**Evaluating monitoring systems for economically important fruit fly species on mango in South Africa**

**E. Kleynhans1, T. Grové2 & P.J.G. Booysen3**

1South African Subtropical Growers’ Association, Tzaneen, South Africa; 2Agricultural Research Council, Institute for Tropical and Subtropical Crops, Nelspruit, South Africa; 3Insect Science (Pty) Ltd. Tzaneen, South Africa.

**Keywords**

Fruit fly lure, *Bactrocera dorsalis*, monitoring systems, tropical fruit

**Correspondence**

E. Kleynhans (corresponding author), 1A Prosperitas Building, 27 Peace street, Tzaneen 0920, South Africa. E-mail: elsje@subtrop.co.za

**Abstract**

Understanding fruit fly species’ responses to lures are critically important, especially when a single lure is recommended for the purpose of trapping multiple fruit fly species in commercial fruit orchards. To date, few studies have tested the relative trapping efficiency of different lures and many commercial fruit growers assume that a general lure would attract multiple species. In addition, South African fruit industries are facing threats from the recent invasion of the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) (initially described as *Bactrocera invadens* Drew, Tsuruta and White and now synonymised with *B. dorsalis*)into novel areas in South Africa. Here, using a multi lure comparison approach we test the relative efficiency of thirteen different trapping systems for various fruit fly species, including *B. dorsalis* in mango orchards in South Africa. This is the first time such a lure comparison has been done, quantifying the number of non-target organisms trapped and including *B. dorsalis.* Pronounced variation in species attractiveness across the trapping systems was found. The enhanced ginger oil (EGO) PherolureTM captured 33.77% of all the *Ceratitis* spp. (Diptera: Tephritidae). Invader-LureTM captured 36.47% of the total number of *B. dorsalis* trapped. These results are important and significant for on-farm monitoring strategies as well as for invasion monitoring systems currently in place to detect the distribution of *B. dorsalis* in South Africa.

**Introduction**

In Africa there are approximately 1000 known fruit fly species (Diptera: Tephritidae) which belong to 150 genera (De Meyer et al. 2014) of which 50 species are of economic importance. Most fruit fly species that oviposit their eggs in commercially grown fruit crops in Africa belong to one of two genera, namely *Ceratitis* and *Dacus* (White and Goodger 2009). A few species belong to other genera such as *Trirhithrum* which are close relatives of *Ceratitis*, or to the genus *Bactrocera*, which are close relatives of the *Dacus* genus. Fruit quality is compromised when the female fruit fly oviposit eggs into the fruit and the larvae feed on the fruit flesh. Fruit fly presence furthermore leads to indirect losses due to quarantine restrictions and the loss of market opportunities. *Ceratitis* and *Bactrocera* species are responsible for vast amounts of mango fruit losses in Africa (Lux et al. 2003a, 2003b; Rwomushana et al. 2008, Ekesi et al. 2006, Grové et al. 2009, Vayssières et al. 2009, Ambele 2012).

In South Africa three *Ceratitis* species pose a significant threat to the fruit industries: the Marula fruit fly, *Ceratitis* (*Ceratalaspis*) *cosyra* (Walker) (Diptera: Tephritidae), which is especially significant in terms of mango production and is usually the most abundant species in mango orchards; the Natal fruit fly, *Ceratitis* (*Pterandrus*) *rosa* Karsch (Diptera: Tephritidae), and the Mediterranean fruit fly, *Ceratitis* (*Ceratitis*) *capitata* (Wiedemann) (Diptera: Tephritidae) (Annecke and Moran 1982; Grové 2001). The oriental fruit fly, *Bactrocera dorsalis* (Hendel) was detected in Africa for the first time in Kenya in 2003 and initially described as *Bactrocera invadens* Drew, Tsuruta and White and now synonymised with *B. dorsalis* (Lux et al. 2003a; Schutze et al. 2014). Since the arrival of *B. dorsalis* in Africa it has rapidly spread throughout the African continent into many newly-invaded fruit-producing countries (Ekesi et al. 2009, Mwatawala et al. 2009). *Bactrocera dorsalis* was detected in South Africa for the first time seven years later, in 2010 (Manrakhan et al. 2011). It was declared present in Vhembe district in northern parts of the country during 2013. It has since spread rapidly throughout the northern part of the country where mango is cultivated commercially.

The first step for the successful management of fruit flies in fruit orchards is to have an effective monitoring system. Monitoring is important to: (1) identify species present in the orchard to establish whether there is in fact a pest problem, (2) determine seasonal changes in population levels, (3) give an indication of the numbers present and the severity of pest, (4) determine the time for control actions to be initiated and (5) determine the efficacy of control measures. Not only must the *Ceratitis* species be monitored throughout the fruiting season, but, the presence (surveillance purposes) and abundance of B. dorsalis must also be determined throughout South Africa.

Two main types of attractants can be used in the monitoring of fruit fly species i.e. male lures and food baits. Male lures are mostly parapheromones that are highly species-specific and they are effective in attracting fruit flies from long distances (Cunningham 1989; White and Elson Harris 1992). Methyl eugenol (ME) is a male attractant used for monitoring male *Bactrocera* species and is used in South Africa for the surveillance of *B. dorsalis* (White 2006, Manrakhan et al. 2012). Methyl eugenol can be chemically described as 4-allyl-1,2-dimethoxybenzene (White 2006). Studies on *B. dorsalis* have demonstrated that ingestion of methyl eugenol increases male mating success (Shelly and Dewire 1994). Methyl eugenol is also a naturally occurring compound reported from different plant families (Tan and Nishida 1996). Second, enriched ginger oil (EGO) is a source of alpha-coapane and is known to be an attracted for *Ceratitis* species (Shelly and Pahio 2002; Grové et al. 2009, Mwatawala et al. 2013). It also has a male enhancing component because exposure to its aroma increases the mating success of males (Shelly 2001; Shelly et al. 2004, Quilici et al. 2011). *Ceratitis cosyra* was especially strongly attracted to enriched ginger oil in a study conducted in mango orchards in South Africa (Grové et al. 2009). Mwatawala et al. (2013) found an unexpected response of a low number of *B. dorsalis* (spesified as *B. invadens*) to enriched ginger oil and mentioned that it need further investigation.

Attraction of both sexes of the invader fruit fly to 3 - Component Lure, a food bait that consists of ammoniumacetate, trimethylamine hydrochloride and putrescine, had also been reported and is also used in the surveillance of *B. dorsalis* in South Africa (Manrakhan et al. 2012). Both males and females of *C. capitata*, *C. cosyra* and *C. rosa* respond to 3 - Component Lure (Grové et al. 2009). The second food bait, Torula yeast, is an autolysed yeast protein and attracts males and females of different fruit fly species (Leblanc et al. 2010).

The presence of the *B. dorsalis* in fruit production areas of South Africa has serious implications for the fruit industries of South Africa. It is therefore important to develop an effective management strategy for fruit flies in this country. The purpose of this study was to evaluate the efficacy of different lures and traps (trapping systems) for monitoring the complex of fruit flies associated with mango production in South Africa. The aim was to identify the best monitoring system to detect *Ceratitis* species and *B. dorsalis* fruit flypresence in a commercial mango orchards in South Africa. The attraction of non-target species to the different lures was also measured and compared across the trapping systems.

**Materials and methods**

Evaluation of the different monitoring systems was conducted in mango orchards in Vhembe district in the Limpopo Province of South Africa. Evaluation was done in four mango orchards of the cultivar ‘Tommy Atkins’ (site coordinates: 23°06’32”S, 30°16’33”E). The orchards were 10 - 12 years old and under dry land cultivation. No pesticides were used in these orchards during the trial. Thirteen different monitoring systems were evaluated and compared. A brief description of each lure and the trap used in the system is given in Table 1. Three different types of traps were used (Table 1). The McPhail trap consisted of three parts i.e. a yellow bottom section, shaped as an inverted funnel, a transparent top and a plastic water ring. The transparent top houses a plastic basket for lures. The height of the trap is 190 mm and the width 175 mm. The Chempac yellow bucket trap consisted of a yellow bucket with a transparent lid. Apart from the funnel on the base of the bucket, it has three side holes through which some transparent cylindrical tubes are introduced towards the inside. The height of the trap is 160 mm and the width is 135 mm. The Lynfield trap used consisted of yellow bucket and lid. The bucket had with four holes at the side and 12 small holes in the bottom of the trap. The height of the trap is 120 mm and the width 130 mm. To evaluate the efficacy of the monitoring systems, traps were placed 1.5m above the ground on the southern side of a mango tree in four mango orchards in a randomized block design. Trapping systems (≥ 30 m apart) were randomized weekly for six consecutive weeks (November – December 2013). All the lures and dichlorvos containing tablets were replaced after completion and the trial continued for another six weeks with fresh lures (January – February 2014), randomising the traps weekly as before. The size of the wild populations of each species of fruit fly was unknown when the lures were compared. The fruit flies and non-target by-catch counts were taken weekly upon randomization of each trap. Each treatment was replicated four times to result in a total of N = 48 observations per trapping system. *Ceratitis* spp. and *B. dorsalis* were identified and the sex of each was recorded. No-target insects were identified to order level and spiders to class level.

Weekly randomization accounted for the effect of system location in the orchard, population density effects as well as immigration paths in, around or into each orchard. The data (average weekly trap catches) for the final 6-week trial were analysed using generalized linear models in R (v. 3.1.0, R Development Core Team [2008]). The assumption of homoscedasticity were tested for every statistical test to make sure the model were valid and the variance of the data means were equal (residual deviance < degrees of freedom for the model). The mean model estimates were plotted and no overlap in 95% confidence intervals of the mean weekly trap catch data defined statistically heterogeneous treatment groups.

**Results**

Fruit fly species captured in the study were *C. capitata*, *C. cosyra*, *C. rosa*, the five-spotted fruit fly, *Ceratitis quinaria* (Bezzi), *B. dorsalis* and *Perilampsis* spp. (Figure 1). The total number of fruit fly species captured with the percentage of the total number per species is given in Table 2. The most abundant species captured were *C. cosyra* followed by *C. rosa* and *C. capitata*. Low numbers of *C. quinaria* were present. A small number of fruit flies of the genus *Perilampsis* Bezzi were found in traps. *Perilampsis* is a small Afrotropical genus, not considered of economic importance, with hosts in the Loranthaceae family (De Meyer 2009). The highest percentage of *C. cosyra*, *C. capitata* and *C. rosa* responded to EGO Pherolure which had the highest concentration of alpha-copaene. EGO Pherolure captured 30.77% of the total number of fruit flies captured in the study. *Ceratitis quinaria* responded to enriched ginger oil-containing products but one specimen was captured in a trap with methyl eugenol. The highest percentage of *B. dorsalis* responded to Invader-Lure (36.47%, Table 2). A small percentage (< 3%) of *B. dorsalis* responded respectively to the EGO Pherolure (New device) and EGO Pherolure + Permethrin (New device). *Ceratitis capitata*, *C. cosyra* and *C. rosa* were more responsive to lures containing enriched ginger oil opposed to the combination with methyl eugenol. The addition of permethrin to EGO Pherolure (New device) seemed to have a negative effect on the response of *C. capitata*, *C. cosyra* and *C. rosa*. The addition of permethrin to ME Pherolure + EGO Pherolure (New device) did not seem to have an effect on the response of *C. capitata*, *C. cosyra*, *C. rosa* or the invader fruit fly. The addition of permethrin to ME Pherolure (New device) had a negative effect on the response of *B. dorsalis*. Trap catch data for males and females are given in Tables 3 and 4 respectively and showed in Figure 2. The food baits i.e. Biolure Fruit Fly, 3 - Component Lure and Torula Yeast Pellets typically captured the highest percentage of female fruit flies. The highest percentage of *B. dorsalis* females was captured with the Torula Yeast Pellets, while Biolure Fruit Fly captured the highest percentage female *C. capitata*, *C. rosa* and *C. cosyra* (Figure 2). Biolure Fruit Fly captured 73.91% of the total number of female flies (Table 4). Figure 3 shows the results for the standard deviation of the average weekly *B. dorsalis* trap catches (calculated over six weeks) with the average number of *B. dorsalis* caught per trap per week corrected for the loading rate of the methyl eugenol. The results showed that the new device containing ME + EGO + Permethrin performed best in terms of the corrected average value (Figure 3).

There was a significant effect of trapping system on non-target catches (χ2 = 236.09, df = 12, *P* < 0.001). The number of non-target insects and Arachnida captured with the different monitoring systems over the total experimental period are given (see Table 5). Of all the non-target species, Diptera was especially attracted to the different monitoring systems. The three food baits attracted the highest number of non-target species and Torula Yeast Pellets attracted 34.86% of total non-target species captured. Invader-Lure attracted the lowest number of non-target species followed by ME Pherolure + EGO Pherolure (New device).

Table 6 gives a summary of the non-parametric statistics for the effects of monitoring system and species on the count data outcomes for calendar weeks 5-7. There were significant differences for male fruit flies in the parameters monitoring system and species. Figure 2 gives the mean fruit fly catches per species per week for thirteen monitoring systems during calendar weeks 5-7 and the significant differences between treatments for fruit fly males.

**Discussion**

Fruit fly numbers were low during the first six weeks of monitoring and started to increase in the second six weeks of monitoring (calendar weeks 1-7, Figure 1). There was especially a rapid increase during calendar week 4 of 2014, and this rapid increase can be ascribed to fruit maturity and the lack of orchard sanitation (Figure 1). The invasive species, *B. dorsalis* was present and it is evident this species is becoming more prominent in mango orchards in South Africa and pose a great threat for the mango production. The highest number of *B. dorsalis* males was present in Invader-Lure followed by Chempac ME Lure and then ME Pherolure. The high capture rates with the Invader-Lure system were probably due to the much higher concentration of methyl eugenol in this system (15g *vs*. 1-4g in the other methyl eugenol-containing systems). This monitoring system also attracted the least non-target species. ME Pherolure + EGO Pherolure (New device), ME Pherolure + EGO Pherolure + Permethrin (New device), ME Pherolure (New device) and ME Pherolure + Permethrin (New device) were lesser effective in capturing *B. dorsalis* males. Although EGO Pherolure did not capture any *B. dorsalis*, EGO Pherolure (New device) and EGO Pherolure + Permethrin (New device) captured 9 and 8 *B. dorsalis* males respectively. Mwatawala et al. 2013 also reported a low response to enrich ginger oil-containing products.

EGO Pherolure was very effective in attracting males of *C. capitata*, *C. cosyra* and *C. rosa*. Only one *C. cosyra* female was captured in EGO Pherolure indicating that it is a male lure. *Ceratitis quinaria* was also trapped in enrich ginger oil-containing products. EGO Pherolure (New device) and EGO Pherolure + Permethrin (New device) were lesser effective in attraction of the *Ceratitis* spp. compared to EGO Pherolure which is probably due to a lower concentration of alpha-copaene. ME Pherolure + EGO Pherolure (New device) and ME Pherolure + EGO Pherolure + Permethrin (New device) were not as effective as EGO Pherolure (New device) and EGO Pherolure + Permethrin (New device) in attracting *Ceratitis* spp. The results showed that, however some trapping systems performed well, there was not a single trapping system adequate for trapping *Ceratitis* spp. and *B. dorsalis* together.

With regards to the food baits, Biolure Fruit Fly attracted the highest number of *Ceratitis* species and *B. dorsalis*. Torula Yeast Pellets attracted the highest number of *B. dorsalis* females and of non-target species. The attraction of non-target species, especially Diptera to Torula Yeast and Biolure Fruit Fly was also demonstrated by LeBlanc et al. (2010). *B. dorsalis* females were trapped in 3 - Component Lure, Biolure Fruit Fly and Torula Yeast Pellets but only 9 females were captured in total. This study also clearly indicates that male lures are much more effective in attracting fruit fly species in comparison with food baits. Food baits attracted the highest number of female fruit flies. Food baits also attracted much higher numbers of non-target species.

**References**

Ambele FC, Billah MK, Afreh–Nuamah K, Obeng–Ofori D, 2012. Susceptibility of four mango varieties to the Africa Invader fly, *Bactrocera invadens* Drew, Tsuruta and White (Diptera: Tephritidae) in Ghana. J. Appl. Biosciences 49, 3425–3434.

Annecke DP, VC Moran, 1982. Insects and Mites of Cultivated Plants in South Africa. Butterworths, Durban.

Cunningham RT, 1989. Parapheromones, pp. 221–230 (Vol. 3A). In Robinson AS, Hooper G (eds.), Fruit Flies, Their Biology, Natural Enemies and Control (Vol. 3A). Elsevier, Amsterdam.

De Meyer M, 2009. Taxonomic revision of the fruit fly genus *Perilampsis* Bezzi (Diptera: Tephritidae). J. Nat. Hist. 43, 2425–2463.

De Meyer M, Mohamed S, White IM. 2014. Invasive Fruit Fly Pests in Africa. A diagnostic tool and information reference for the four Asian species of fruit fly (Diptera: Tephritidae) that have become accidentally established as pests in Africa, including the Indian Ocean Islands.

http,//www.africamuseum.be/fruitfly/AfroAsia.htm.

Ekesi S, Nderitu PW, Rwomushana I, 2006. Field infestation, life history and demographic parameters of the fruit fly *Bactrocera invadens* (Diptera: Tephritidae) in Africa. Bull. Ent. Res. 96, 379–386.

Grové T, 2001. Tephritidae, pp. 293–304. In M.A. Van Den Berg, E.A. De Villiers and P.H. Joubert. (eds.), Pests and Beneficial Arthropods of Tropical and Subtropical Crops in South Africa. Dynamic Ad, Nelspruit, South Africa.

Grové T, De Beer MS, Joubert PH, 2009. Monitoring fruit flies in mango orchards in South Africa and determining the time of fruit infestation. Acta Hortic. 820, 589–596.

Hill MP, Terblanche JS, 2014. Niche Overlap of Congeneric Invaders Supports a Single–Species Hypothesis and Provides Insight into Future Invasion Risk, Implications for Global Management of the *Bactrocera dorsalis* Complex. PLoS ONE 9(2), e90121. doi,10.1371/journal.pone.0090121.

Leblanc L, Vargas RI, Rubinoff D, 2010. Captures of Pest Fruit Flies (Diptera: Tephritidae) and Nontarget Insects in BioLure and Torula Yeast Traps in Hawaii. Environ. Entomol. 39, 1626–1630.

Lux SA, Copeland RS, White IM, Manrakhan A, Billah MK, 2003a. A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in East Africa. Insect Sci. Appl. 23, 355–360.

Lux SA, Ekesi S, Dimbi S, Mohamed S, Billah M, 2003b. Mango–infesting fruit flies in Africa, perspectives and limitations of biological approaches to their management, pp. 277–293. In Neuenschwander P, Borgemeister C, Langewald J (eds.), Biological control in IPM systems in Africa. Centre Agriculture Bioscience International, Wallingford, United Kingdom.

Manrakhan A, Venter J–H, Hattingh V, 2012. Action plan for the control of the African Invader fruit fly, *Bactrocera invadens* Drew Tsuruta and White. Department of Agriculture, Forestry and Fisheries, Republic of South Africa, Pretoria.

Manrakhan A, Hattingh V, Venter J–H, Holtzhauzen M, 2011. Eradication of *Bactrocera invadens* (Diptera: Tephritidae) in Limpopo Province, South Africa. Afr. Entomol. 19, 650–659.

Mwatawala MW, De Meyer M, Makundi RH, Maerere AP, 2009. An overview of *Bactrocera* (Diptera: Tephritidae) invasions and their speculated dominancy over native fruit fly species in Tanzania. J. Entomol. 6, 18–27.

Mwatawala M, Virgilio M, Quilici S, Dominic M, 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.

Quilici S, Schmitt C, Vidal J, Franck A, Deguine JP, 2011. Adult diet and exposure to semiochemicals influence male mating success in *Ceratitis rosa* (Diptera: Tephritidae). J. Appl. Entomol. 137, 142–153.

R Development Core Team 2008. R, A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Rwomushana I, Ekesi S, Gordon I, Ogol CKPO, 2008. Host plants and host plant preference studies for *Bactrocera invadens* (Diptera: Tephritidae) in Kenya, a new invasive fruit fly species in Africa. Ann. Entomol. Soc. Am. 101, 331–340.

Schutze MK, Mahmood K, Pavasovic A, Bo W, Newman J, Clarke AR, Krosch MN, Cameron SL, 2014. One and the same: integrative taxonomic evidence that *Bactrocera invadens* (Diptera: Tephritidae) is the same species as the Oriental fruit fly *Bactrocera dorsalis*. Systematic Entomology. doi 10.1111/syen.12114.

Shelly TE, 2001. Exposure to alpha–copaene and alphacopaene containing oils enhances mating success of male Mediterranean fruit flies (Diptera: Tephritidae). Ann. Entomol. Soc. Am. 94, 497–502.

Shelly TE, Dewire ALM, 1994. Chemically mediated mating success in male Oriental fruit flies (Diptera: Tephritidae). Ann. Entomol. Soc. Am. 87, 375–382.

Shelly, TE, Pahio E, 2002. Relative attractiveness of enriched ginger root oil and trimedlure tomale Mediterranean fruit flies (Diptera: Tephritidae). Fla. Entomol. 85, 545–551.

Shelly TE, McInnis DO, Pahio E, Edu J, 2004. Aromatherapy in the Mediterranean fruit fly (Diptera: Tephritidae), sterile males exposed to ginger root oil in pre–release, storage boxes display increased mating competitiveness in field–cage trials. J. Econ. Entomol. 97, 846–853.

Tan KH, Nishida R, 1996. Sex pheromone and mating competition after methyl eugenol consumption in the *Bactrocera dorsalis* complex, pp. 147–153 In McPheron BA, Steck GJ (eds.), Fruit Fly Pests, A World Assessment of Their Biology and Management. St. Lucie Press, Delray Beach, FL.

Tan K, Tokushima HI, Ono H, Nishida R, 2011. Comparison of phenylpropanoid volatiles in male rectal pheromone gland after methyl eugenol consumption, and molecular phylogenetic relationship of four global pest fruit fly species, *Bactrocera invadens, B. dorsalis, B. correcta* and *B. zonata*. Chemoecology 21, 25–33.

Vayssières JF, Korie S, Ayegnon D, 2009. Correlation of fruit fly (Diptera Tephritidae) infestation of major mango cultivars in Borgou (Benin) with abiotic and biotic factors and assessment of damage. Crop Prot. 28, 477–488.

White IM, Elson–Harris MM, 1992. Fruit flies of economic significance; their identification and bionomics. CAB International, Wallingford, UK.

White IM, 2006. Taxonomy of the *Dacina* (Diptera: Tephritidae) of African and the Middle East. African Entomology Memoir 2, 1–156.

White IM, Goodger KFM, 2009. African *Dacus* (Diptera: Tephritidae); new species and data, with particular reference to the Tel Aviv University collection. Zootaxa, 2127, 1–49.

**Figures**

**Fig. 1**



**Fig. 1** Weekly fruit fly catch results (number of fruit flies per week) across all thirteen monitoring systems, shown for the duration of 12 weeks.

**Fig. 2**

****

**Fig. 2** Fly catches (mean ± 95% confidence intervals) per species per week for thirteen monitoring systems during calendar weeks 5-7, 2014 across four mango orchards. Significant differences between treatments can be distinguished by no overlap in confidence intervals.

**Fig. 3**



Fig. 3 The average number of *Bactrocera dorsalis* caught per trap per week and the standard deviation of the trap catches over the final six weeks of trapping. The number of flies trapped per week per milligram methyl eugenol is given next to the graph for every trapping system.

**Tables**

**Table 1** Description of the lures, traps and killing agents used in the thirteen trapping systems evaluated.

| Abbreviations | Lure description | Trap | Killing agent  |
| --- | --- | --- | --- |
| 1. 3CL | 3 - Component Lure(Insect Science (Pty) Ltd)Consists of three components i.e. ammonium acetate @ 5 g, trimethylamine hydrochlorid @ 1 g and 1,4-diaminobutane (putrescine) @ 50 mg | McPhail Trap(Insect Science (Pty) Ltd) | Dichlorvos tablet 6 g (Acorn Products (Pty) Ltd) Contains 1.17 g dichlorvos |
| 2. BFF | Biolure® Fruit Fly (Suterra LLC, Bend, USA and distributed in South Africa by Chempac (Pty) Ltd)Consists of three components i.e. ammonium acetate @ 211 g/kg, trimethylamine hydrochlorid @ 91 g/kg and 1,4-diaminobutane (putrescine) @ 3 g/kg  | Chempac bucket trap(Chempac (Pty) Ltd) | Dichlorvos tablet 6 g(Acorn Products (Pty) Ltd) Contains 1.17 g dichlorvos |
| 3. C ME | Chempac ME Lure(Chempac (Pty) Ltd, Suider Paarl, South Africa) Contains methyl eugenol @ 4 g/lure | Chempac bucket trap(Chempac (Pty) Ltd) | Dichlorvos tablet 6g (Acorn Products (Pty) Ltd)Contains 1.17 g dichlorvos |
| 4. EGO | Enriched Ginger Oil (EGO) Pherolure™ (Insect Science (Pty) Ltd, Tzaneen, South Africa)Contains alpha-copaene @ 2 g/lure | McPhail Trap(Insect Science (Pty) Ltd) | Dichlorvos tablet 6 g (Acorn Products (Pty) Ltd, Strubens Valley, South Africa)Contains 1.17 g dichlorvos |
| 5. EGO ND | EGO Pherolure™ (New device)(Insect Science (Pty) Ltd)Contains alpha-copaene @ 0.5 g/lure  | McPhail Trap(Insect Science (Pty) Ltd) | Dichlorvos tablet 6g(Acorn Products (Pty) Ltd)Contains 1.17 g dichlorvos |
| 6. EGO P ND | EGO Pherolure™ + Permethrin (New device)(Insect Science (Pty) Ltd)Contains alpha-copaene @ 0.5 g/lure | McPhail Trap(Insect Science (Pty) Ltd) | Permethrin @ 0.03 g/lure |
| 7. IL | Invader-Lure(River BioScience (Pty) Ltd, Addo, South Africa)Contains methyl eugenol @ 15 g/block | Lynfield trap(River BioScience (Pty) Ltd) | Dichlorvos tablet 6 g(Acorn Products (Pty) Ltd)Contains 1.17 g dichlorvos |
| 8. ME  | ME Pherolure™(Insect Science (Pty) Ltd) Contains methyl eugenol @ 2 g/lure | McPhail Trap(Insect Science (Pty) Ltd) | Dichlorvos tablet 6g(Acorn Products (Pty) Ltd)Contains 1.17 g dichlorvos |
| 9. ME EGO ND | ME + EGO Pherolure™ (New device)(Insect Science (Pty) Ltd)Contains methyl eugenol @ 0.5 g and alpha-copaene @ 0.5g/lure | McPhail Trap(Insect Science (Pty) Ltd) | Dichlorvos tablet 6g (Acorn Products (Pty) Ltd) Contains 1.17 g dichlorvos |
| 10. ME EGO P ND | ME + EGO Pherolure™ + Permethrin (New device) (Insect Science (Pty) Ltd)Contains methyl eugenol @ 0.5 g and alpha-copaene @ 0.5g/lure  | McPhail Trap(Insect Science (Pty) Ltd) | Permethrin @ 0.06g/lure |
| 11. ME ND | ME Pherolure™ (New device)(Insect Science (Pty) Ltd)Contains methyl eugenol @ 1 g/lure | McPhail Trap(Insect Science (Pty) Ltd)  | Dichlorvos tablet 6 g (Acorn Products (Pty) Ltd)Contains 1.17 g dichlorvos |
| 12. ME P ND. | ME Pherolure™ + Permethrin (New device)(Insect Science (Pty) Ltd)Contains methyl eugenol @ 1 g/lure | McPhail Trap(Insect Science (Pty) Ltd) | Permethrin@ 0.06 g/lure |
| 13. TYP | Torula Yeast Pellets (ISCA Technologies, Inc., California, USA)One pellet was dissolved in 500 ml water | Chempac bucket trap(Chempac (Pty) Ltd) | None, insects drown in the water mixture |

**Table 2** Fruit fly catches in the study expressed as a total number captured over a period of 12 weeks where all the traps were re-baited after 6 weeks. The percentage of the total catch data for the respective species is given in brackets.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | *C. capitata* | *C. cosyra* | *C. rosa* | *C. quinaria* | *B. dorsalis* | *Perilampsis spp.* | TOTAL |
| 3CL | 3 (0.53%) | 5 (0.58%) | 15 (2.41%) |  | 3 (0.72%) |  | 26 (1.05%) |
| BFF | 27 (4.74%) | 27 (3.13%) | 119 (19.13%) |  | 8 (1.93%) |  | 181 (7.28%) |
| C ME |  |  |  |  | 98 (23.67%) | 1 (10.00%) | 99 (3.98%) |
| EGO | 197 (34.56%) | 350 (40.67%) | 216 (34.73%) | 2 (25.00%) |  |  | 765 (30.77%) |
| EGO ND | 148 (25.96%) | 211 (24.48%) | 96 (15.43%) | 1 (12.50%) | 9 (2.17%) |  | 465 (18.70%) |
| P ND | 100 (17.54%) | 101 (11.02%) | 72 (11.58%) | 2 (25.00%) | 8 (1.93%) |  | 283 (11.38%) |
| IL |  |  |  |  | 151 (36.47%) | 8 (80.00%) | 159 (6.40%) |
| ME |  |  |  |  | 51 (12.32%) |  | 51 (2.05%) |
| ME EGO ND | 48 (8.42%) | 67 (7.77%) | 39 (6.27%) | 2 (25.00%) | 24 (5.80%) | 1 (10.00%) | 181 (7.28%) |
| ME EGO P ND | 46 (8.07%) | 95 (11.02%) | 47 (7.56%) |  | 22 (5.31%) |  | 210 (8.45%) |
| ME ND |  |  |  | 1 (12.50%) | 22 (5.31%) |  | 23 (0.93%) |
| ME P ND |  | 2 (0.23%) | 1 (0.16%) |  | 12 (2.90%) |  | 15 (0.60%) |
| TYP | 1 (0.18%) | 4 (0.46%) | 17 (2.73%) |  | 6 (1.45%) |  | 28 (1.13%) |
| TOTAL | **570 (100%)** | **862 (100%)** | **622 (100%)** | **8 (100%)** | **414 (100%)** | **10 (100%)** | **2486 (100%)** |

**Table 3** Male fruit fly catches in the study expressed as a total number captured over a period of 12 weeks where all the traps were re-baited after 6 weeks. The percentage of the total catch data for the respective species is given in brackets.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | *C. capitata* | *C. cosyra* | *C. rosa* | *C. quinaria* | *B. dorsalis* | *Perilampsis spp.* | TOTAL |
| 3CL |  | 3 (0.36%) | 6 (1.15%) |  | 2 (0.49%) |  | 11 (0.47%) |
| BFF | 11 (2.00%) | 5 (0.60%) | 41 (7.87%) |  | 5 (1.23%) |  | 62 (2.67%) |
| C ME |  |  |  |  | 98 (24.20%) | 1 (10.00%) | 99 (4.26%) |
| EGO | 197 (35.82%) | 349 (41.90%) | 216 (41.46%) | 2 (33.33%) | 0 |  | 764 (32.86%) |
| EGO ND | 148 (26.91%) | 211 (25.33%) | 96 (18.43%) | 1 (16.67%) | 9 (2.22%) |  | 465 (20.00%) |
| EGO P ND | 100 (18.18%) | 101 (12.12%) | 72 (13.82%) | 2 (33.33%) | 8 (1.98%) |  | 283 (12.17) |
| IL |  |  |  |  | 151 (37.28%) | 8 (80.00%) | 159 (6.84%) |
| ME |  |  |  |  | 51 (12.59%0 |  | 51 (2.19%) |
| ME EGO ND | 48 (8.73%) | 67 (8.04%) | 38 (7.29%) |  | 24 (5.93%) | 1(10.00%) | 178 (7.66%) |
| ME EGO P ND | 46 (8.36%) | 94 (11.28%) | 47 (9.02%) |  | 22 (5.43%) |  | 209 (8.99%) |
| ME ND |  |  |  | 1 (33.33%) | 22 (5.43%) |  | 23 (0.99%) |
| ME P ND |  | 2 (0.24%) | 1 (0.19%) |  | 12 (2.96%) |  | 15 (0.65%) |
| TYP |  | 1 (0.12) | 4 (0.77%) |  | 1 (0.25%) |  | 6 (0.26%) |
| TOTAL | **550 (100%)** | **833 (100%)** | **521 (100%)** | **6 (100%)** | **405 (100%)** | **10 (100%)** | **2325 (100%)** |

**Table 4** Female fruit fly catches in the study expressed as a total number captured over a period of 12 weeks where all the traps were re-baited after 6 weeks. The percentage of the total catch data for the respective species is given in brackets.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | *C. capitata* | *C. cosyra* | *C. rosa* | *C. quinaria* | *B. dorsalis* | *Perilampsis spp.* | TOTAL |
| 3CL | 3 (15.00%) | 2 (6.90%) | 9 (8.91%) |  | 1 (12.50%) |  | 15 (9.32%) |
| BFF | 16 (80.00%) | 22 (75.86%) | 78 (77.23%) |  | 3 (37.50%) |  | 119 (73.91%) |
| C ME |  |  |  |  |  |  |  |
| EGO |  | 1 (3.45%) |  |  |  |  | 1 (0.62%) |
| EGO ND |  |  |  |  |  |  |  |
| EGO P ND |  |  |  |  |  |  |  |
| IL |  |  |  |  |  |  |  |
| ME |  |  |  |  |  |  |  |
| ME EGO ND |  |  | 1 (0.99%) | 2 (100%) |  |  | 3 (1.86%) |
| ME EGO P ND |  | 1 (3.45%) |  |  |  |  | 1 (0.62%) |
| ME ND |  |  |  |  |  |  |  |
| ME P ND |  |  |  |  |  |  |  |
| TYP | 1 (5.00%) | 3 (10.34%) | 13 (12.87%) |  | 5 (62.50%) |  | 22 (13.66%) |
| TOTAL | **20 (100%)** | **29 (100%)** | **101 (100%)** | **2 (100%)** | **9 (100%)** |  | **161 (100%)** |

**Table 5** Non-target insect catches in the study expressed as a total number captured over a period of 12 weeks where all the traps were re-baited after 6 weeks. Other non-target insect catches include the orders: Blattodea, Colleoptera, Hemiptera, Isoptera, Neuroptera, Orthoptera and Thysanoptera and the class: Arachnida

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | *Diptera* | *Hymenoptera* | *Lepidoptera* | *Other* | TOTAL |
| 3CL | 1018 (14.88%) | 135 (10.45%) | 8 (8.79%) | 20 (5.15%) | 1181 (13.72%) |
| BFF | 1291 (18.87%) | 153 (11.84%) | 8 (8.79%) | 49 (12.63%) | 1501 (17.43%) |
| C ME | 458 (6.7%) | 42 (3.25%) | (0%) | 36 (9.28%) | 536 (6.22%) |
| EGO | 100 (1.46%) | 52 (4.02%) | 1 (1.1%) | 22 (5.67%) | 175 (2.03%) |
| EGO ND | 97 (1.42%) | 98 (7.59%) | (0%) | 24 (6.19%) | 219 (2.54%) |
| EGO P ND | 87 (1.27%) | 79 (6.11%) | 2 (2.2%) | 32 (8.25%) | 200 (2.32%) |
| IL | 61 (0.89%) | 13 (1.01%) | 1 (1.1%) | 15 (3.87%) | 90 (1.05%) |
| ME | 359 (5.25%) | 99 (7.66%) | 6 (6.59%) | 26 (6.7%) | 490 (5.69%) |
| ME EGO ND | 95 (1.39%) | 37 (2.86%) | (0%) | 30 (7.73%) | 162 (1.88%) |
| ME EGO P ND | 151 (2.21%) | 66 (5.11%) | 2 (2.2%) | 25 (6.44%) | 244 (2.83%) |
| ME ND | 257 (3.76%) | 58 (4.49%) | 8 (8.79%) | 34 (8.76%) | 357 (4.15%) |
| ME P ND | 359 (5.25%) | 52 (4.02%) | 6 (6.59%) | 37 (9.54%) | 454 (5.27%) |
| TYP | 2507 (36.65%) | 408 (31.58%) | 49 (53.85%) | 38 (9.79%) | 3002 (34.86%) |
| TOTAL | **6840 (100%)** | **1292 (100%)** | **91 (100%)** | **388 (100%)** | **8611 (100%)** |

**Table 6** Summary of the non-parametric (generalized linear model with Poisson distribution of errors and log link function) statistics for the effects of monitoring system and species on the count data outcomes for calendar weeks 5-7. The Chi-square value (χ2), degrees of freedom (df) and *P*-value for each test is shown. Significant effects are highlighted in bold.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Parameter tested | χ2 | df | *P*-value |
| Male fruit flies | **Monitoring system** | **155.42** | **12** | **< 0.001** |
|  | **Species** | **450.65** | **4** | **< 0.001** |
|  | **Monitoring system x Species** | **126.81** | **19** | **< 0.001** |
| Female fruit flies | Monitoring system | 5.29 | 2 | 0.071 |
|  | Species | 12.40 | 3 | 0.006 |
|  | Monitoring system x Species | 7.77 | 4 | 0.103 |