TRAP-LURE COMBINATIONS FOR SURVEILLANCE OF *ANASTREPHA* FRUIT FLIES (DIPTERA: TEPHRITIDAE)

Donald B. Thomas[1], Timothy C. Holler[2], Robert R. Heath[3], Elma J. Salinas4, and Amy L. Moses[2]
[1]USDA-ARS, Kika de la Garza Subtropical Agricultural Research Center, 2413 E. Highway 83, Weslaco, TX 78596

[2]USDA-APHIS-PPQ, 1913 SW 34th St., Gainesville, FL 32608.

[3]USDA-ARS Subtropical Horticulture Research Station, 13601 Old Cutler Road, Miami, FL 33158

[4]USDA-APHIS-PPQ, P.O. Box 2140, Moore Air Base, Mission TX 78572

Abstract

Trap/lure combinations were tested against populations of *Anastrepha suspensa* (Loew) and *Anastrepha ludens* (Loew) as substitutes for the traditional glass McPhail trap. Open-bottom, plastic traps baited with a two component synthetic lure (ammonium acetate and putrescine) caught as many and sometimes more fruit flies than the McPhail trap baited with torula yeast. Sex ratio of flies caught with the synthetic lure was similar to that caught with torula yeast, i.e., generally female biased, but variable among seasons and locations. The synthetic lure attracted fewer non-target insects giving a substantial time savings in trap maintenance. Moreover, the synthetic lure was effective for ten weeks without replacement. Propylene glycol antifreeze increased captures significantly and improved preservation of specimens when used as the trap liquid compared to water. Dry jar traps and cardboard sticky traps were ineffective in comparison with the liquid baited traps.

Key Words: *Anastrepha*, traps, synthetic lure, fruit flies, pest detection

Resumen

Combinaciones de varias trampas con diferentes cebos fueron evaluadas contra poblaciones de *Anastrepha suspensa* (Loew) y *Anastrepha ludens* (Loew) para substituir para la tradicionál trampa vídrio de McPhail. Trampas de plastico con un cebo syntético de dos componientes (acetato amoniaco y putrescina), capturaron igual o mas moscas de fruta que la trampa McPhail cebada con torula en agua. La proporción sexuál de las moscas capturadas con el cebo syntético fue igual que las capturadas con torula; generalmente hubo mas hembras, pero, variable con respecto a ubicación y temporada. El cebo syntético atrayeron menos insectos de otros tipos por su mejor eficiéncia resultando en menos tiempo manejando las trampas. Además, el cebo syntético fue efectivo por diéz semanas sin recebar. El anti-congelante (glycol propilico), mezclado con el agua, aumenta las capturas y preserva mejor los especimenes capturadas. Trampas secas y laminas pegajosas no fueron efectivas en comparación con las trampas cebadas con líquido.

McPhail traps baited with an aqueous slurry of torula yeast have long been the industry standard for tephritid fruit fly surveillance programs (Burditt 1982; Cunningham 1989). However, trap-back studies using marked flies have shown that at the usual trap densities, around 2-4 traps per km^2, McPhail traps recapture substantially less than one percent of the released individuals (Plant & Cunningham 1991; Thomas et al. 1999). When one considers this degree of trap efficacy in the context of early detection of wild fly infestations, there is an obvious need to increase trap densities, or, to develop a more effective trap. Because the former option is the less desirable for reasons of cost, the latter potential has been investigated.

The McPhail trap is a bell-shaped, invaginated glass jar, designed to be suspended in fruit trees, with an opening at the bottom and a reservoir for fluid of about 0.5 l capacity. The fluid serves as both the attractant and the catch mechanism, with the flies attracted into the trap by the food odor, then drowning in the liquid. In an early design, McPhail (1937) employed fermenting sugar solutions, but later found success with protein based lures (McPhail 1939; Steyskal 1977). This led to the present standard of torula yeast hydrolysate with borax (Lopez et al. 1971).

Robacker & Warfield (1993), Heath et al. (1995), and Robacker & Heath (1997), found that amino acid metabolites associated with bacteria and fermenting host fruits were highly attractive to *Anastrepha* fruit flies. However, delivery systems designed to contain and release these chemicals are not easily inserted in the solid glass of the McPhail trap. Therefore, trap devices compatible with the new lures have been designed and tested. In experiments conducted in Guatemala, Heath et al. (1997) found that a sticky trap baited with three components, ammonium acetate, trimethylamine and putrescine, caught about as many and sometimes more Medflies, *Ceratitis capitata* (Weidemann), and Mexflies *Anastrepha ludens* (Loew), than did the McPhail/torula yeast trap. Katsoyannos et al. (1999) reported that a plastic, open-bottom, trap, baited with water and the three component lure was five times more effective for catching Medflies than the same plastic trap containing protein hydrolysate. The protein based liquids are attractive to a broad range of insects which is not the case with the synthetic lures (Aluja 1999; Heath et al. 1995; Katsoyannos et al. 1999). Because far fewer of the non-target insects are caught, time spent servicing the traps is substantially reduced.

Based on these preliminary experiences, we conducted a series of tests in Florida against wild populations of Caribfly, *Anastrepha suspensa* (Loew), in Texas against released, radiosterilized, Mexflies, and in Nuevo Leon, Mexico against wild *A. ludens* in their native habitat. It is known that species of *Anastrepha* are not equally responsive to the traditional McPhail trap (McPhail 1939; Aluja et al. 1989). Ideally, one combination of trap and attractant could be deployed effectively against several different pest tephritids. The purpose of these tests was to provide direct comparisons of the more promising trap/lure combinations.

Materials and Methods

Trap Devices

The standard glass McPhail trap was included for comparison with the new trap/lure devices. Two new plastic traps were tested which in size, liquid reservoir capacity, and bottom opening diameter, were similar to the McPhail trap. One is manufactured by Florence Agri Investment Inc. (Miami FL), hereinafter referred to as the FAI trap, and the other by International Pheromone (South Wirral, UK), hereinafter referred to as the IPM trap. Both traps are of two piece construction consisting of transparent upper halves separable from yellow lower halves. They differed slightly in conformation, the IPM trap being cylindrical with a flat top, whereas the FAI trap is cylindrical but with a rounded top. Also, in the IPM trap the top half inserts within the bottom half, whereas in the FAI trap the bottom half inserts into the top. A sticky trap, called the ChamP[R] trap (Seabright, Albany, CA) was also included in the tests. This trap consisted of a square (15 × 15 cm), folding, double-sided, perforated, yellow cardboard with glue on the outside surfaces. Developed for use in combination with fruit fly sex pheromones, this trap has a metal hook for suspension in the target host tree.

Attractants

The standard aqueous torula yeast slurry, three 5 gm yeast pellets (2% borax, manufactured by ERA International, Freeport NY) dissolved in 350 ml water, was used in the McPhail traps, and in some tests, the plastic traps. The yeast slurry was renewed weekly when the traps were serviced. A two component lure consisting of ammonium acetate and putrescine was tested in the ChamP traps and in both plastic traps. The lure is marketed as Mediterranean fruit fly lure dual-paks by CONSEP Inc. (Bend, OR). The capture liquid was either 350 ml of water with 2% borax and five droplets of Triton X-100R synthetic detergent (Fisher Scientific, Pittsburgh, PA) to break water tension, or, antifreeze (propylene glycol). The liquid, but not the lure, was renewed each week when the traps were serviced. A dry version of these traps included a ¼ inch plastic strip impregnated with pesticide (DDVP) and baited with the two component lure.

Study Sites and Test Protocols

A series of pairwise tests, or in some cases, 3-way tests, were conducted in Florida against populations of *A. suspensa* between February and July, 1998, comparing different trap/lure combinations. The duration of the tests varied from three to 12 weeks, depending on fly activity, with each test including five of each trap/lure tested, with one of each combination in the same tree following Aluja et al., 1989. It was reasoned that proximity would intensify the competition among the traps. Tests were conducted at Labelle FL with the traps hung in loquat trees, *Eriobotrya japonica* (Thunb.) with a minimum distance of 1 m separating each trap. All traps were serviced and their position within the tree alternated weekly. At Ft. Pierce FL the target host was a hedge, *Eugenia uniflora* (L.) (Surinam Cherry), with the traps spaced at 3 m and rotated weekly.

In the Rio Grande Valley of Texas, McPhail traps with torula yeast slurry, IPM traps with two component lure and antifreeze, and IPM traps with antifreeze alone, were compared during six weeks of November and December 1998. Thirty of each trap type were placed in individual trees in a large commercial citrus grove (mainly grapefruit but some oranges) targeted by the weekly sterile release program. The traps were positioned randomly with a minimum distance of 30 m (3 trees) separating each trap. The traps were rotated when the traps were serviced weekly.

Near the town of Linares in the state of Nuevo Leon, Mexico, traps were placed in yellow chapote trees, *Sargentia greggi* (Wats.), for testing against wild populations of *Anastrepha ludens*. This test was conducted during the spring of 1999 at five sites with one of each of five trap/lure combinations. These were: 1) the standard glass McPhail trap with torula yeast, 2) the plastic IPM trap baited with the two component lure and water, 3) the plastic IPM trap with two component lure and 20% propylene glycol, 4) the dry version IPM trap with the two component lure and a vapona strip, and, 5) the ChamP sticky trap with the lure packets inside. Although the sticky traps were replaced weekly, the lure packets were simply removed from the old sticky trap and placed inside the new trap each week.

Within each site a minimum distance of at least 50 m was maintained between traps. The trap positions were designated A-B-C-D-E and each week the traps were rotated so that the trap at A was moved to B, the trap at B went to C, etc. The Mexican test continued for ten consecutive weeks so that each trap was at each position twice during the course of the test.

Statistical Analysis

Because populations and activity changed over the course of the season, the numbers of flies trapped tended to vary greatly from week to week. Because this variation could mask differences in trap efficacy statistical comparisons were made by converting the numbers captured to percent of total weekly captures following Heath et al. (1995). The mean percent weekly values were then compared by a pairwise students t-test, The t-score probabilities calculated by the software program TPROB (Speakeasy Computing 1987).

RESULTS

Florida Tests

The results, including statistical analysis of all trap-lure combinations, are shown in Table 1 and summarized below.

Plastic vs. Glass McPhail Traps. The FAI plastic trap was tested against the McPhail trap in an area where *A. suspens*a was breeding in loquat. The test was run for eight consecutive weeks; both traps baited with aqueous torula yeast with borax as preservative. The McPhail traps caught slightly more flies on average with a capture rate of 18 flies vs. 13 flies per trap-week. The difference in captures expressed as a percent of total was not statistically significant between the traps.

Synthetic Lure vs. Torula Yeast. The two component lure was tested in the FAI plastic trap against the McPhail trap containing the torula yeast slurry. The synthetic lure trap was equivalent in effectiveness to the traditional trap capturing a weekly mean of 42 flies vs. 37 flies per trap; rates that were not significantly different. The IPM trap gave somewhat better results. At Labelle FL in loquats the IPM trap with the two component lure caught many more flies than the McPhail/torula trap, 77 vs. 34 flies per trap-week. The same result was obtained at Ft. Pierce FL in surinam cherry with the IPM trap taking 64 vs. 52 flies per trap-week. These differences when expressed as a percentage of flies caught gave a borderline t-score of 1.93 which has a p of 0.06. Importantly, the synthetic lure was effective throughout the ten week test period. The longest previous test of these lures was four weeks (Kat-

TABLE 1. FLORIDA TRAPPING RESULTS: TOTAL NUMBERS OF *ANASTREPHA SUSPENSA* CAPTURED AND MEAN PERCENTAGE OF CAPTURES BY TRAP-WEEK COMPARED BY PAIR-WISE T-TEST. MAC = MCPHAIL TRAP, IPM = INTERNATIONAL PHEROMONE TRAP, FAI = FLORENCE AGRI-INVESTMENT TRAP, TY = TORULA YEAST, AP = AMMONIUM ACETATE & PUTRESCINE, WB = WATER & BORAX, PG = PROPYLENE GLYCOL.

Trap-Lure	N	Mean ± s.d.	Trap-Lure	N	Mean ± s.d.	t	df	p
MAC-TY-WB	725	53.9 ± 10.5	FAI-TY-WB	535	46.1 ± 10.5	1.50	14	0.078
MAC-TY-WB	551	43.3 ± 8.6	FAI-AP-WB	622	51.1 ± 4.6	1.37	4	0.121
FAI-AP-WB	622	51.1 ± 4.6	FAI-AP-dry	62	5.5 ± 4.4	12.32	4	<0.001
FAI-AP-dry	62	5.5 ± 4.4	MAC-TY-WB	551	43.3 ± 8.6	6.73	4	0.001
MAC-TY-WB	509	40.5 ± 14.2	IPM-AP-WB	1165	57.5 ± 5.4	1.93	4	0.063
IPM-AP-dry	288	17.0 ± 13.7	MAC-TY-WB	509	40.5 ± 14.2	3.57	4	0.012
IPM-AP-WB	1165	57.5 ± 5.4	IPM-AP-dry	288	17.0 ± 13.7	4.76	4	0.004
MAC-TY-WB	4880	42.6 ± 22.7	IPM-AP-WB	3835	57.4 ± 22.7	1.22	12	0.123
MAC-TY-WB	975	31.8 ± 10.1	IPM-AP-PG	204	68.2 ± 10.1	5.70	8	<0.001
IPM-AP-WB	2616	38.0 ± 5.9	IPM-AP-PG	4315	62.0 ± 5.9	7.08	10	<0.001
IPM-AP-WB	6333	33.4 ± 9.0	IPM-AP-PG	11029	66.6 ± 9.0	7.37	14	<0.001
IPM-AP-WB	335	80.0 ± 7.8	FAI-AP-WB	105	20.0 ± 7.8	15.38	14	<0.001
IPM-AP-PG	5262	54.4 ± 5.4	FAI-AP-PG	4450	45.6 ± 5.4	2.84	10	0.009
IPM-AP-PG	5703	92.7 ± 2.4	ChamP-AP	443	7.3 ± 2.4	56.18	8	<0.001

soyannos et al. 1999). Also, similar to previous experience, we noted fewer non-target insects in the synthetic lure traps.

Dry vs. Wet Traps. Flies captured in aqueous solutions tend to decompose, constraining the amount of information that can be recovered from these specimens. This problem is exacerbated by evaporation due to dry or windy weather, or delays in servicing the traps. Another concern is that the aqueous liquid may not be an effective capture mechanism and that flies entering might escape. A series of tests were conducted by substituting insecticide strips for the liquid as the killing agent. However, these test results were not encouraging. The FAI trap with water captured ten times as many flies per week on average (41.5 ± 6.4) as the dry insecticide version (4.1 ± 2.4). Similarly, the IPM trap with water captured four times as many flies weekly (77.0 ± 43.2) as the dry version IPM trap (19.2 ± 10.7).

Capture Liquid. Another alternative to the preservation and evaporation problem is the use of antifreeze instead of water as the capture liquid. IPM plastic traps with the two component lure and propylene glycol was tested against the standard McPhail trap with torula yeast slurry. The result was a marked improvement. The IPM trap with antifreeze captured nearly twice as many flies per trap: 89 vs. 39 mean flies weekly. Another pair of tests was conducted using all IPM plastic traps and synthetic lures so that the only variable in the design was the capture liquid. In both tests the water based traps captured only half as many flies weekly as did the antifreeze traps. The rate of capture expressed as a percentage of captures and compared by the t-test were found to be significantly different (Table 1).

A series of tests were conducted to determine the best antifreeze concentration. The results were suggestive but inconclusive. A 50% solution was tested against a 10% solution in April and again in May. In the first test the 10% solution was significantly better than the 50% solution (45.1% vs. 35.7% of the flies per week). But, the results reversed in the May test where the 50% solution caught slightly more flies, 40.9% vs. 35.4%, although the difference was not statistically significant. Also, in Texas an 8 week comparison was made between the 10 and 20% concentration against sterile *Anastrepha ludens* with no significant difference in captures (33.2% vs. 26.9%).

IPM vs. FAI Traps. Two pairwise tests were conducted to compare the plastic traps; one with water as the capture liquid and one with antifreeze. The two component lure was used in all traps in both tests. With water as the trap liquid the IPM trap outperformed the FAI trap with a rate of 7 vs. 2 flies per trap-week. With antifreeze as the trap liquid the difference was less dramatic but still significant when the data was converted to percentages with the IPM trap catching 54.4% vs. 45.6% of the flies.

Sticky Traps vs. Liquid Traps. The ChamP traps were tested at Labelle FL against the IPM traps baited with two component lure and 10% propylene glycol as the capture liquid. The ChamP trap was ineffective, capturing an order of magnitude fewer flies, only 18 vs. 228 flies per trap-week over 5 weeks.

Mexico Test

The experiment in Mexico differed from the Florida testing in that all traps were tested simultaneously instead of pairwise, and the targeted insects were native populations of *A. ludens*. Table 2 provides acompilation of the results which were similar to those obtained in Florida with *A. suspensa*. The IPM trap with synthetic lure and antifreeze was the best trap for capturing wild Mexflies by a wide margin. It caught the most flies at all five sites. Moreover, it was the best trap in seven of the ten week test period and was never worse than second best in the other weeks. The next best trap/lure combination was the synthetic lure in the IPM trap with water and borax which caught about half as many flies as the antifreeze version but twice as many as the McPhail-torula trap. The IPM trap with synthetic lure outperformed the McPhail trap in nine out of the ten weeks tested and was the second best trap, after the antifreeze trap, at all five sites. The sticky trap was the least effective trap. It caught the fewest flies at all five sites, catching none at

TABLE 2. MEXICO TRAPPING RESULTS: NUMBER OF *ANASTREPHA LUDENS* CAPTURED AND MEAN WEEKLY PERCENTAGE CAPTURED BY EACH TRAP/LURE COMBINATION. MEANS TESTED PAIRWISE WITH STUDENT'S T-TEST. MAC = MCPHAIL TRAP, IPM = INTERNATIONAL PHEROMONE TRAP, TY = TORULA YEAST, AP = AMMONIUM ACETATE & PUTRESCINE, PG = PROPYLENE GLYCOL.

Trap-Lure	Flies	Mean ± s.d.	t	df	p
IPM-AP-PG	558	47.8 ± 17.4	2.41	18	0.013
IPM-AP-WB	295	29.1 ± 17.2	2.40	18	0.014
MAC-TY-WB	177	14.2 ± 9.5	2.45	18	0.012
IPM-AP-dry	81	6.3 ± 3.7	2.43	18	0.013
ChamP-AP	33	2.6 ± 3.1			

two sites. It was the worst trap in six of the ten weeks and was never better than next to worst in the other weeks. All of these differences in trapping rates were statistically significant (Table 2).

Texas Test

The Texas test was conducted in a commercial grove against aerially released, radiosterilized, *A. ludens*. Temperatures varied sharply during this test such that although an equal number of flies was released weekly, the numbers trapped back also varied sharply. The McPhail trap averaged from 2.2 to 33.2 flies weekly for a mean of 17.0 ± 10.5 flies per trap per week. The IPM traps averaged from 4.4 to 24.8 flies weekly for a mean of 13.7 ± 8.6 flies per trap per week. Because of the variation in weekly captures, these numbers were converted to percentage rates for comparison. Nonetheless, the difference in means, 46.3% (McPhail) vs. 41.3% (IPM), was not statistically significant ($t = 0.62$, 10 d.f., $p = 0.274$). Interestingly, the control traps containing only antifreeze succeeded in capturing an average of 5.0 ± 3.9 flies per trap per week. By comparison, Heath et al. (1994) found that traps containing water alone were not attractive to the Mexfly.

During this test three experienced trappers were separately observed and timed with a stopwatch as they serviced the traps. Servicing involved emptying the trap, separating the fruit flies from the other insects and placing them in vials containing preservative, and recharging the trap liquid. The average time required for one person to service the McPhail trap was 150.7 sec ($n = 90$). The average time required to service the IPM traps was 107.7 sec ($n = 90$). It was judged that the average difference, 43 sec, was due to the lesser time it took to separate the fruit flies from the IPM trap due to the presence of fewer non-target insects. It should be noted that had these studies been conducted in an urban setting a greater differential might have been found. Trappers have reported incidents wherein house flies have filled McPhail traps requiring up to 15-20 minutes in service time.

We attempted a cost-benefit analysis to compare operating expenses of a program with the plastic traps and synthetic lure versus a program using the traditional McPhail trap with torula yeast. However, because costs vary regionally, especially for labor, and some materials are not universally available, these, cost estimates are relative. As of this writing the plastic traps range about 2-3 times more expensive than the glass McPhail trap. But, because the plastic traps are stackable and light in weight there is a substantial savings in shipment costs over the bulky glass traps. The cost of the commercially available synthetic lure packets is about ten times the cost of three torula yeast pellets. However, whereas the yeast slurry must be renewed every week, the packets need be renewed only once every ten weeks, giving an equivalent cost for lure over the season. The use of 20% propylene glycol incurs an additional cost which would about double the weekly expense in expendable materials, except that this liquid can be recycled and reused three to four times before replacement. The replacement rate varies because it is due mainly to loss in handling (spillage and absorption) rather than deterioration.

Sex Ratio and Reproductive Stage of Trapped Flies

Gender bias is an important concern because surveillance trapping is often combined with SIT suppression programs. Under these conditions there could be an advantage to a female biased trap (Katsoyannos et al. 1999). Trapping *A. suspensa* in Florida, Calkins et al. (1984) reported a strong female bias in McPhail traps baited with protein by a ratio of 2:1 over males. Our Florida results were similar. The *A. suspensa* females outnumbered the males in all trap-lure combinations. In five tests the McPhail trapped flies ranged from 66.4 to 82.9% females with a mean of 75.0 ± 6.2 percent. Captures in the plastic traps baited with ammonium acetate and putrescine with water ranged from 61.6 to 78.7% females for a mean of 75.0 ± 4.4 ($n = 8$). Traps with the two component lure, but using propylene glycol as the trap fluid, obtained the same result: a range of 62.9 to 85.3% females over six tests for a mean of 77.7 ± 8.02 percent.

However, we obtained very different results with *A. ludens* in Mexico. The McPhail traps caught exactly the same number of males and females. But, the synthetic lure traps were strongly male biased during the ten week study. The flies caught by the plastic traps baited with ammonium acetate and putrescine with water were 71.3% males. The flies caught with the same lure but with propylene glycol were 68.4% males. This result might be explained by the studies of Lopez & Hernandez (1967) with *A. ludens* who found that traps baited with corn protein tended to catch more females, while traps with fermenting bait (sugar and yeast) tended to catch more males. Monitoring populations of *A. ludens* in Belize, Houston (1981) found that sex ratio varied over the season, and from place to place, although the variation was between unity and a skewness in favor of females. Likewise, Robacker (1999) reported gender differences in attraction to the synthetic lures by location and season. Thus, sex ratio of trapped flies is influenced by confounding factors which include changes in the population structure and corresponding changes in the response of the adults to the attractant over the season. Our previous experience with *A. ludens* trapping has been equally ambiguous. Annual surveys for Mexflies in citrus groves in Texas with McPhail traps are consistently female biased at a ratio of 3:1 (1,387 females vs. 411 males from January 1997 through May, 2000). But traps in the chapote mots of Nuevo Leon are generally male biased. From 1995 through 1998 we trapped 3,794 males to 2,711 females, a ratio of approximately 3:2. One explanation is that there may be a stronger influence from lekking behavior in the chapote mots compared to the citrus groves such that male captures are favored in the traps. Robacker (1993) demonstrated experimentally that the male sex pheromone strongly inhibits the attraction of the immature females to the chapote trees with leks.

Using lab bioassays, Robacker & Warfield (1993) found no significant difference between the sexes of *A. ludens* in attraction to torula yeast or to synthetic lure. But, in further refining these tests, Robacker (1999) demonstrated that male response was strongly influenced by age, with older males being significantly more attracted to the synthetic lure. Our data (Table 3) shows the change in reproductive status of the females over the course of the Mexican field test in 1999. The larger numbers captured in the last two weeks of the test was evidently due to an influx of immature flies, indicating a strong local emergence of new adults. The weeks with the largest numbers of flies were also the weeks with the least skew in sex ratio. This suggests that a factor contributing to the bias in sex ratio over most of the test period was a general absence of immature females. Thus, our results indicate that with the two species of *Anastrepha* tested there is a general bias for female captures with the synthetic lure, as there is with the McPhail-torula trap, but that this is subject to local and seasonal variation in population structure and prevailing environmental conditions.

Discussion

The efficacy of a fruit fly trap is influenced by weather (Cunningham et al. 1978, Gazit et al. 1998), by the habitat surrounding the tree with the trap (Aluja et al. 1996), and even the position of the trap within the tree (Hooper & Drew 1979; Robacker et al. 1990). By rotating the traps weekly we hoped to minimize these effects, but because weather conditions also vary from week to week, it was impossible to completely neutralize the influence of the environment. It was also known that different species of tephritids respond differentially to the traps and lures (Aluja et al. 1989). Thus, we deemed it important to apply our studies in different locations, in different habitats, and against different species of fruit flies.

The results of the tests in Florida against *A. suspensa* suggest that the plastic versions of the open-bottom trap can be substituted for the traditional glass McPhail trap without significant loss in effectiveness. Likewise, the artificial lures based on ammonia and putrescine can be used in the plastic traps and catch as many, and often more Caribflies, but with fewer non-target insects, than the McPhail trap. Another advantage of the plastic traps over the McPhail traps is their yellow color. Greany et al. (1977) and Robacker (1992) found that yellow to orange hues are visually attractive to Caribfly and Mexfly respectively. Of the plastic traps tested, the IPM trap outperformed the FAI trap. Tests in Mexico against wild populations of *A. ludens* likewise demonstrated the superiority of the plastic traps with synthetic lures over the traditional glass McPhail with torula yeast. Tests in Texas against sterile flies only demonstrated equivalence between the trap configurations in terms of numbers captured, but a greater selectivity on the part of the synthetic lures, resulting in a reduction of handling time by about one-third.

One might conjecture why there was such large differences among the three configurations of IPM traps and synthetic lure but different preservatives. A concern with the open bottom trap is that flies can exit the trap without getting caught (Aluja et al. 1989). The flies have to fall into the

Table 3. Reproductive age of female *Anastrepha ludens* and sex ratio by Julian week at Santa Rosa Canyon, Nuevo Leon, Mexico (data from wet traps only).

Julian week	Gravid females	Non-gravid females	Males	Percent males
14	15	3	50	73.5
15	29	5	50	59.5
16	32	2	72	67.9
17	25	1	68	72.3
18	65	0	100	60.6
19	14	1	22	59.5
20	14	3	19	52.8
21	8	6	48	77.4
22	6	4	55	84.6
23	7	43	67	59.0
Totals	215	68	551	66.1

liquid and drown to be actually trapped, an essentially passive catch mechanism. The use of a knockdown insecticide or a sticky contact surface might have been expected to solve that problem, yet the two traps with those active trap advantages underperformed all of the liquid traps.

The greater captures by the wet IPM trap compared to the McPhail trap can be explained as resulting from the superior lure in the former. However, it is much more difficult to explain the better catch in the antifreeze trap compared to the water trap, having the same lure and configuration. The capture of flies in traps containing only antifreeze suggests that the antifreeze has an attractance. Inasmuch as propylene glycol itself is unlikely to be attractive to insects there may be an impurity or breakdown product in the commercial formulation which is attractive to flies. For whatever reason, the antifreeze greatly improved captures when used as the trap fluid in combination with the two component lure.

Among the liquid based configurations we cannot make absolute recommendations for one trap over another. Ultimately, program managers must decide which trap is appropriate for their situation, among which, efficacy is but one consideration. In programs where traps are rotated among sites to follow fruit phenology, the portability of the traps may be an overriding factor. Our studies provide information on the characteristics of some of the trap-lure designs now available among those most likely to be useful in fruit fly surveillance programs. For some programs the detection of new infestations is the objective, as opposed to the monitoring of existing populations, and the trapping protocol will vary accordingly. Having uniformity in trapping protocols among programs is a consideration in that it facilitates comparisons across regions. In some cases, for example, where quarantine restrictions are triggered by fly finds, the requisite trap design may be codified (e.g., Nilakhe et al. 1991). Lastly, it might also be noted that the improvement in efficacy of the synthetic lures over the torula yeast is incremental. Until the degree of improvement reaches an order of magnitude, one has to expect that further enhancements will be discovered, and thus, even the best trap-lure designs now available could be outmoded in the near future as research in this area continues.

ACKNOWLEDGMENTS

We are grateful to David C. Robacker, USDA-ARS, Weslaco, TX, David Lance, USDA-APHIS, Otis, MA, Richard L. Penrose, California Department of Food & Agriculture, Sacramento, CA, and two anonymous reviewers, for advice and comments on the manuscript. Mr. Danny Gates, USDA-APHIS, suggested the experimental design for the Mexican portion of the testing. Manuel Beltran of Florence Agri Investments, Miami FL, provided the multilure traps. Pat Minyard of the California Department of Food & Agriculture provided the ChamP traps. Dan Flores and Santiago Moreno, Jr. assisted in the trapping study in Texas. Celestino Cervantes, Ronay Riley and Francisco Daniel were diligent in the servicing of the trap lines in Mexico.

LITERATURE CITED

ALUJA, M. 1999. Fruit fly (Diptera: Tephritidae) research in Latin America: myths, realities and dreams. An. Soc. Entomol. Brasil 28: 565-594.

ALUJA, M., M. CABRERA, J. GUILLEN, H. CELEDONIO, AND F. AYORA. 1989. Behavior of *Anastrepha ludens*, *A. obliqua* and *A. serpentina* (Diptera: Tephritidae) on a wild mango tree (*Mangifera indica*) harbouring three McPhail traps. Insect Sci. Applic. 10: 309-318.

ALUJA, M., H. CELEDONIO, P. LIEDO, M. CABRERA, F. CASTILLO, J. GUILLEN, AND E. RIOS. 1996. Seasonal population fluctuations and ecological implications for management of *Anastrepha* fruit flies (Diptera: Tephritidae) in commercial mango orchards in southern Mexico. J. Econ. Entomol. 89: 654-667.

BURDITT, A. K. 1982. *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), McPhail traps for survey and detection. Florida Entomol. 65: 367-373.

CALKINS, C. O., W. J. SCHROEDER, AND D. L. CHAMBERS. 1984. Probability of detecting Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), populations with McPhail traps. J. Econ. Entomol. 77: 198-201.

CUNNINGHAM, R. T. 1989. Population detection. pp. 169-173, *In* A. S. Robinson and G. Hooper (eds.). World Crop Pests 3B. Fruit Flies: their biology, natural enemies and control. Elsevier, Amsterdam.

CUNNINGHAM, R. T., S. NAKAGAWA, D. Y. SUDA, AND T. URAGO. 1978. Tephritid fruit fly trapping: liquid food baits in high and low rainfall climates. J. Econ. Entomol. 71: 762-763.

GAZIT, Y., Y. ROSSLER, N. D. EPSKY, AND R. R. HEATH. 1998. Trapping females of the Mediterranean fruit fly (Diptera: Tephritidae) in Israel: comparison of lures and traps. J. Econ. Entomol. 91: 1355-1359.

GREANY, P. D., H. R. AGEE, A. K. BURDITT, AND D. L. CHAMBERS. 1977. Field studies on color preferences of the Caribbean fruit fly *Anastrepha suspensa* (Diptera: Tephritidae). Entomol. Exp. & Appl. 21: 63-70.

HEATH, R. R., N. D. EPSKY, S. BLOEM, K. BLOEM, F. ACAJABON, A. GUZMAN, AND D. CHAMBERS. 1994. pH effect on the attractiveness of a corn hydrolysate to the Mediterranean fruit fly and several *Anastrepha* species (Diptera: Tephritidae). J. Econ. Entomol. 87: 1008-1013.

HEATH, R. R., N. D. EPSKY, B. D. DUEBEN, J. RIZZO, AND F. JERONIMO. 1997. Adding methyl-substituted ammonia derivatives to a food-based synthetic attractant on capture of the Mediterranean and Mexican fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 90: 1584-1589.

HEATH, R. R., N. D. EPSKY, A. GUZMAN, B. D. DUEBEN, A. MANUKIAN, AND W. L. MEYER. 1995. Development of a dry plastic insect trap with food based synthetic attractant for the Mediterranean and Mexican fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 88: 1307-1315.

HOOPER, AND DREW. 1979. Effect of height of trap on capture of tephritid fruit flies with cuelure and methyl eugenol in different environments. Environ. Entomol. 8: 786-788.

HOUSTON, W. W. K. 1981. Fluctuations in numbers and the significance of the sex ratio of the Mexican fruit fly, *Anastrepha ludens*, caught in McPhail traps. Entomol. Exp. & Appl. 30: 140-150.

KATSOYANNOS, B. I., R. R. HEATH, N. T. PAPADOPOULOS, N. D. EPSKY, AND J. HENDRICHS. 1999. Field evaluation of Mediterranean fruit fly (Diptera: Tephritidae) female selective attractants for use in monitoring programs. J. Econ. Entomol. 92: 583-589.

LOPEZ, F., AND O. HERNANDEZ. 1967. Sodium borate inhibits decomposition of two protein hydrolysates attractive to the Mexican fruit fly. J. Econ. Entomol. 60: 137-140.

LOPEZ, F., L. F. STEINER, AND F. R. HOLBROOK. 1971. A new yeast hydrolysate-borax bait for trapping the Caribbean fruit fly. J. Econ. Entomol. 64: 1541-1543.

MCPHAIL, M. 1937. Relation of time of day, temperature and evaporation to attractiveness of fermenting sugar solution to Mexican fruitfly. J. Econ. Entomol. 30: 793-799.

MCPHAIL, M. 1939. Protein lures for fruit flies. J. Econ. Entomol. 32: 758-761.

NILAKHE, S. S., J. N. WORLEY, R. GARCIA, AND J. L. DAVIDSON. 1991. Mexican fruit fly protocol helps export Texas citrus. Subtrop. Plant Sci. 44: 49-52.

PLANT, R. E., AND R. T. CUNNINGHAM. 1991. Analyses of the dispersal of sterile Mediterranean fruit flies (Diptera: Tephritidae) released from a point source. Environ. Entomol. 20: 1493-1503.

ROBACKER, D. C. 1992. Effects of shape and size of colored traps on attractiveness to irradiated, laboratory-strain Mexican fruit flies (Diptera: Tephritidae). Florida Entomol. 75: 230-241.

ROBACKER, D. C. 1993. Understanding olfactory attraction in *Anastrepha* using *A. ludens* as a model system. pp. 201-206. *In* M. Aluja and P. Liedo (eds.). Fruit Flies: biology and management. Springer-Verlag, New York, NY.

ROBACKER, D. C. 1999. Attraction of wild and laboratory-strain Mexican fruit flies (Diptera: Tephritidae) to two synthetic lures in a wind tunnel. Florida Entomol. 82: 87-96.

ROBACKER, D. C., AND R. R. HEATH. 1997. Decreased attraction of *Anastrepha ludens* to combinations of two types of synthetic lures in a citrus orchard. J. Chem. Ecol. 23: 1253-1262.

ROBACKER, D. C., D. S. MORENO, AND D. A. WOLFENBARGER. 1990. Effects of trap color, height, and placement around trees on capture of Mexican fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 83: 412-419.

ROBACKER, D. C., AND W. C. WARFIELD. 1993. Attraction of both sexes of Mexican fruit fly, *Anastrepha ludens*, to a mixture of ammonia, methylamine and putrescine. J. Chem. Ecol. 19: 2999-3016.

STEYSKAL, G. C. 1977. History and use of the McPhail trap. Florida Entomol. 60: 11-16.

SPEAKEASY COMPUTING. 1987. Speakeasy Manual, Speakeasy Computing. Chicago, IL.

THOMAS, D. B., J. N. WORLEY, R. L. MANGAN, R. A. VLASIK, AND J. L. DAVIDSON. 1999. Mexican fruit fly population suppression with the sterile insect technique. Subtrop. Plant Sci. 51: 61-71.