

## Research Article

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# Relative captures and detection of male *Ceratitis capitata* using a natural oil lure or trimedlure plugs

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**Abstract:** Traps baited with a lure emitting a natural oil enriched in  $\alpha$ -copaene captured more male *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) than traps baited with a 2 g plug of trimedlure during year-long trials in Tunisian citrus (*Citrus sinensis* Osbeck, Rutaceae) and Costa Rican coffee (*Coffea arabica* Linnaeus, Rubiaceae). In Costa Rica, traps were plastic McPhail traps while in Tunisia Tephriti traps were used. Trimedlure plugs were changed every six weeks while the natural oil lures were renewed every 12 weeks. During high population season, traps in all locations baited with the natural oil outperformed traps baited with 2 g plugs of trimedlure by 2–3 times. During the low season, a significantly higher percentage of traps baited with the natural oil caught at least one male medfly in comparison to traps baited with 2 g plugs of trimedlure in Tunisia, but statistical differences were not observed in Costa Rica. A longevity trial in Tunisia showed that traps baited with 16–18 weeks aged natural oil lures still captured statistically more male *C. capitata* than traps baited with 2 g plugs of trimedlure renewed every six weeks. These results show that traps baited with  $\alpha$ -copaene lures are more sensitive than traps baited with the widely used 2 g trimedlure plugs.

**Keywords:** mediterranean fruit fly; medfly;  $\alpha$ -copaene; monitoring; traps

**Resumen:** Trampas cebadas con un atrayente que emite un aceite natural enriquecido en  $\alpha$ -copaeno capturaron más

machos de *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) que las trampas cebo con un tapón de 2 g de trimedlure durante ensayos de un año en cítricos en Túnez (*Citrus sinensis* Osbeck, Rutaceae) y café costarricense (*Coffea arabica* Linnaeus, Rubiaceae). En Costa Rica, se usaron trampas plásticas McPhail, mientras que en Túnez se utilizaron trampas Tephriti. Los tapones de trimedlure se cambiaron cada seis semanas, mientras que los atrayentes de aceite natural se renovaron cada 12 semanas. Durante la temporada con alta población, en todas las ubicaciones las trampas cebadas con aceite natural superaron entre 2 y 3 veces a las trampas cebo con tapones de trimedlure. Durante la temporada baja, un porcentaje significativamente mayor de trampas cebadas con aceite natural capturaron al menos un macho de la mosca del Mediterráneo en comparación con las trampas cebadas con tapones de trimedlure en Túnez, aunque no se observaron diferencias estadísticas en Costa Rica. Un ensayo de longevidad en Túnez mostró que las trampas cebadas con atrayentes de aceite natural envejecidos entre 16 y 18 semanas aún capturaron estadísticamente más machos de *C. capitata* que las trampas cebadas con tapones de trimedlure renovados cada seis semanas. Estos resultados demuestran que trampas cebadas con  $\alpha$ -copaeno son más sensibles que trampas cebadas con los ampliamente usados tapones de 2 g de trimedlure.

**Palabras clave:** mosca mediterránea de la fruta; moscamed;  $\alpha$ -copaeno; monitoreo; trampas

## 1 Introduction

In most fruit growing areas large-scale fruit fly monitoring programs are conducted to detect infestations before they become economically important. Several types of lures are used for monitoring. Some are food based lures that emit odors common to protein decomposition that attract both males and females (Broughton and Rahman 2017; Kean et al. 2024). Several lures are male-specific attractants discovered during intensive screening programs (Beroza and Green 1963). The most important male-specific lures are trimedlure (*Ceratitis* spp.; Diptera: Tephritidae), methyl

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eugenol (*Bactrocera/Dacus* spp.; Diptera: Tephritidae), and cue-lure (*Bactrocera* and *Zeugodacus* spp.; Diptera: Tephritidae) (Tan et al. 2014). The goal for the United States Department of Agriculture during 2024–2028 is to deploy and service approximately 153,000 traps per year to monitor exotic fruit flies (USDA APHIS 2024). In support of this effort, a minimum of 100,000 trimedlure 4 g plugs per year are purchased (USDA APHIS 2022). Trimedlure attracts only male *Ceratitis* spp. and has been the gold standard for monitoring the mediterranean fruit fly since its discovery in the 1950s (Beroza and Green 1963; Francis et al. 2023).

Since the discovery of trimedlure, more attractive replacements have been sought. Ceralure, an iodo analog of trimedlure, was more attractive than trimedlure but has defied economical synthesis (Khrimian et al. 2002; McGovern and Cunningham 1988). Another approach stems from the use of Angelica seed oil (*Angelica archangelica* Linnaeus, Apiaceae) as the bait in monitoring traps to survey medfly populations in Florida in the mid-1950s (Steiner et al. 1957). The active ingredient in this oil was determined to be  $\alpha$ -copaene (Guiotto et al. 1972), and the dextrorotary optical isomer was confirmed by Jacobson et al. (1987). The favored source of (+)- $\alpha$ -copaene has been ginger root oil (*Zingiber officinale* Roscoe, Zingiberaceae; Shelly and Pahio 2002). Fractional distillation increases the (+)- $\alpha$ -copaene concentration from 0.3 to 0.4 % to 3 % or more, and the latter fractions are highly attractive to male *Ceratitis capitata* Wiedemann (Shelly and Pahio 2002). Several trials on multiple continents have compared captures of male medflies to traps baited with trimedlure or ginger root oil enriched in (+)- $\alpha$ -copaene (also known as EGRO). Studies in Tunisia (Hafsi et al. 2019) and Hawaii (Shelly 2013; Shelly and Pahio 2002) found that trimedlure was significantly more attractive than EGRO but trials in southern Africa (Manrakhan et al. 2017; Mwatawala et al. 2013, 2015) found that EGRO was equally or even more attractive to male medfly than trimedlure. However, the release rates of EGRO and trimedlure were not defined, so interpretation of the results is confounded.

In a search for additional natural products attractive to male medfly, Flath et al. (1994) isolated several sesquiterpenes and examined their attractiveness in short-term field tests. While both (+) and (–)- $\alpha$ -copaene were attractive to male medfly, (+)- $\alpha$ -copaene was observed to be the most attractive sesquiterpene in the 7-day trial (Flath et al. 1994). In this trial (–)- $\alpha$ -copaene baited traps captured fewer male medflies than traps baited with any other sesquiterpene examined (Flath et al. 1994). Recently, the relative attractiveness of several essential oils containing  $\alpha$ -copaene has been examined, but no correlation between  $\alpha$ -copaene content and attractiveness was detected (Niogret et al. 2017). Lull et al. (2023) recently found that the terpene fraction of

deegenolized clove oil, which is a low-cost source of sesquiterpenes, yields a mixture of the enantiomers of  $\alpha$ -copaene attractive to male *C. capitata*. Thus, the search for new sources of  $\alpha$ -copaene to enhance trapping of medfly continues.

In 2020 our group began a search for new sources of attractants for male *C. capitata*. Screening of natural oils from several sources led to identification of an  $\alpha$ -copaene containing oil, which when enriched in  $\alpha$ -copaene through fractional distillation was highly attractive to male *C. capitata*. This  $\alpha$ -copaene enriched natural oil has been formulated into a slow-release membrane for evaluation (P388-lure). This report compares the attractiveness of this formulation to a standard 2 g trimedlure plug on three farms in Costa Rica and two farms in Tunisia over year-long intervals.

## 2 Materials and methods

### 2.1 Costa Rica

All study sites contained orange (*Citrus sinensis* Osbeck, Rutaceae) and tangerine (*Citrus reticulata* Blanco, Rutaceae) trees planted to shade coffee (*Coffea arabica* Linnaeus, Rubiaceae). The first farm was located near Atenas, Alajuela, Costa Rica, at 10.0077778 °N, 84.4086111 °E, at an elevation of 840 m a.s.l. (4 ha). The second farm was located near Puriscal, San José, Costa Rica, at 9.8366667 °N, 84.2158333 °E, at an elevation of 1,050 m a.s.l. (2 ha). The third farm in Costa Rica was located near Acosta, San José, Costa Rica at 9.8030556 °N, 84.1750000 °E, at an elevation of 1,025 m a.s.l. (3 ha). All three farms were located on the western side of the central valley of Costa Rica and experienced similar climatic conditions. Trapping was conducted between June 2021 and June 2022 during which average daily minimum and maximum temperatures were 17.3 and 27.8 °C at all locations. Relative humidity ranged between 42 and 70 % during the dry season (January–April) and 75 and 87 % during the wet season (mid-May–December) for all locations. Rainfall averaged 8.6 mm/month in the dry season and 44.17 mm/month in the wet season. Weather data from Instituto Meteorológico Nacional, weather stations located approximately 5–10 km from the field sites.

Traps were McPhail traps (Chemtica Internacional, P043-trap, Figure 1, left). These traps were used instead of Jackson traps, because they offered more space in which to place the natural oil sachet. Traps were baited with either 2 g trimedlure (Farma Tech International Corp., North Bend, Washington, USA) plugs or a sachet containing a commercially available natural oil (P388; Chemtica Internacional, Heredia, Costa Rica) as previously described (Shelly et al. 2023). Traps contained ~300 mL water with 1 % unscented



**Figure 1:** Medfly trap designs used in (left) Costa Rica (McPhail traps) and (right) Tunisia (Tephriti traps) to capture *Ceratitidis capitata*.

laundry detergent thoroughly dissolved in the water as the killing agent. Plugs were in a basket suspended from inside the top of the trap, while sachets were suspended by a wire from inside the top. Traps were placed in the canopy of orange or tangerine trees between 1.5 and 2.5 m above ground. Traps were 15–20 m apart and were  $\geq 10$  m from any coffee planting border. Coffee plantings were bordered by plantain (*Musa  $\times$  paradisiaca* Linnaeus, Musaceae), orange trees (*C. sinensis* Osbeck, Rutaceae) and living fences of ornamentals (mainly *Duranta erecta* L., Verbenaceae, and *Cordyline* spp., Asparagaceae).

Traps were serviced weekly, i.e., insects were removed, identified and counted, and soapy water was renewed in all traps. Trimedlure plugs were replaced at six-week intervals, and natural oil lures were replaced at 12-week intervals. In Costa Rica, five traps were placed for each treatment at each farm. The small number of replicates used at each farm was due to area restrictions and has proven satisfactory for analogous studies (Mwatawala et al. 2013). Our primary goal was to determine if traps baited with the natural oil lures were more effective than those baited with 2 g trimedlure plugs. Traps were advanced by one position in a line at each servicing to lower positional effects.

## 2.2 Tunisia

In Tunisia traps were placed in orange (*C. sinensis*) or tangerine trees (*C. reticulata*) planted in orchards. Farm 1 site was at 36.577720 °N, 10.639656 °E, at an elevation of 90 m a.s.l. (8 ha). Farm 2 site was at 36.576548 °N, 10.641859 °E, at an elevation of 112 m a.s.l. (7 ha). Trapping was conducted

between September 2021 and September 2022, during which average daily minimum and maximum temperatures were 11 and 30 °C, respectively, and relative humidity between 43 and 58 % in the dry season (June–August) and 67 and 81 % in the wet season (September–May). Rainfall averaged 5 mm/month in the dry season and 31 mm/month in the wet season as recorded at Bouchrik Agricultural Weather Station, approximately 12.9 km from the field sites.

Traps were plastic with a yellow tank, transparent lid and an attachment hook, also known as Tephriti traps (Figure 1, right). The trap contains an insecticidal ring beneath the lid impregnated with the insecticide esfenvalerate, a synthetic pyrethroid that is known for its rapid knockdown and is commonly used in Tunisian citrus. Lures were the same as used in Costa Rica. Plug lures were in baskets and sachet lures were hung from wires attached to the lower sides of the trap lids. Trap placement and replicates per treatment were equivalent to those used in Costa Rica. Traps were advanced by one position in a line at each servicing to lower positional effects. The use of only five replicates per farm was due to the restriction in space and manpower. Traps were serviced every 2 weeks, with 2 g trimedlure plugs replaced every 6 weeks and natural oil lures replaced every 12 weeks.

In addition to the yearlong test described above, an ancillary test was conducted. This test compared traps baited with natural oil lures aged 14 weeks in the field versus traps containing new natural oil lures and traps containing new trimedlure plugs (seven replicates for each treatment). This trial was conducted in Farms 1 and 2 in Tunisia between 5 July 2022 and 30 August 2022. For this trial, traps baited with field aged natural oil lures were added as additional

treatments to seven replicates being evaluated as part of the yearlong trapping program. Traps in these seven replicates were evaluated for medfly capture rates at the same frequency and time as traps in replicates being evaluated as part of the yearlong study. During the evaluation period only trimedlure plugs were changed. In Tunisia, the insecticide malathion (Keythion, 500 cc/ha, Industrial Química Key, Lleida, Spain) was applied against *C. capitata* every ten days from 3 September 2022 until 30 November 2022.

### 2.3 Statistical analyses

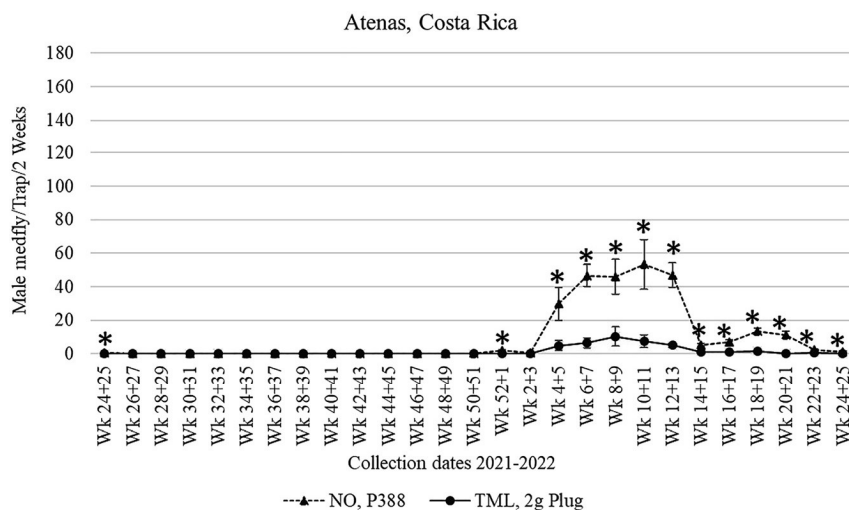
Due to the characteristic natural population dynamics of the pest and the lack of normally distributed data, for the yearlong captures we compared the average of captures of both treatments (trimedlure and the natural oil sachet) through individual Wilcoxon Mann-Whitney tests for each one of the pairs of weeks evaluated at each farm in each country. Also, to determine the ability of each attractant for monitoring at very low male medfly abundance, we calculated the percentage of traps with at least one single male capture per trap during the low season and used this data to determine if there were significant differences through standard two-proportion Z-tests. For both Tunisian and Costa Rican data, we defined the low season as the collection periods in which captures were close to zero, being between weeks 26 of 2021 (28 June 2021) and 50 of 2021 (13 December 2021) for Costa Rican farms and between weeks 52 of 2021 (27 December 2021) and 17 of 2022 (18 April 2022) for Tunisian farms. Finally, in the Tunisian trial of the aged natural oil lures versus fresh natural oil lures and trimedlure, a Kruskal-Wallis Test was performed and differences between treatments were compared with Wilcoxon Mann-Whitney test. All

analyses were performed with InfoStat (version 2014, Universidad de Córdoba, Argentina).

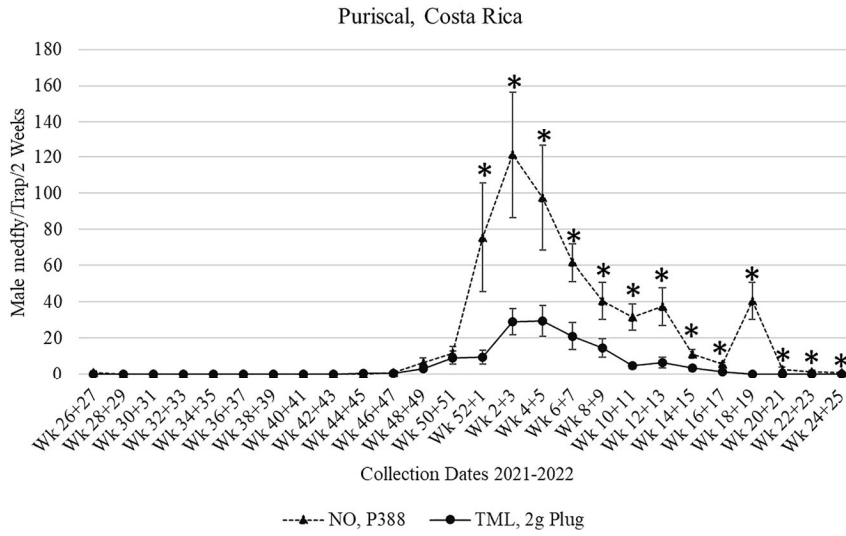
## 3 Results

For all three locations of Costa Rica, medfly populations were highest during the dry season (January–April), and during this period traps baited with the natural oil sachet significantly out-performed traps baited with 2 g trimedlure plugs (Figures 2–4). During the low season there were 340 assessments of individual traps for each lure. Of these, only 20 assessments revealed medfly captures for trimedlure-baited traps compared to 33 assessments positive for natural oil-baited traps. However, proportions of traps that caught >1 male medfly did not differ statistically between lure types (Z-Test of proportions,  $\chi^2 = 2.95$ ,  $P > 0.05$ ).

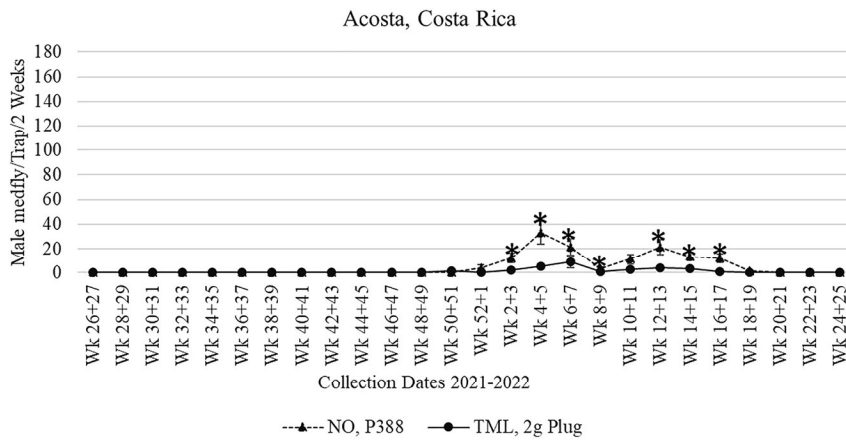
In Tunisia there were two periods during which medfly captures were high. The first peak began between the third week of April to the first week of May and lasted until the third week of July. The second peak occurred from the third week of September to the first week of December. These are both periods of mild temperatures and low rainfall. At Farm 1, the second population peak was greater than the first but at Farm 2 greater numbers of medflies were captured during the first population peak. At Farm 1 during the first period of maximum capture, traps baited with the natural oil sachet captured 2.7 times as many medflies as traps baited with trimedlure. During the second population peak, traps baited with the natural oil sachet captured 6.9 times as many as those baited with trimedlure (Figure 5). At Farm 2 during the first population peak, traps baited with the natural oil sachet captured 2.8 times as many medflies as traps baited with



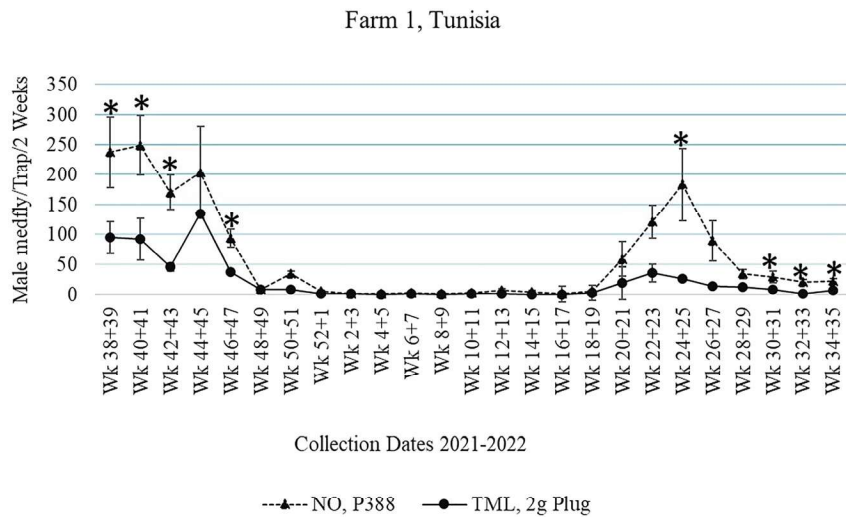
**Figure 2:** Captures of *Ceratitis capitata* in five McPhail traps baited with a natural oil lure (NO, P388) or a 2 g trimedlure plug (TML) in a coffee plantation near Atenas, Costa Rica during June 2021 to June 2022. The error bars show standard error of the mean. Stars indicate significant differences in capture rates (Wilcoxon Mann-Whitney test,  $P < 0.05$ ).



**Figure 3:** Captures of *Ceratitis capitata* in five McPhail traps baited with a natural oil lure (NO, P388) or a 2 g trimedlure plug (TML) in a coffee plantation near Puriscal, Costa Rica during June 2021 to June 2022. The error bars show standard error of the mean. Stars indicate significant differences in capture rates (Wilcoxon Mann-Whitney Test,  $P < 0.05$ ).



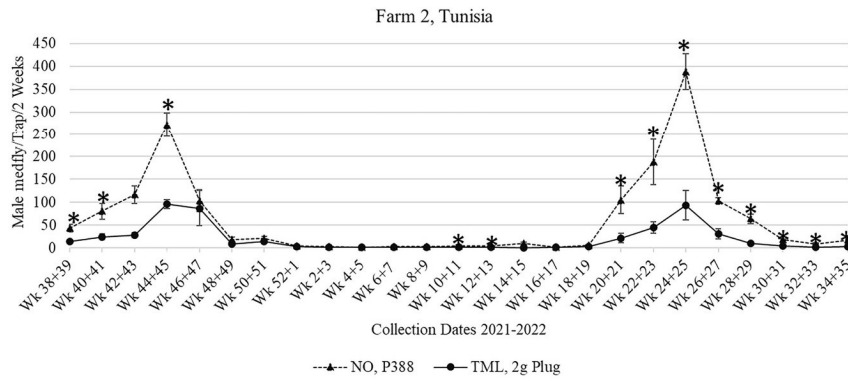
**Figure 4:** Captures of *Ceratitis capitata* in five McPhail traps baited with a natural oil lure (NO, P388) or a 2 g trimedlure plug (TML) in a coffee plantation near Acosta, Costa Rica during June 2021 to June 2022. The error bars show standard error of the mean. Stars indicate significant differences in capture rates (Wilcoxon Mann-Whitney Test,  $P < 0.05$ ).



**Figure 5:** Captures of *Ceratitis capitata* in five Tephriti traps baited with a natural oil lure (NO, P388) or a 2 g trimedlure plug (TML) in a citrus orchard on Farm 1, Tunisia, during September 2021 to September 2022. The error bars show standard error of the mean. Stars indicate significant differences in captures (Wilcoxon Mann-Whitney Test,  $P < 0.05$ ).

trimedlure. During the second population peak, traps baited with the natural oil captured 4.1 times as many medflies as those with trimedlure (Figure 6).

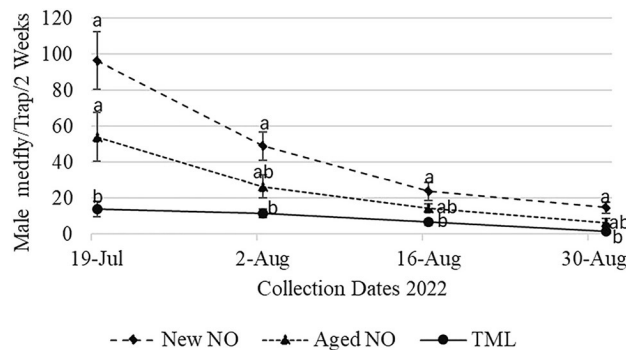
During the Tunisian low season, only 19 out of 50 trap evaluations conducted showed captures in trimedlure baited traps, while for the traps baited with the natural oil



**Figure 6:** Captures of *Ceratitis capitata* in five Tephriti traps baited with a natural oil lure (NO, P388) or a 2 g trimedlure plug (TML) in a citrus orchard on Farm 2, Tunisia, during September 2021 to September 2022. The error bars show standard error of the mean. Stars indicate significant differences in captures (Wilcoxon Mann-Whitney Test,  $P < 0.05$ ).

sachet, at least one single fly was captured in 41 times of 50 evaluations. Based on these values, traps baited with the natural oil sachet had a significantly higher chance of catching at least one medfly in comparison to those baited with trimedlure (Z-Test of proportions,  $\chi^2 = 18.375$ ,  $P < 0.001$ ).

Finally, when it comes to the last experiment conducted in Tunisia, the comparison between fresh trimedlure and the two treatments of the natural oil in sachets showed that both natural oil treatments attracted significantly higher numbers of medflies than trimedlure (Figure 7). Interestingly, for the first two evaluations, when the aged natural oil sachets were 16 and 18 weeks old the captures were as good as the fresh natural oil sachets and both of them presented significantly higher captures than trimedlure plugs. Although numerical differences were observed, at the last two evaluations the aged natural oil lures (ages of 20 and 22 weeks old), showed no significant differences between those lures and trimedlure.



**Figure 7:** Comparison of medfly captures in traps baited with aged natural oil lure (Aged NO) versus new natural oil lure (New NO) and new trimedlure plug (TML) in a citrus orchard on Farms 1 and 2, Tunisia, during 5 July 2022 and 30 August 2022. Aged natural oil lure weathered 14 weeks at 5 July 2022. The error bars show standard error of the mean. Different letters indicate significant differences between treatments at the evaluation dates (Kruskal-Wallis and Wilcoxon Mann-Whitney Test,  $P < 0.05$ ).

## 4 Discussion

The discovery of trimedlure in the 1950s during the screening of several thousand compounds stands as a testament to perseverance (Beroza and Green 1963). Of the three principal male fruit fly attractants (trimedlure, cue-lure, methyl eugenol) used in areawide monitoring programs trimedlure is considered the weakest (for a recent review see Shelly and Cloonan 2024). Although synthetic analogs have been identified that are highly attractive, none are currently within economic reach (Shelly and Cloonan 2024). The most attractive natural attractant is (+)- $\alpha$ -copaene, which is present in Angelica seed oil (Steiner et al. 1957) and can be enriched in ginger root oil to levels that allow  $\alpha$ -copaene enriched ginger root oil to compete in attractancy with trimedlure (Hafsi et al. 2019; Manrakhan et al. 2017; Mwatawala et al. 2013, 2015; Shelly 2013; Shelly and Pahio 2002). Unfortunately,  $\alpha$ -copaene enriched ginger root oil (ERGO) and Angelica seed oil, as well as other minor reported sources of  $\alpha$ -copaene face the same problem of scalability in terms of low content, synthesis complexity and high costs (Lull et al. 2023). In 2020, we initiated a search for new attractants for male *C. capitata*. We recently reported discovery of an  $\alpha$ -copaene enriched natural oil that can be formulated into long lived lures (P388) for medflies (Gonzalez et al. 2022; Shelly et al. 2023).

In the present work we evaluated capture of male *C. capitata* in McPhail or Tephriti traps baited with an  $\alpha$ -copaene enriched natural oil sachet (P388) or a 2 g trimedlure plug. During the approximate yearlong study in three Costa Rican coffee farms, we found that in the season of high population, traps baited with the natural oil lure captured significantly more male medflies than traps baited with 2 g trimedlure plugs (Figures 2–4). In Costa Rica, during the season of low population there was a slight advantage exhibited by traps containing the  $\alpha$ -copaene enriched natural oil lures versus those baited with 2 g trimedlure plugs but no significant differences were evident.

When the Costa Rican trials were repeated on two citrus farms in Tunisia using Tephriti traps (Figures 5 and 6), high season captures were significantly greater in traps baited with the  $\alpha$ -copaene enriched natural oil lure (P388) than in traps baited with 2 g trimedlure plugs. Furthermore, during the low season in Tunisia a significantly higher percentage of traps baited with the natural oil captured at least one single medfly in comparison to traps baited with the trimedlure plug.

The longevity of natural oil lures was examined in an 8-week trial wherein traps baited with natural oil lures aged 14 weeks were placed in Farms 1 and 2 in Tunisia and compared versus fresh natural oil lure sachets and trimedlure. During the entire period of this test, traps baited with the aged  $\alpha$ -copaene enriched natural oil lures captured more male *C. capitata* than traps baited with new trimedlure plugs, being significantly higher during the first two evaluations when the aged lures were 16 and 18 weeks old (Figure 7). Interestingly, at the astonishing age of 20 and 22 weeks, the captures of those aged lures were just as good as the fresh natural oil lure sachets and the trimedlure. This observation is consistent with the performance of Jackson traps baited with  $\alpha$ -copaene enriched natural oil lure (P388) in Hawaii, wherein it was observed that traps baited with  $\alpha$ -copaene enriched natural oil lure (P388) outperformed Jackson traps baited with 2 g of trimedlure on a dental wick renewed weekly, 4 g trimedlure plugs and trimedlure sachets for up to 20 weeks after deployment of the natural oil (Shelly et al. 2023).

In the current studies 2 g trimedlure plugs were replaced at six-week intervals, and the natural oil sachets were replaced at 12-week intervals. As traps baited with the natural oil sachets consistently captured more male medflies than those baited with 2 g trimedlure plugs the attraction and longevity of the natural oil lure is superior to the 2 g trimedlure plug. On a weight and release rate basis the cost of the natural oil is less than trimedlure (Oehlschlager, unpublished).

Although trimedlure-induced skin irritation has been an issue in the past (Beroza et al. 1975), most current plug formulations of trimedlure minimize skin contact. Formulation of the natural oil into a format that avoids contact of the liquid with personnel if the lure is punctured, easily fits into the basket normally used to hold trimedlure in Jackson traps and is more effective than 2 g of trimedlure on a dental wick renewed weekly for at least 12 weeks is a current focus of study. Recently, field trials have yielded positive results for a formulation whose price was presented as being lower than the currently used 4 g trimedlure plug (Gonzalez et al. 2024).

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**Conflict of interest:** F.G., C.C, C.R. and C.O are all employed by ChemTica International S.A., while S.K. declares no conflict of interest.

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**Data availability:** The raw data can be obtained on request from the corresponding author.

## References

- Beroza, M. and Green, N. (1963). *Materials tested as insect attractants*, 239th ed. Agricultural Research Service, United States Department of Agriculture, Washington, DC, USA.
- Beroza, M., Inscocoe, M.N., Schwartz, P.H., Keplinger, M.L., and Mastri, C.W. (1975). Acute toxicity studies with insect attractants. *Toxicol. Appl. Pharmacol.* 31: 421–429.
- Broughton, S. and Rahman, T. (2017). Evaluation of lures and traps for male and female monitoring of Mediterranean fruit fly in pome and stone fruit. *J. Appl. Entomol.* 141: 441–449.
- Flath, R.A., Cunningham, R.T., Mon, T.R., and John, J.O. (1994). Additional male Mediterranean fruitfly (*Ceratitidis capitata* Wied.) attractants from Angelica seed oil (*Angelica archangelica* L.). *J. Chem. Ecol.* 20: 1969–1984.
- Francis, A., Levy, A., Martin, R.M., Mosser, L., Bazelet, C., and Shelly, T. (2023). Relationship between field captures of Mediterranean fruit flies (Diptera: Tephritidae) and the residual amount and release rate of trimedlure from polymeric plugs. *Fla. Entomol.* 106: 97–103.
- Gonzalez, F., Calvo, C., Rodríguez, C., González, L., and Oehlschlager, A.C. (2022). Detección y monitoreo de la mosca del mediterráneo, *Ceratitidis capitata*, con un fitometabolito secundario, como alternativa al uso de trimedlure. In: *Proceedings of the VI International Congress of Biotechnology and Biodiversity*, Marseille, France, 21–23 May 2021.
- Gonzalez, F., Rodríguez, C., Calvo, C., Gonzalez-Puschendorf, E., and Oehlschlager, A.C. (2024). A more potent lure for monitoring *Ceratitidis capitata* than trimedlure. In: *11th Tephritid Workers of the Western Hemisphere Meeting*, Montego Bay, Jamaica, 3–7 June 2024.
- Guiotto, A., Fornasiero, U., and Baccichetti, F. (1972). Investigations on attractants for males of *Ceratitidis capitata*. *Farmaco Sci.* 27: 663–669.
- Hafsi, A., Rahmouni, R., and Chermiti, B. (2019). Detection of *Ceratitidis capitata* Wiedemann (Diptera: Tephritidae) using trimedlure versus enriched ginger oil in citrus orchards. *Int. J. Pest Manag.* 66: 378–384.
- Jacobson, M., Uebel, E.C., Lusby, W.R., and Waters, R.M. (1987). Optical isomers of alpha-copaene derived from several plant sources. *J. Agric. Food Chem.* 35: 798–800.

- Kean, J.M., Manoukis, N.C., and Dominiak, B.C. (2024). Review of surveillance systems for tephritid fruit fly threats in Australia, New Zealand, and the United States. *J. Econ. Entomol.* 117: 8–23.
- Khrimian, A., Jang, E.B., and Casaña-Giner, V. (2002). A practical synthesis of ceralure B1, a potent attractant for the Mediterranean fruit fly. In: *Proceedings of the 6th International Fruit Fly Symposium*, Stellenbosch, South Africa, pp. 279–282, 6–10 May 2002.
- Lull, C., Gil-Ortiz, R., and Cantín, Á. (2023). A chemical approach to obtaining  $\alpha$ -copaene from clove oil and its application in the control of the medfly. *Appl. Sci.* 13: 5622.
- Manrakhan, A., Daneel, J.H., Beck, R., Virgilio, M., Meganck, K., and De Meyer, M. (2017). Efficacy of trapping systems for monitoring of Afrotropical fruit flies. *J. Appl. Entomol.* 141: 825–840.
- McGovern, P.T. and Cunningham, R.T. (1988). Attractant for the Mediterranean fruit fly, the method of preparation and method of use, United States Patent 6,375,943.
- Mwatawala, M., Virgilio, M., Joseph, J., and de Meyer, M. (2015). Niche partitioning among two *Ceratitis rosa* morphotypes and other *Ceratitis* pest species (Diptera, Tephritidae) along an altitudinal transect in Central Tanzania. *ZooKeys* 540: 429–442.
- Mwatawala, M., Virgilio, M., Quilici, S., Dominic, M., and De Meyer, M. (2013). Field evaluation of the relative attractiveness of enriched ginger root oil (EGO)lure and trimedlure for African *Ceratitis* species (Diptera: Tephritidae). *J. Appl. Entomol.* 137: 392–397.
- Niogret, J., Gill, M.A., Espinoza, H.R., Kendra, P.E., and Epsky, N.D. (2017). Attraction and electroantennogram responses of male Mediterranean fruit fly (Diptera: Tephritidae) to six essential oils. *J. Entomol. Zool. Stud.* 5: 958–964.
- Shelly, T. (2013). Detection of male Mediterranean fruit flies (Diptera: Tephritidae): performance of trimedlure relative to Capilure and enriched ginger root oil. *Proc. Hawaii. Entomol. Soc.* 45: 1–7.
- Shelly, T.E. and Cloonan, K.R. (2024). Male lures and the detection of tephritid fruit flies: assessing the relationships between lure amount and release rate and trap captures of invasive pest species. *Crop Prot.* 176: 106504.
- Shelly, T. and Pahio, E. (2002). Relative attractiveness of enriched ginger root oil and trimedlure to male Mediterranean fruit flies (Diptera: Tephritidae). *Fla. Entomol.* 85: 545–551.
- Shelly, T., Oehlschlager, C., and Kurashima, R. (2023). Natural oil lure outperforms trimedlure in capturing males of the Mediterranean fruit fly, *Ceratitis capitata* (Diptera: Tephritidae). *Neotrop. Entomol.* 52: 1138–1143.
- Steiner, L.F., Miyashita, D.H., and Christenson, L.D. (1957). Angelica oils as Mediterranean fruit fly lures. *J. Econ. Entomol.* 50: 505.
- Tan, K.H., Nishida, R., Jang, E.B., and Shelly, T.E. (2014). Pheromones, male lures, and trapping of tephritid fruit flies. In: *Trapping and the detection, control, and regulation of tephritid fruit flies*. Springer, Netherlands, pp. 15–74.
- USDA APHIS (United States Department of Agriculture, Animal and Plant Inspection Service) (2022). Trimedlure dispenser, <https://www.developmentaid.org/tenders/view/962516/trimedlure-dispenser> (Accessed 4 September 2024).
- USDA APHIS (United States Department of Agriculture, Animal and Plant Inspection Service) (2024). Fruit fly exclusion and detection program strategy fiscal years 2024–2028, [https://www.aphis.usda.gov/plant\\_health/plant\\_pest\\_info/fruit\\_flies/downloads/feed-strategy-plan.pdf](https://www.aphis.usda.gov/plant_health/plant_pest_info/fruit_flies/downloads/feed-strategy-plan.pdf) (Accessed 4 September 2024).