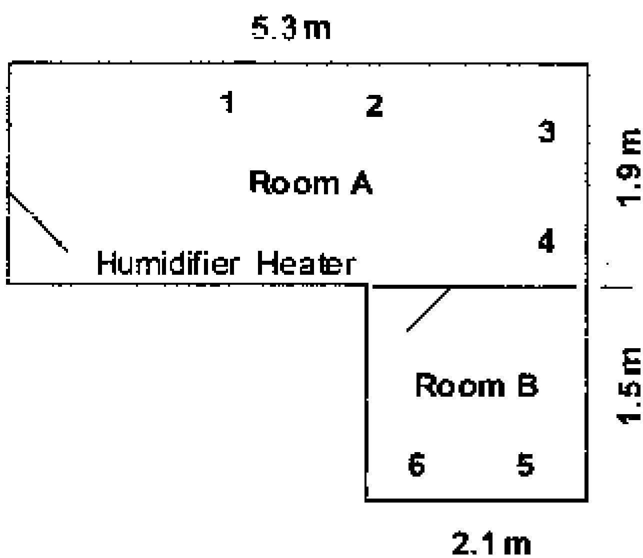

Figure 1. Diagram of evaluation laboratory for UV light traps; 1-6 indicate the positions of light traps in Rooms A and B.

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The trap holds up to two identical glueboards (43 cm x 20 cm), one along the back, and one that fits into a three-sided tray at the bottom of the trap. At the conclusion of all evaluations the glueboards were removed, the flies counted and recorded, and the glueboard discarded.

Trap Position on Wall, Glueboard or Background Color, and Amount of Grill

Position on wall. To evaluate the influence of right or left trap position on a wall, traps were hung in pairs and rotated to different locations at least four times. In all cases, the trap locations were considered to be identical with regard to the distance from room corners and floor. This test design considered two identical trap locations on the wall, and the rotation of two traps at those locations. Each trap had one new 25-watt bulb and one white glueboard directly behind the bulb. Traps were placed 1.5 meters from the floor and rotated between each test. Each of the four tests lasted 1 hour during the daytime. All tests were conducted during a continuous 4 hours and with house flies that emerged as adults at the same time.

Glueboard or background color. The influence of the glueboard colors white and black at the back of the trap was tested. The black and white background colors of the FM-4 Matrix traps were the glueboards inserted at the back of the trap, both the black and the white glueboards were identical except for color. For this test procedure, traps had one or two 15-watts bulbs, for a total bulb wattage of 15 or 30 watts. When light traps have bulbs fully exposed from the front, and a glueboard is placed at the back of the trap behind the bulbs, the color of the glueboard is considered the background color. The color behind the bulbs affects the reflection of light from the front of the trap.

Grill amount. The effects of the grill on the front of the light trap were also evaluated. Two different types of metal grill were placed on the front of traps and trap catch measured. The small grill had a total of 129 linear centimeters of metal bars over the open front, and the large grill had a total of 922 linear centimeters of metal work.

Trap Height

To evaluate the influence of trap height from the floor on trapping efficacy, traps were placed in Room A at 0.6, 0.9, and 1.5 meters from the floor to the top of the traps. When the traps where placed at 0.6 meters, the bottom of the traps were 1-2 centimeters off the floor, above the baseboard. Each of the traps had bulbs providing a total of 100 watts of UV light.

Total Wattage Per Square Meter, Bulb Age

To evaluate the influence of the total wattage on trap efficacy, the background color and grill amounts were tested. In both evaluations four tests were conducted of each variable with 30 watts in both traps (60 watts total), and with 15 watts in both traps (30 watts total). This can be summarized as 1.13 watts per cubic meter, with 15 watts per trap and 2.26 watts per cubic meter, with 30 watts in each trap. Tests were also conducted with traps using new bulbs, and bulbs with 96 hours of use.

Fly Age, Total Number of Flies in Test

The background color was used as the standard to evaluate the effects of fly age and the total number of flies released on trap efficacy. Each evaluation consisted of four rotated tests in succession during the same day. The combination of features tested were: more than 200 flies with 2-3 day-old flies, more than 200 flies with 4-7 day-old flies, less than 100 flies with 2-3 day-old flies, and less than 100 flies with 4-7 day-old flies. This procedure provided data to compare both variables separately as well as combinations of variables.

Overnight Trapping

Light traps were evaluated at night, during the natural resting cycle of *M. domestica*. The standard white background color was used in four tests, which started at 6:00 p.m. and ended at 8:00 a.m. the following morning. These tests were compared to the tests of background color with different age flies and different numbers of flies; all were done with 1-hour test periods during daytime. Two tests were conducted with flies that were 2-3 days old, and two tests with flies 4-7 days old.

Statistical Analysis

A 't' statistic is used to test for a significant difference between two groups of data (Hays, 1981). For instance the percentage of flies captured across repeated trials for one condition compares to a percentage of flies captured across trials for another condition. The t value therefore reflects a standardized mean difference between the two conditions. Larger t values reflect a difference between conditions that are unlikely to occur purely by chance. Thus any t value that generates a probability (p) value of 0.05 or less is considered to be a statistically significant difference between conditions. Larger t values, and/or smaller p values, indicates a larger difference between the two conditions.

RESULTS

The testing methods presented here were designed to evaluate the role of trap design on trap efficacy. The primary goal was to determine the causes of fluctuations between tests in order to improve the sensitivity of the testing methods and shorten the number of repetitions required to have confidence in the data.

Trap Position on Wall

Table 1 presents data for tests evaluating the position of the trap on the wall, from four tests with two traps at positions 5 (left), and 6 (right) in Room A. The results indicate that significantly ($t = 7.474$, $p < 0.001$) more flies were caught by traps at the right side (position 6); on the right side, the percentage of flies trapped ranged from 53% to 58%. The percentage trapped is calculated as the percentage of the total flies caught, and does not account for the number of flies remaining after the test. Table 2 shows data from two traps placed at positions 3 (left) and 4 (right) in Room A. There is a statistical difference ($t = 9.839$, $p < 0.001$) in these positions, although the two locations are only about 0.5 meters apart. The percentage of flies trapped in the right position ranged from 58% to 65%. Table 3 shows the data from tests placed at positions 1

Table 1. Different UV light trap locations: small laboratory, long wall. Matrix with one 25-watt bulb. $t = 7.473$, $p < 0.001$

Position	Test 1	Test 2	Test 3	Test 4	Average
Rt Side - 6	55%	56%	58%	53%	55.5%
Lf Side - 5	45%	44%	42%	47%	44.5%

Table 2. Different UV light trap locations: large laboratory, short wall. Matrix with one 25-watt bulb. $t = 9.839$, $p < 0.001$

Position	Test 1	Test 2	Test 3	Test 4	Average
Rt Side - 4	65%	58%	62%	59%	61%
Lf Side - 3	35%	42%	38%	41%	39%

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Table 3. Different UV light trap locations: large laboratory, long wall. Matrix with one 25-watt bulb. t = 0.378, p< 0.712

Position	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Average
Rt Side - 2	52%	42%	49%	48%	50%	56%	50%	50%
Lf Side - 1	48%	58%	51%	52%	50%	44%	50%	50%

and 2 in Room A. The percentage of flies trapped ranged from 44% up to 58% on the left side, with an average of 50% at each position. There is no significant difference (t = 0.378, p <0.712) between these two locations.

For the five tests summarized in Table 4, the door between Room A and B was open and flies could move between the two rooms. Both traps were placed in Room A, at positions 1 (left), and 2 (right). The results are that there were significantly (t = 8.159, p < 0.001) more flies trapped at position 1 (left) than at position 2 (right).

Trap Height

Table 5 shows that there is no significant difference (t = -1.739, p < 0.133) in the number of flies trapped when traps are placed 0.9 meters from the floor, and placed at right and left positions on the wall. The data in Table 6 show that traps with their tops 0.9 meters from the floor were significantly (t = 13.013, p <0.001) more effective in trapping flies than traps with their tops at 1.5 meters from the floor. Table 7 shows that there is a statistical difference when trap locations are evaluated (r = right, t = 4.317, p < 0.001). The traps placed on the right side position consistently

Table 4. Different UV light trap locations: large and small laboratory. Matrix with one 25-watt bulb. t = 8.159, p< 0.001

Position	Test 1	Test 2	Test 3	Test 4	Test 5	Average
Rt Side - 2	39%	44%	42%	42%	42%	43.5%
Lf Side -1	61%	56%	51%	58%	58%	56.5%

Table 5. UV light trap located 0.9 meters above ground; large laboratory, long wall. Matrix with one 25-watt bulb. t = 1.739, p< 0.133

Position	Test 1	Test 2	Test 3	Test 4	Average
Rt Side	50%	52%	44%	33%	47%
Lf Side	50%	48%	56%	67%	53%

Table 6. Different UV light trap height: large laboratory, long wall. Matrix with four 25-watt bulbs. t = 13.013, p< 0.001, r = right

Position	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average
0.9 m	69%	68% r	66%	76% r	79%	66%	71%
1.5 m	31% r	32%	34% r	24%	21% r	34% r	29%

Table 7. Different UV light trap heights: large laboratory, long wall. Tests 1-3, Matrix with four 25-watt bulbs; tests 4-7, Matrix with two 15-watt bulbs. Height: t = 1.33, p< 0.208. Position: t = 4.317, p< 0.001

Position	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Average
0.9 meters	56%	68% r	46%	38%	65% r	40%	71% r	55%
0.6 meters	44% r	32%	54% r	62% r	35%	60% r	29%	45%

caught the largest percentage of flies, regardless of the trap height (Height: $t = 1.33$, $p < 0.208$); the right side traps average 61% of the flies caught in the tests.

Trap Wattage, Background Color, and Amount of Grill

Wattage. The data in Table 8 show that increasing the bulb wattage in a trap from 25 to 50 watts in a laboratory test significantly ($t = 7.006$, $p < 0.001$) increases the number of flies trapped. Table 9 shows that increasing the wattage from 15 watts to 30 watts significantly ($t = 14.311$, $p< 0.001$) increased the number of flies trapped. The total bulb wattage was reduced from 75 watts (tests reported in Table 8), to only 45 watts (tests reported in Table 9), and there was less overall attraction to the flies in the tests with the lowest bulb wattage. The improved t value relates to the reduced fluctuations between tests. The traps reported in Table 10 have the same 15-watt difference as previous tests, and the total wattage (75 watts) in the room. The data reported in Table 10 show there is a significant difference ($t = 3.14$, $p < 0.01$) in the flies trapped at the traps with a total of 45 watts than at the traps with a total of 30 watts.

Background Color. The data presented in Table 11 show that the reflection of the one 15-watt bulb off the background of the traps can influence the total overall attractiveness of a trap ($t = 5.937$, $p <0.001$). Table 12 presents data for black and white backgrounds, but each trap had 30 watts, for a total of 60 watts in the room. An average of 58% of the flies were attracted to these traps, compared to the average of 69% attracted to the traps with lower wattage.

Table 8. UV light trap wattage affects: 25 watt versus 50 watts. Matrix with one or two 25-watt bulbs; r = right. $t = 7.066$, $p< 0.001$

Wattage	Test 1	Test 2	Test 3	Test 4	Average
25 watts	20%	38% r	24%	34% r	29%
50 watts	80% r	62%	76% r	66%	71%

Table 9. UV light trap wattage affects: 15 watt versus 30 watts. Matrix with one or two15-watt bulbs; r = right. $t = 14.311$, $p< 0.001$

Wattage	Test 1	Test 2	Test 3	Test 4	Average
15 watts	19%	26% r	20%	30% r	24%
30 watts	81% r	74%	80% r	70%	76%

Table 10. UV light trap wattage affects: 35 watt versus 45 watts. Matrix with two or three 15-watt bulbs; r = right. $t = 3.14$, $p< 0.01$

Wattage	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average
30 watts	69%	68% r	66%	76% r	79%	66%	71%
45 watts	31% r	32%	34% r	24%	21% r	34% r	29%

Table 11. UV light trap background color affects: black versus white glueboard. Matrix with one 15-watt bulb; r = right. $t = 5.937$, $p< 0.001$

Background	Test 1	Test 2	Test 3	Test 4	Average
Black	34%	29% r	42%	21% r	32%
White	66% r	71%	58% r	79%	69%

Grill Amount. The data presented in Table 13 show that there is a significant difference (t = 16.809, p <0.001) in the number of flies caught in traps with the large and small grills. The traps with the least amount of grill (129 linear centimeters) trapped significantly more flies than traps with a large amount (922 linear centimeters) of grill. Table 14 also reports the effects of the two grill sizes, but with 30 watts per trap, and the results are similar, but less significant (t = 12.05, p < 0.001), with the small grill trapping more flies than the traps with the large grill.

Total Wattage per Cubic Meter, and Bulb Age

Wattage per cubic meter. The data reported in Table 8 and Table 10 are for test conditions of 2.83 watts per cubic meter; the data reported in Table 9 are for test conditions of 1.70 watts per cubic meter. For the 25-watts and 50-watts comparison, the traps with 50 watts trapped significantly (t = 7.066, p< 0.001) more flies than did the traps with 25 watts total (Table 8). For the 15-watts and 30-watts comparison, the traps with 30 watts total trapped significantly (t = 14.311, p< 0.001) more flies than did the traps with 15 watts total (Table 9). For the 30-watts and 45-watts comparison, the traps with 30 watts total trapped significantly (t = 3.14, p< 0.01) more flies than did the traps with 45 watts total (Table 9).

Age of UV Bulb. Table 15 presents data that show there were significantly (t = 2.504, p < 0.046) fewer flies trapped with the bulbs that had 96 hours of bulb life than with new bulbs.

Table 12. UV light trap background color affects: black versus white glueboard. Matrix with two15-watt bulbs; r = right. t = 3.639, p< 0.011

Background	Test 1	Test 2	Test 3	Test 4	Average
Black	43%	45% r	33%	47% r	42%
White	57% r	55%	67% r	53%	58%

Table 13. UV light trap grill affects: 129 versus 922 linear cm. Matrix with one 15-watt bulb; r = right. t = 16.809, p< 0.001

Grill Size	Test 1	Test 2	Test 3	Test 4	Average
51 linear in.	64% r	60%	60% r	61%	61%
363 linear in.	36%	40% r	40%	39% r	39%

Table 14. UV light trap grill affects: 51 versus 363 linear inches. Matrix with two15-watt bulbs; r = right. t = 12.05, p< 0.001

Grill Size	Test 1	Test 2	Test 3	Test 4	Average
51 linear in.	62% r	71%	68% r	65%	67%
363 linear in.	38%	29% r	32%	35% r	39%

Table 15. UV light trap bulb age affects: new bulb versus bulb with 96 hours use; large laboratory, long wall. Matrix with two 15-watt bulbs; r = right. t = 2.504, p< 0.046; right/left: t = 0.83, p < 0.936

UV Bulb	Test 1	Test 2	Test 3	Test 4	Average
96 hr old	44% r	47%	51% r	46%	47%
New bulb	56%	53% r	49%	54% r	53%

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Fly Age and Total Number of Flies

Tables 16 through 19 present data that compare two age groups of flies as well as two different numbers of flies per test. To review the effect of the fly age groups, the results of Tables 16 and 17 can be compared, and Tables 18 and 19 can be compared. To review the effects of the total number of flies in each test, the data in Tables 16 and 19 can be compared, and Tables 17 and 18 can be compared. The effects of fly age show that the statistical significance is reduced with flies that are 4-7 days old compared to flies that are 2-3 days old. For example, when there are more than 200 flies used in each test, the significance ($t = 3.586$, $p < 0.012$) is higher for 2-3 day-old flies, shown in Table 16, than the significance ($t = 1.082$, $p < 0.012$) of older 4-7 day-old flies, shown in Table 17. A similar difference occurs in data reported in Table 19 with 2-3 day-old flies ($t = 5.916$, $p < 0.001$) compared to 4-7 day old flies in Table 18 ($t = 3.602$, $p < 0.011$).

The total number of flies in a test also influences the statistical significance of the results. The significance of results is decreased when there are more than 200 flies compared to tests with fewer than 100 flies. For example, the significance ($t = 5.916$, $p < 0.001$) of the results in Table 19 with fewer than 100 flies is more relevant than tests in Table 16 with more than 200 flies ($t = 3.586$, $p < 0.012$) when the flies are 2-3 days old. When the flies are 4-7 days old, the significance ($t = 3.602$, $p < 0.011$) in Table 18 is again higher when there are fewer than 100 flies compared to tests with more than 200 flies and 4-7 day-old flies ($t = 1.082$, $p < 0.012$) in Table 17. The results of combining 4-7 day-old flies with more than 200 flies in each tests provides the least significant data ($t = 1.082$, $p < 0.012$) in the entire analysis.

Overnight Test Periods

The data in Table 20 shows that for testing procedures that extend overnight, which for these tests is approximately 14 hours, there is a high significant ($t = 14.032$, $p < 0.000$) difference in measured effectiveness of the traps when compared to tests with similar parameters, but evaluated for 1-2 hours (Tables 16-19, each with t values of less than 6.00).

Table 16. UV light trap background affects and age of flies: black background versus white background; 2-3 day-old flies, more than 200 flies, 1 hour test. Matrix with one 15-watt bulb. $t = 3.586$, $p < 0.012$; right/left: $t = -1.202$, $p < 0.275$

Background Color	Test 1	Test 2	Test 3	Test 4	Average
White	58% r	62%	49% r	61%	58%
Black	42%	38% r	51%	39% r	43%

Table 17. UV light trap background affects and age of flies: black background versus white background; 4-7 day-old flies, more than 200 flies, 1 hour test. Matrix with one 15-watt bulb. $t = 1.082$, $p < 0.012$;right/left: $t = -4.243$, $p < 0.005$

Background Color	Test 1	Test 2	Test 3	Test 4	Average
White	47% r	54%	49% r	57%	52%
Black	53%	46% r	51%	43% r	48%

Table 18. UV light trap background affects and age of flies: black background versus white background; 4-7 day-old flies; less than 100 flies,1 hour test. Matrix with one 15-watt bulb. $t = 3.586$, $p < 0.012$; right/left: $t = 0$

Background Color	Test 1	Test 2	Test 3	Test 4	Average
White	74%	66% r	59% r	51%	62.5%
Black	26% r	34%	41%	49% r	37.5%

Table 19. UV light trap evaluating number and age of flies: black background versus white background; 2-3 day-old flies; fewer than 100 flies, 1 hour test. Matrix with one 15-watt bulb. t = 5.916, p < 0.001; right/left: t = 0.675, p < 0 .519

Background Color	Test 1	Test 2	Test 3	Test 4	Test 5	Average
White	61%	61%	53% r	55% r	55% r	57%
Black	39% r	39% r	47%	45%	45%	43%

Table 20. UV light trap evaluation of length of test: overnight (8 hours), more than 200 flies of various ages; black background versus white background. Matrix with one 15-watt bulb. t =14.032, p < 0.000; right/left: t = 0.127, p < 0.903

Background Color	Test 1	Test 2	Test 3	Test 4	Average
White	56% r	54%	55%	54% r	55%
Black	44%	46% r	45% r	46%	45%

DISCUSSION

Trap Position on Wall

If research is to be presented regarding different traps or trap features, two factors should be proven: 1) that two identical traps will provide less than 10% differences when evaluated in tandem, and 2) that similar data are achieved when the trap positions are rotated. Even though two trap positions may appear identical to us, the flies may see a completely different realm. It is not as simple as looking at a floor plan to decide where two matched locations exist in any lab. Such assumptions will create unreliable data and should not be trusted without supporting data of identical trap positions and data that are presented with the rotation of trap positions.

Trap Wattage, Background Color, and Amount of Grill

Numerous factors influence the capture rate of fly light traps. These factors can be divided between attraction and distraction features. The function of bringing flies to a trap is a result of various attraction factors. However, once a fly has arrived at a trap, there are numerous other design elements that result in distracting a fly before it is caught and in reducing capture rates. Attraction factors can be divided between light intensity (or other trap design factors) and position elements. Attractive features of a fly light trap are typically related to the use of light. Bulb wattage is one of the most important factors, but this is enhanced by the bulb size, reflections, angle of the light output, background color, and other elements. Position can also be a true trap enhancement, such as placing the trap in an area with little air movement, the proper height, using the proper amount of light for the size of the room, and mounting the trap on the wall instead of hanging it from the ceiling.

Wattage. The most significant, and often overlooked, feature of a fly light trap is the intensity and degree of light output. Some research papers have previously stated that wattage does not matter with regard to fly light traps. The conclusion can be made that laboratory tests of different bulb wattage in a trap are not measuring incremental changes, but the percentage difference between two traps. In the data reported in Tables 8 and 9, the difference was 100% more wattage between the two traps. In the data reported in Table 10, the traps were only 67% different from one another. Clearly, a high number of flies were able to distinguish between higher wattage over lower wattage, even though there was only 67% difference between the two. This points to a possible conclusion that flies will distinguish even minor changes in a trap's light intensity and therefore make it more competitive in the real world.

In a laboratory of 26.5 cubic meters, doubling the wattage from 25 watts to 50 watts will increase the likelihood of catching flies by as much as 3 times. This is critical since the 'real world' has far more distractions, such as people moving, changing air currents, competitive odors, and visual obstructions. Most glueboard-based fly light traps on the market today use only 30-watt bulbs and are marketed to cover much larger areas than 26.5 cubic meters. Wattage does make a strong difference in attracting flies to an indoor fly light trap. The more bulb wattage, the better the attraction. With the lack of data regarding house fly attraction to different wattages and the lack of data on the amount of wattage needed per square foot, it does not make sense for manufacturers to state that each trap covers a known amount of square feet. Based on the data presented in this paper, it appears that we are currently a long way away from having accounts with adequate wattage to attract a high percentage of the flies in a given room.

Background color. The background color tests reported in Tables 11 and 12 are an illustration of the fact that the total wattage per trap, and possibly the combined wattage in a test, can dictate the success of a paired laboratory test. In Table 11, the white glueboard trap averages 69% of the total flies caught, compared to 58% for white in the Table 12. In addition, the t value also increases for the statistical relevance of the lower wattage test reported in Table 11. Since the total wattage per trap and per test was reduced, the tests in Table 11 were able to better evaluate the results of the background color variable without influence from light output by the traps. When the wattage factor is minimized, a black background is more than 50% less attractive than a white one. This result illustrates that the lower the total wattage per test, the more sensitive the test is for measuring variables.

Many companies use black glueboards so that the public can not see the trapped flies. However, the reduction in the trap's attraction power recorded here will most likely be magnified in the 'real world' and should be avoided whenever possible. The light reflection off its background can result in poor catch rates if the background is black. Alternatives to the black color should be available when it is desired by food merchants and restaurants.

Grill Amount. Many factors can add to the flies' distraction. However, many of these factors are difficult to evaluate. The bulbs themselves serve as landing sites for flies. For this reason, manufacturers have developed traps that have clear glueboards that are placed in front of the bulbs. In theory this reduces the distraction of the bulb as a landing surface. However, there has yet to be discovered a glue that will allow much UV light to penetrate without being harmed by the UV in a short period of time.

The amount of protective or decorative covering that manufacturers place over the bulbs of a trap can greatly influence the total distraction factor of a trap design. Many traps have large amounts of grill surface, even though the traps are glueboard-based and not electrocution. Electrocution traps have safety guidelines that dictate a high level of protective bars and therefore are automatically hindered. Some glue trap models have plastic covers that act for both protective and decorative purposes. This section of the research deals with quantifying the effects of metal cylindrical grill fixtures over the front of forward-facing light-trap bulbs.

When considering the distraction factor as presented earlier, it now can seem obvious that too much material in front of the catching method can have dire consequences. However, most commercially available glueboard light traps on the market today have far more than 922 linear centimeters of surface area in front of their openings. Many traps have wide plastic grid work, or metal stampings with wide borders, both creating a devastating effect that has been overlooked in their design.

The amount of grill over a trap has has been ignored by nearly all modern light trap manufacturers. Over the past 15 years, traps have gained more and more degrees of grill over the front. In the future, light trap manufacturers must play a careful role in providing traps with adequate protection of the bulbs without "overprotecting the fly". The negative attraction of shatterproof bulbs must be factored into the equation in providing adequate bulb safety in high-risk accounts instead of automatically manufacturing excess front covers for use on all account types.

The difference between the two types of grills at the front of the light traps actually increased compared to the previous tests with an average of 67% for the light grill but decreased in significance with a lower t value. In theory, an increase in wattage per trap should have demonstrated a reduced percentage for the favored trap. This test was an evaluation of a distraction factor and not an attraction factor. Since the 15-watt traps were not that attractive in the first place, the degree of difference between these two distraction variables was reduced.

Total Wattage per Cubic Meter, and Bulb Age

Tables 8-10 present data that show several critical points about the total wattage used in a laboratory test. First, the lower the overall wattage in the room, the greater statistical significance and the less the fluctuations that will occur due to random interactions with the flies (Table 9). That is, the sensitivity of a test is increased with lower total wattage. Second, when too much wattage is used overall in the test and there are only minor differences in wattage between each trap, the statistical significance will be greatly reduced (Table 10). The difference in wattage between traps is not the variable that is critical. Instead, the percentage difference between the wattage of each trap as it relates to the overall wattage in the room will be the important variable.

Fly Age and Total Number of Flies

One of the most common methods of conducting laboratory research is to use a large number of flies. This practice creates larger numerical differences between trap designs and allows the results to be presented as the total number caught in each trap. This allows for the difference to be inflated by showing that "Trap X caught 200 more flies" when in fact it may have only caught 5% more flies (well within reasonable position differences).

As light trap designs begin to improve, it will be necessary to measure small design improvements in order to combine several changes for a serious advance in trap efficiency. As researchers begin to measure slight differences between trap designs, the need to use more sensitive research tools becomes critical. We need to consider the use of the proper ratio of flies to the square meter of the laboratory, the use of the correct age of flies, the use of the proper amount of wattage per square meter of room, and the proper positioning of the two traps.

Overnight Test Periods

This consistency can be explained by the diurnal activity of the flies. Flies become much more subdued before 6:00 p.m. when these tests were all started. Therefore, there is less accidental interaction with the flies. Since the flies are not moving as much, individual responses to each of the two light traps is more calculated and intentional by the flies. This allows for a more reliable analysis. With reduced influence from the variables, this testing method has greater power to find the true effect of a variable. Since the flies are less active and the test period is much longer, the use of more than 200 flies per test is less of a factor than it is with shorter daytime tests.

The results shown in Table 20 illustrate the need for further studies of longer time periods during the day as well as different age groups and numbers of flies during the nighttime. The use of long test periods and nighttime studies is highly limiting to researchers, and would mean much less data collection over time. If the age of the flies matters in nighttime tests, it will greatly complicate the data collection since flies are constantly getting older and it would take several weeks to get four nighttime tests with the same age group of flies.

CONCLUSIONS

So what does all of this mean to researchers and practitioners? Most important, we must understand the variables that influence each laboratory that conducts research. For the users of insect light traps, this research can be used in different ways. First, what should be considered when reviewing published data on light traps? Data presented without rotated trap positions and proof of identical locations should be reviewed with a cautious eye. Second, can laboratory research finally start to improve the quality of fly control provided to restaurants and food plants? For research laboratories, this report should assist in finding better ways to improve the data-collection process.

Data are presented here for paired testing procedures. Hindsight from individual testing was helpful in monitoring variables. During the early stages of paired testing, many trap design features that showed significant differences in the individual tests were not as pronounced in the paired testing. It appears that the paired testing method is less sensitive than the individual testing procedures. This lack of sensitivity in paired testing requires a more in-depth analysis of the variables so that slight design differences can be measured with accuracy and confidence. There are two reasons to conduct laboratory analysis on insect light traps: 1) to develop improved trap designs, and, more commonly, 2) to compare competitive trap designs for choosing which traps are more effective. In both cases, the accuracy and sensitivity of a paired test is critical.

In conclusion, there is still a lot of research needed to better understand the most efficient way of testing light traps in a laboratory. To attempt to research light traps in the field seems somewhat futile with the vast degree of variables shown here in a small laboratory. We need to further understand how to make laboratory research more sensitive to variables and to have minimal fluctuations between tests. Once we can better understand all the variables, we can accelerate the advancement of fly control with light traps.

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