Chapter 12
Detection and Monitoring of Fruit Flies in Africa

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Abstract The production and trade of fresh fruit is currently increasing in Africa, as is the movement of people into and within the region. This increases the risk of new fruit fly invasions. The increase in production of fresh fruit also requires for more effective management of established insect pests like fruit flies in order to maximise yield and facilitate trade. It is imperative, therefore, that effective fruit fly detection and monitoring systems are developed, set up and maintained in Africa in order to protect and expand the fresh fruit sector which brings income and employment to the region. Effective trapping systems have been developed for many fruit fly pests and they enable the early detection and monitoring of these pests. However, for a number of important established fruit fly pests in Africa, notably in the *Dacus* group, trapping systems are yet to be developed and optimised. Moreover, new recently developed fruit fly attractants have yet to be tested on African species.

Keywords *Bactrocera* • *Zeugodacus* • *Dacus* • *Ceratitis* • Traps • Attractants

1 Introduction

Fruit fly populations can be characterised by surveys using traps and attractants (IAEA 2003; Cunningham 1989b). These surveys have two purposes: detection of the presence of new fruit fly species in an area and monitoring of the fluctuations in populations of established fruit fly species (IAEA 2003; Cunningham 1989b).

Olfactory attractants form the basis of most fruit fly detection and monitoring systems (Light and Jang 1996). The olfactory attractants are contained in traps with different retention systems: liquid, insecticide, sticky insert (IAEA 2003). A number of fruit fly attractants have been discovered over the years and a thorough understanding of fruit fly behaviour in response to them, has led to the development of effective trapping systems for some species (Economopoulos and Haniotakis 1994). Many fruit fly attractants are commercially available. Trapping procedures using

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commercially available attractants and traps for fruit fly detection and monitoring have been harmonised in published guidelines (IAEA 2003; IPPC 2008; Manrakhan 2006).

Although attractants and traps are commercially available and trapping procedures have been established for many species, fruit fly trapping surveys at producer, national and regional levels are not systematically implemented in many African countries. Trapping surveys are costly investigations. Due to funding constraints it is difficult for most African countries to implement extensive detection and monitoring surveys. However, strategic detection networks should still be established and maintained to protect individual countries and indeed the region from invasions of exotic fruit fly species in the future (Papadopoulos 2014). Moreover, there should be more transparency concerning fruit fly interceptions within the region so that regional approaches can be taken to effectively deal with invasive fruit fly species (Papadopoulos 2014). Currently in the African region, new fruit fly interceptions are reported through bilateral meetings and on the International Plant Protection Portal. Often though, detections of new fruit fly pests are not reported immediately, and the status of actions against new fruit fly species are not regularly updated, leaving neighbouring countries uninformed of the current pest status in the region and at risk of invasion. The lack of effective national and regional detection surveys has resulted in the introduction, spread and establishment of four exotic fruit fly species in Africa over the last 200 years. With increasing trade and movement of people in the African region, there is an increased risk of introduction and spread of more exotic fruit fly species. Detection surveys are therefore required nationally and regionally in Africa. Furthermore, for development of competitive fresh fruit export sectors in Africa, monitoring surveys of established fruit fly pests are essential at the level of the producers as well as at the national level, in order to implement timely and effective control actions and ensure export of fruit-fly-free fresh fruit consignments.

Here I review the tools available for fruit fly detection and monitoring and the current status of trapping surveys in Africa. Future prospects in the establishment of detection and monitoring systems in Africa are discussed.

2 Tools Used in Fruit Fly Trapping Surveys

There are currently four exotic, invasive fruit fly species within the African region: the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (previously reported in Africa as *Bactrocera invadens* Drew, Tsuruta & White); the solanum fruit fly, *Bactrocera latifrons* (Hendel); the melon fly, *Zeugodacus cucurbitae* (Coquillet) (previously known as *Bactrocera cucurbitae* (Coquillett)); and the peach fruit fly, *Bactrocera zonata* (Saunders) (Ekesi and Muchugu 2006). To date, only *B. dorsalis* is widely distributed within the region (Ekesi and Muchugu 2006), making trapping efforts for early detection of the other three species essential in currently pest-free countries to prevent further spread. Other potentially invasive species that have currently not been reported in Africa should also be included in detection surveys and these include: other members of the *B. dorsalis* complex (Clarke et al. 2005), other exotic *Bactrocera* species such as the Queensland fruit fly *Bactrocera tryoni* (Froggatt) and species in the genus *Anastrepha* (White and Elson-Harris 1994; Norrbom and Foote 1989). Furthermore, it would also be worthwhile to include indigenous *Ceratitis* and *Dacus* species that currently have a limited distribution in Africa in detection programmes as it is likely that their distribution could expand in the future with increasing movement of people and trade within the region.

For fruit fly species already present within a country, it is important that their populations are monitored within commercial fruit production areas for timely control actions. Monitoring of fruit flies should, ideally, be area-wide, covering all habitat types within a fruit-producing region to underpin more effective area-wide management actions.

There are known olfactory attractants for many fruit fly species of which some are present in African countries, but others are under exclusion. Olfactory attractants can be categorised as male lures, food-odour attractants and pheromones. Other categories of attractants such as fruit volatiles are still being investigated but could, in the future, play a role in detection and monitoring systems in Africa. Male lures and pheromones are species-specific and are usually preferred in detection programmes due to their specificity. For those species with no known male lures or pheromones, food-odour attractants are usually recommended. Different types of traps are recommended for use with different categories of attractants (IAEA 2003). Depending on the type of attractant, some traps are more effective than others. However, the cost, availability and handling efficacy of traps, as well as the environment being sampled often dictate the choice of traps. The efficacy of fruit fly detection systems has been evaluated for only a few species of economic importance and remains to be evaluated for other important fruit fly pests in Africa under African field conditions.

2.1 Olfactory Attractants

2.1.1 Male Lures

Dacine Flies (Bactrocera, Zeugodacus, Dacus *species*)

Populations of many species in the subtribe Dacina (*Bactrocera* species, *Zeugodacus* species, *Dacus* species) can be surveyed using species-specific male lures (Drew 1974; Drew and Hooper 1981; White 2006), most of which are commercially available. Ever since the mid 1980s there has been extensive research on new and improved male lures; most recent investigations have provided promising results on the efficacy of some of these new male lures, thereby expanding the toolkit of male lures for detection and monitoring of Dacine flies. The availability and cost of these new male lures are likely to influence their use in the African region.

Male lures for Dacine fruit fly pests are either compounds that naturally occur in many plant species or synthetic analogues of naturally occurring compounds (Cunningham 1989a), and they are categorised in two groups: methyl eugenol (4-allyl-1,2-dimethoxy-benzene) and cue-lure (4-(p-acetoxyphenyl)-2-butanone) (Drew 1974; Drew and Hooper 1981). The functional significance of male lures in this group of fruit flies has been widely debated (see review by (Raghu 2004)). There is strong support for the hypothesis that the response of Dacine flies to male lures is a mechanism of sexual selection and this is based on evidence of an increased reproductive success in Dacine flies following exposure to male lures (Kumaran et al. 2013; Shelly 2000; Shelly et al. 2003).

Males of most *Bactrocera* species are attracted to methyl eugenol (Cunningham 1989a; Tan et al. 2014; White 2006). Due to the potential carcinogenicity of methyl eugenol, there have been studies to identify alternative compounds (Khrimian et al. 1994; Mitchell et al. 1985). Fluorination of methyl eugenol does reduce its toxicity (Liquido et al. 1998), but also reduces its attractiveness as a bait in the field (Khrimian et al. 2009). Subsequently human exposure to methyl eugenol was deemed to be too low to be of concern (Tan et al. 2014), and as such the search for further alternatives to methyl eugenol have not been prioritised. In the African region, methyl eugenol has to be imported and is often unaffordable for resource-poor farmers. For this reason researchers in Senegal evaluated local products as alternatives to methyl eugenol (Ndiaye et al. 2008). They compared the attractiveness of methyl eugenol, ground nutmeg and a local beauty cream to adult male *B. dorsalis*. They found that methyl eugenol was the most attractive product compared to the two other products but that there was some degree of attraction to ground nutmeg which they recommended for use if methyl eugenol was unavailable (Ndiaye et al. 2008). Further investigations on natural sources with high methyl eugenol content are required in order to increase the use of methyl eugenol-based products as monitoring and control tools for resource-poor farmers in Africa.

Bactrocera latifrons is attracted to methyl eugenol (Flath et al. 1994). However during screening of a range of essential oils, aroma formulations and synthetic compounds, *B. latifrons* males were more attracted to α-ionol, a compound used in the perfume and flavour industry, than to methyl eugenol (Flath et al. 1994). Subsequently, cade oil and eugenol were found to separately synergise the attractiveness of α-ionol to males of *B. latifrons* (McQuate and Peck 2001; McQuate et al. 2004). For monitoring of *B. latifrons* in Africa, the combination of α-ionol and cade oil is currently recommended (Manrakhan 2006). A combination of α-ionol and eugenol could also become an option for this pest species. The synergist eugenol was reported to have less of a 'smoky' smell than the cade oil and would possibly enhance handling of the attractant (McQuate et al. 2004).

Males of other important *Bactrocera*, *Zeugodacus* and some *Dacus* species are attracted to cue lure (Cunningham 1989a; Tan et al. 2014; White 2006). Amongst the *Dacus* species, response to cue lure is known only for particular subgenera with no reported male lures for the other subgenera which include important pest species (White 2006). Cue lure is a synthetic compound whilst its analogue and break down product, raspberry ketone (4-(4-hydroxyphenyl)-2-butanone), is known to occur in a number of plants (Cunningham 1989a). Males of *Z. cucurbitae* are attracted to raspberry ketone (Cunningham 1989a). In field tests done in the early 2000s, the formate ester of raspberry ketone (i.e. raspberry ketone formate) was more attractive to *Z. cucurbitae* than cue lure (Oliver et al. 2002). However, in more recent field investigations, conflicting results were found for *Z. cucurbitae*. In one trial, raspberry ketone formate outperformed cue lure in terms of catches of *Z. cucurbitae* when exposed as a liquid lure (1 g per wick) or as a plug (Jang et al. 2007a). In a separate trial cue lure was more attractive to *Z. cucurbitae* than raspberry ketone formate (Shelly et al. 2012). The raspberry ketone formate, recently referred to as melolure, was also inferior in attracting *B. tryoni* compared with cue lure (Dominiak et al. 2015). However Dominiak et al. (2015) reported increased capture rates of *Dacus* spp in melolure-baited traps compared with cue lure-baited traps. These conflicting results indicate the need for further evaluation of raspberry ketone formate under contrasting field conditions, and further evaluations on other 'cue-lure responding' flies.

Vertlure is one of several male attractants for Dacine flies that is in a category of its own (Hancock 1989). Vertlure is specific to the jointed pumpkin fly, *Dacus vertebratus* Bezzi, an important pest of cucurbits in Southern Africa (Hancock 1989). To date there are no reports of other *Dacus* species being attracted to this lure.

A novel and promising male attractant for Dacine fruit flies is zingerone (4-hydroxy, 3-methoxyphenyl-2-butanone) which was identified from the floral components of a wild orchid (Tan and Nishida 2000). The discovery of this attractant followed observations of visits of 'methyl eugenol-responding flies' and 'cue lure-responding flies' to the flowers of this wild orchid (Tan and Nishida 2000). In subsequent studies done in northern Australia, zingerone was attractive to *Bactrocera jarvisi* (Tryon), and other Dacine species, some of which were not responsive to other known male lures (Fay 2012; Royer 2015). In a recent study conducted in South Africa, zingerone was attractive to a few *Dacus* species including the pumpkin fly, *Dacus frontalis* Becker, which is an important pest of water melon (Manrakhan et al. unpublished data). Further evaluation of this new attractant is warranted in Africa in order to determine the response of African Dacine to this lure.

Other new compounds in the phenylpropanoid and phenylbutanoid groups (such as isoeugenol, methyl isoeugenol, dihydroeugenol and 2-methoxy-4-propyl phenol) also attract Dacine flies that were previously non-responsive to methyl eugenol and cue lure in northern Australia (Royer 2015; Fay 2010). It would be important to trial these same compounds in Africa in order to determine the full range of Dacine flies that may be responsive.

Ceratitis *species*

Terpinyl acetate and trimedlure are the most commonly used male lures for pest fruit flies in the *Ceratitis* group (Cunningham 1989a; Ripley and Hepburn 1935; Beroza et al. 1961). Some early studies conducted in South Africa showed greater responses of the Natal fly, *Ceratitis rosa* Karsch and the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann) to trimedlure than to terpinyl acetate (Georgala 1964). Currently in South Africa, the male lure capilure, which is a blend of trimedlure and extenders (Leonhardt et al. 1984), is recommended for monitoring *C. capitata* and *C. rosa* (Manrakhan and Grout 2010). Studies comparing the relative attractiveness of trimedlure and capilure to *C. capitata* have produced varied results; one study showed a better performance for capilure compared with trimedlure (Hill 1987) while other studies showing the reverse (Baker et al. 1988; Rice et al. 1984; Shelly 2013). In trapping studies done in avocado orchards in South Africa (Grove et al. 1998), the mango fly, *Ceratitis cosyra* (Walker), was non-responsive to capilure-baited traps. Male *C. cosyra* were instead attracted to traps baited with β-caryophyllene (Grove et al. 1998). In mark-release-recapture studies conducted by Grout et al. (2011), capilure was less attractive to *C. rosa* than to *C. capitata* and the authors confirmed the lack of response of *C. cosyra* to capilure. In those same studies *C. cosyra* responded to a β-caryophyllene-based lure commercially sold as 'Ceratitis lure' in South Africa (Grout et al. 2011). Interestingly, Grout et al. (2011) also reported higher catches of *C. capitata* and *C. rosa* in traps baited with 'Ceratitis lure' than capilure. A new promising male lure for *Ceratitis* species is enriched ginger root oil (EGO) which attracted a wide range of *Ceratitis* species in studies done in Tanzania (Mwatawala et al. 2013). The EGO lure is a commercially available product in South Africa and in recent trapping studies was a superior male lure for *Ceratitis* flies compared with trimedlure (Manrakhan et al., unpublished data). In South Africa, an EGO-based product known as 'Last FF' is registered for control of *Ceratitis* species such as *C. capitata* and *C. rosa*. Further evaluation of EGO lures and the 'Ceratitis lure' is required across the African region in order to establish the responsiveness of all *Ceratitis* species. Studies done in Hawaii showed that the EGO lure was less effective than trimedlure in attracting *C. capitata* (Shelly 2013; Shelly and Pahio 2002). A new promising lure for *C. capitata* called ceralure B1 (an analogue of trimedlure) is currently being evaluated and has shown promise in some recent field trials (Jang et al. 2010). Ceralure B1 is yet to be evaluated in the African region.

2.1.2 Food-Odour Attractants

Many fruit fly species require both sugar and protein during their adult life for survival and reproduction. The protein requirements of fruit fly pests, and subsequently their attraction to protein sources, have been exploited in the development of food-odour attractants for fruit fly monitoring and control. The history and development of food-based attractants were recently reviewed by Epsky et al. (2014). Currently, there are two main types of food-odour attractants being used for fruit fly detection and monitoring: (1) liquid protein hydrolysates and (2) synthetic lures that contain synthetic versions of the main volatile components found in protein hydrolysate lures. Food-odour attractants are not species specific and are generally female biased. Protein hydrolysates, similar to the ones developed by the pioneers in this field such as McPhail (1939) and Gow (1954), are still in use today. The protein hydrolysates developed are from hydrolysis (using alkalis, acids or enzymes) of proteinaceous compounds such as corn protein, animal protein and yeast. Protein hydrolysates are usually available in liquid form and require dilution with water before use in traps. There are, however, practical problems in the use of liquid lures. Liquid lures are cumbersome to carry to the field and difficult to handle during trap placement and servicing. Putrefaction of liquid protein baits inside traps is problematic as it leads to decomposition of the fruit flies captured, rendering identification impossible. Lopez and Becerril (1967) investigated the addition of borax to liquid protein hydrolysates to prevent decomposition of captured flies. Addition of borax at a rate of 2 % to protein hydrolysates prevented putrefaction but led to a reduction in the number of flies captured (Lopez and Becerril 1967). In the late 1960s, Lopez et al. (1968) developed pelleted lures in order to improve transport and handling of the liquid protein hydrolysates. However, pelleted lures were slightly less effective than freshly-diluted protein lures and this lower efficacy was attributed to the fact that the pellets dissolved slowly (Lopez et al. 1968). The role of ammonia in the attraction of flies to protein hydrolysates was suggested by McPhail (1939) in the late 1930s and later proven by Bateman and Morton (1981). The latter authors also showed that, at high concentrations, ammonia was repellent. Since solutions of ammonium salts were more attractive to flies at high pH, Bateman and Morton (1981) suggested that other volatiles may also be released at high pH. There were then further investigations in to other possible volatile components of the protein hydrolysates that may have been luring fruit flies (Buttery et al. 1983; Morton and Bateman 1981). Synthetic mixtures matching the attractiveness of protein hydrolysates were then investigated with the aim of finding alternatives to the bulky protein hydrolysate liquid lures that were difficult to handle. Wakabayashi and Cunningham (1991) found a nine component synthetic mixture that was as attractive as protein hydrolysate to *Z. cucurbitae*; they described four of the components as being most important in attraction: ammonium bicarbonate, linoleic acid, putrescine, pyrrolidine. Heath et al. (1997) investigated the efficacy of synthetic mixtures in luring *C. capitata* and found that, for this particular species, the addition of methyl-ammonia derivatives to a mixture of ammonium acetate and putrescine increased the capture of the pest. Work in the 1990s led to the development, recommendation and use of what we now know as 'three-component lures' and 'two-component lures' as food-odour attractants for fruit flies (IPPC 2008). These synthetic food lures have the advantages of easy handling, long field life and the possibility of use in dry traps. The major disadvantages of synthetic lures are cost and availability. In Africa, these have to be imported and are likely to be unaffordable for large-scale government-funded detection programmes and for resource-poor farmers. Moving on from sophisticated synthetic mixtures there has been a line of research in many parts of the world, including Africa, on the development of low-cost protein baits. In Australia and the Pacific islands, the use of beer waste as an alternative low-cost fruit fly bait was explored in the late 1990s (Lloyd and Drew 1996). Lloyd and Drew (1996) described a simple method of converting waste yeast slurry from breweries into protein bait for fruit flies using a batch process involving the enzyme papain for digestion of the waste yeast cells. In Mauritius, waste brewer's yeast was shown to be a promising equivalent to local protein baits in terms of control efficacy (Sookar et al. 2002). In Nigeria, waste yeast slurry from breweries that was autolysed by heat was as attractive to fruit flies as imported protein hydrolysate (Umeh and Garcia 2008). Other promising low-cost fruit fly protein baits that were explored include human urine and chicken faeces, which were attractive to *Anastrepha* species (Piñero et al. 2003; Aluja and Pinero 2004). Other lines of investigation evaluated bacterial cultures and bacterial filtrates as attractants for fruit flies, but, to date, these have not been commercially produced and used (Reddy et al. 2014; Jang and Nishijima 1990). Food-odour attractants elicit different responses from different fruit fly species. For *C. capitata* and most *Anastrepha* species, synthetic lure mixtures were more effective than protein hydrolysates (Thomas et al. 2001; Robacker 1995; Katsoyannos et al. 1999; Holler et al. 2006; Epsky et al. 2011; Broughton and De Lima 2002). In contrast, for Dacine flies (*Bactrocera* spp. and *Zeugodacus* spp), comparative studies on the relative performance of synthetic mixtures and protein hydrolsates were variable (Wakabayashi and Cunningham 1991; Leblanc et al. 2010; Ekesi et al. 2014; Cornelius et al. 2000). For *B. dorsalis*, the dominant pest species in many African countries, liquid protein hydrolysates were more effective than synthetic mixtures (Leblanc et al. 2010; Ekesi et al. 2014; Cornelius et al. 2000). Responses of some fruit fly species to protein hydrolysates were increased with additives such as propylene glycol (antifreeze) and ammonium acetate (Thomas et al. 2001; Pinero et al. 2015). Depending on the type of protein hydrolysate, Duyck et al. (2004) improved efficacy by acidification or alkalinisation. It must be emphasized that not all congeneric fruit fly species have the same level of response to protein baits. In studies with *Anastrepha* species, the West Indian fruit fly *Anastrepha obliqua* (Macquart), was more responsive to Biolure (synthetic food-based attractant) and Nulure (protein hydrolysate) compared with the Mexican fruit fly, *Anastrepha ludens* (Loew) (Diaz-Fleischer et al. 2009). Differences in responses to baits between congeneric species were linked to differences in the life history traits of the species concerned (Diaz-Fleischer et al. 2009). Similarly in studies on *Ceratitis* species, *C. capitata* responded more strongly to protein baits than other *Ceratitis* species such as *C. rosa* and *C. cosyra* (Manrakhan and Kotze 2011). The methods for determining bait efficacy have recently been debated by Mangan and Thomas (Mangan and Thomas 2014) who suggested that baits should not only be evaluated by the magnitude of the catches, but also by the frequency of zero catches over time. In other words, a good bait should also be the one with the lowest frequency of zero captures. In their recent study, the authors showed that the performance of olfactory attractants varied over time (Mangan and Thomas 2014).

2.1.3 Pheromones

For most fruit fly species, except the olive fruit fly, *Bactrocera oleae* (Rossi), and the papaya fruit fly, *Toxotrypana curvicauda* Gerstaecker, there are no commercial pheromones available or recommended as attractants for use in detection and monitoring programmes (IPPC 2008;

IAEA 2003). The identification of a female sex pheromone produced by *B. oleae* led to the subsequent synthesis and commercial development of the olive fruit fly pheromone referred to as spiroketal (1,7-dioxaspiro [5,5] undecane) (Mazomenos 1989). In recent studies, Yokoyama et al. (2006) found that responses of *B. oleae* to pheromone-baited traps can be greatly improved when combined with food-odour attractants. For *T. curvicauda*, which is non-responsive to food-odour attractants, the synthetic male sex pheromone (2-6-methylvinyl pyrazine abbreviated as MVP and commonly referred to as papaya fruit fly pheromone) was effective when incorporated within a visual stimulus such as a fruit model (Landolt et al. 1988). The non-availability of pheromones for monitoring of other fruit fly pests is due to the lack of a detailed understanding of pheromone-mediated attraction during courtship and the current availability of effective lures for some important fruit fly pests (Tan et al. 2014). However, for fruit fly species that respond poorly or are non-responsive to commercially available olfactory attractants, an understanding of the mating behaviour and pheromone mediated courtship behaviour would be important. If pheromone mediated responses are found to be long range, it would then be important to explore the synthesis of these chemicals for further development and commercialisation.

2.1.4 Other Olfactory Attractants such as Fruit Volatiles

For some fruit fly species that respond poorly or are non-responsive to male lures and food-odour attractants, the potential use of plant volatiles has been investigated (see review by Quilici et al. [2014]) Recent research studies conducted on the lesser pumpkin fly, *Dacus ciliatus* (Loew), and *Dacus demmerezi* (Bezzi) have indicated that these species are poor responders to protein-based attractants (Deguine et al. 2012). Current trapping studies being conducted in the Limpopo and Mpumalanga provinces in South Africa also show that very few *Dacus* flies are collected in traps baited with food odour attractants, although the same species are trapped within the same sites in high numbers in male lure traps (Manrakhan et al. unpublished data). The use of fruit volatiles as attractants for *Dacus* species should be explored further. For *B. dorsalis*, which does not respond strongly to currently available synthetic food odour attractants, the responses of the pest to host and non-host odours were also studied (Jang et al. 1997; Kimbokota et al. 2013; Biasazin et al. 2014). Jang et al. (1997) showed that mated *B. dorsalis* females were highly attracted to volatile components of leaves from a non-host plant commonly known as Panax (*Polyscias guilfoylei* [Bull]). Volatiles from host fruit, in particular mature fruit, were also highly attractive to *B. dorsalis* (Kimbokota et al. 2013; Biasazin et al. 2014).

2.1.5 Lure Formulations and Combinations

Male lures are commercially available in different formulations: liquid, polymeric plug, laminate and wafers (IPPC 2008). The formulations differ in their field longevity (IPPC 2008). Liquid lures are generally dispensed on dental rolls or cotton wicks (IAEA 2003). Some earlier studies have shown that evaporation rates of male lures from cotton wicks were fairly constant. Cotton wicks impregnated with trimedlure were, however, ineffective after 2–4 weeks (Leonhardt et al. 1989) while those impregnated with methyl eugenol remained effective for at least 9 weeks (Qureshi et al. 1992). Polymeric plugs containing male lures had slower release rates than other dispensers such as mesoporous dispensers and wafers (Suckling et al. 2008; Domingues-Ruiz et al. 2008). Release rates of polymeric plugs are temperature dependent with higher release rates at higher temperatures (Domingues-Ruiz et al. 2008). Larger fruit fly catches were achieved when using wafers and mesoporous dispensers compared with polymeric plugs (Suckling et al. 2008; Domingues-Ruiz et al. 2008).

The effect of mixtures of different male lures has been investigated by a number of researchers with the justification that it could lead to savings in cost and time by monitoring more species of fruit flies at a time. In studies conducted by Vargas et al. (2000) and Shelly et al. (2004), mixtures of methyl eugenol and cue lure led to a decrease in catches of *B. dorsalis* compared with methyl eugenol on its own. While Vargas et al. (2000) found that mixtures of methyl eugenol and cue lure did not significantly change catches of *Z. cucurbitae* compared with cue lure on its own, Shelly et al. (2004) found that methyl eugenol had a synergistic effect when mixed with cue lure for *Z. cucurbitae*. In some more recent studies by Vargas et al. (2010), wafers containing methyl eugenol and raspberry ketone were as effective as either methyl eugenol or cue lure on their own for capturing *B. dorsalis* and *Z. cucurbitae*, respectively. Shelly et al. (2012) found that wafers containing mixtures of trimedlure, methyl eugenol and raspberry ketone were as effective as each separate lure used on its own. Such 'trilure' wafers could certainly reduce the time and costs associated with fruit fly monitoring.

With respect to food-odour attractants, the three-component and two-component lures are generally available as two and three separate dispensers, respectively – each containing a particular component. The use of three-component or two-component lures entails opening up all the required dispensers before placement in traps. The time involved in preparation and servicing of traps requiring two or three separate membrane dispensers could be considerably shortened if each lures were combined into one dispenser. In studies conducted on *C. capitata* and the guava fruit fly, *Anastrepha suspensa* (Loew), single dispensers of the three- and two-component lures were as effective as lures comprising separate dispensers (Jang et al. 2007b; Holler et al. 2009). In trials done in citrus orchards in South Africa, the single dispenser of the three-component lure was less effective than the lure comprised of three separate dispensers for females of *C. rosa* and *C. capitata*, but not for *C. cosyra* (Manrakhan et al., unpublished data).

Combinations of male lures and food-odour lures have also been tested; results from studies on combinations of trimedlure or ceralure with synthetic food lures have shown that catches of female *C. capitata* were reduced when the two groups of lures were combined compared with catches using synthetic food lures only (Toth et al. 2004; Broughton and De Lima 2002). In contrast, there were no changes in catches of male *C. capitata* when male lures were combined with synthetic food lures (Toth et al. 2004; Broughton and De Lima 2002). Liquido et al. (1993) found that male catches in traps baited with trimedlure and ammonia (ammonium bicarbonate solution) were significantly higher than catches in traps baited with trimedlure alone.

There are, therefore, positive and negative effects of combining lures depending on the target pest groups and the survey objectives. As such, the effects of lure combinations should be properly assessed before implementation in fruit fly detection and monitoring programmes.

2.2 Trap Types for Use with Olfactory Attractants

Trap types for fruit flies can be classified into two main categories, dry traps and wet traps, depending on their retention systems (IPPC 2008). Some traps such as modified and plastic McPhail-type traps can be used as either dry or wet traps. Sticky inserts or insecticidal strips are generally the retention systems used in dry traps. With wet traps, a liquid medium (liquid protein bait or water) is the retention system with flies being killed or retained by drowning in the liquid. A number of commercially available dry and wet traps are available for use with olfactory fruit fly attractants (IPPC 2008). The widely used dry traps with sticky inserts include the Cook and Cunningham trap, Jackson/Delta trap and ChamP trap. Widely used dry traps with insecticidal strips include the Lynfield trap and the Steiner trap. The most widely used wet trap is the McPhail trap. Male lures are mostly used with dry traps while food-odour attractants can be used in either dry or wet traps depending on the type of attractants, trapping environment and trapping methodology.

Amongst the dry traps, bucket type traps and modified McPhail type traps were more effective than Jackson traps when baited with male lures (Katsoyannos 1994; Cowley 1992; Cowley et al. 1990). Prokopy et al. (1996) studied the behaviour of *C. capitata* males arriving and entering Jackson traps and Nadel-Harris bucket traps under field cage conditions; they found no significant differences in the numbers of males arriving and entering either of these trap types. Jackson traps were deemed to be more suitable for early detection as opposed to regular monitoring programmes because the capture surface of the traps is limited (Uchida et al. 1996). When using male lures in regular monitoring programme for established fruit fly pests, bucket traps would be suitable (Uchida et al. 1996). There were no significant effects of entrance hole size or trap colour of the bucket traps baited with trimedlure on catches of *C. capitata* (Uchida et al. 1996). In contrast, for *B. dorsalis*, the colour of methyl-eugenol baited bucket traps did influence catches of males; white and yellow bucket traps attracted more males than green, red or black bucket traps (Stark and Vargas 1992). In a recent study using methyl eugenol or cue lure, targeting *B. dorsalis* and *Z. cucurbitae* respectively, toxicant-free bucket traps containing holes with a one way entrance design where flies could easily enter traps and not escape were more effective than toxicant-containing bucket traps with similar sized entrance holes (Jang 2011).

With food-odour attractants, trapping efficiency was also influenced by trap type; McPhail-type traps, Probodelt and multilure traps were the most effective for a range of different fruit fly species (Robacker and Czokajlo 2005; Navarro-Llopis et al. 2008; Heath et al. 1995; Hall et al. 2005; Katsoyannos and Papadopoulos 2004). When using synthetic food lures, the colour of dry traps influenced capture rates of *C. capitata*; *C. capitata* females were more attracted to green traps compared with orange traps (Epsky et al. 1995).

Research has also been ongoing on the development of inexpensive traps for resource poor farmers. In a study on *A. ludens*, inexpensive plastic bottles with 10 mm lateral holes were as effective as costly McPhail-type traps, in particular when used with the effective liquid-food bait, ceratrap, which is enzymatic hydrolysed protein from pig intestinal mucosa (Lasa et al. 2015). Lasa et al. (2014) recently argued that, under field conditions, the type of lure was more critical for trap efficacy than trap type and design.

2.3 Efficacy of Trapping Systems

Despite the availability of effective olfactory attractants and traps, information on the efficacy of trapping systems for early detection of fruit fly pests is, to date, still limited. The efficacy of male-lure-based trapping systems has been determined for only a few major pest species, namely *C. capitata*, *B. dorsalis* and *Z. cucurbitae* (Shelly and Edu 2010; Shelly et al. 2010; Lance and Gates 1994; Cunningham and Couey 1986). Estimates of detection probability have suggested that, for trimedlure-based traps, a density of 10 traps per 2.6 km^2 would only be able to detect *C. capitata* infestations consisting of more than 1000 individuals, whilst for methyl eugenol and cue lure-baited traps densities of 5 traps per 2.6 km^2 would be able to detect *B. dorsalis* and *Z. cucurbitae* infestations of 50 and 350 individuals respectively (Shelly et al. 2010; Lance and Gates 1994; Cunningham and Couey 1986). Studies have shown that congeneric species responding to a particular male lure might have different sensitivity to the same male lure (Wee et al. 2002; Grout et al. 2011). As such generic trapping density recommendations for early detection using a particular male lure might not be optimal for all pests within a particular lure category.

For species that do not respond to existing male lures and pheromones, food-odour attractants are usually used. Efficacy of trapping grids based on food-odour lures have not been determined for many pest species. Calkins et al. (1984) estimated that McPhail traps baited with liquid protein lures would only be able to detect a low population of *A. suspensa* if the traps are placed at a density of at least 83 traps per ha. More recently the effective sampling range of traps baited with synthetic food lures was estimated as ≈ 30 m for *A. suspensa* and *C. capitata* (Kendra et al. 2010; Epsky et al. 2010). Trapping grids based on food-odour attractants would therefore be not as sensitive as those based on male lures.

3 Current Status of Fruit Fly Detection and Monitoring in Africa

3.1 Detection Surveys of Exotic Fruit Flies in Africa

The discovery in Africa of the exotic invasive species, *B. dorsalis*, and its subsequent rapid spread to several African countries (Lux et al. 2003; Drew et al. 2005) was a wake-up call to the risk of exotic fruit fly invasions for many countries in the African region. This led to a number of nationally and internationally-funded fruit fly detection surveys in many countries across the region. However, these detection surveys were often short term, possibly due to financial constraints and lack of resources (materials and labour). The discontinuity in detection surveys is worrying and leaves countries in the African region at risk. Early detection of an invasive pest is one of the key factors in the successful eradication of the pest (Liebhold and Tobin 2008).

There are few examples of successful national fruit fly early detection programmes in Africa. In South Africa, the initiation of a Plant Health Early Warning Systems Division and the forging of an industry and government participatory forum led to the implementation of a national fruit fly surveillance programme and relevant control actions that did eventually delay the introduction of *B. dorsalis* into South Africa (Manrakhan et al. 2015; Manrakhan et al. 2009; Barnes and Venter 2008). In Mauritius, early detection of *B. dorsalis* led to two separate and successful eradication campaigns of *B. dorsalis* between 1996 and 1997 (Seewooruthun et al. 2000; Sookar et al. 2008) and more recently between 2013 and 2014 (Sookar P., personal communication).

With increasing trade in fresh fruit within the African region, a regional early detection programme would be more advantageous (Ekesi 2010). There are a few ongoing regional fruit fly detection programmes in Africa, notably in the Indian Ocean region and in West Africa. There is, however, a real need to initiate similar programmes in other parts of Africa: East Africa, North Africa and Southern Africa. Ideally, collaboration and sharing of knowledge between the programmes should be fostered.

3.2 Monitoring of Established Fruit Fly Pests

Effective control of established fruit fly pests in fruit-producing areas requires knowledge of the fruit fly present and their population dynamics. This can be achieved by monitoring surveys in both commercial and non-commercial orchards within fruit producing areas. Currently fruit fly monitoring surveys are not done systematically in all fruit producing areas within the African region. In South Africa, it is recommended that monitoring of fruit fly pests in citrus starts at least 2 months before the earliest harvest dates (Manrakhan and Grout 2010). The recommendation is for traps to be checked weekly and on the basis of catches, decisions are made on the intensity of control actions. Thresholds for specific trap and lure combinations have been developed for particular fruit fly pests in the citrus industry (Grout et al. 2011). Adherence to these threshold levels has led to very few fruit fly export market interceptions in fresh fruit consignments from South Africa. It is important that threshold levels for fruit flies in recommended trap lure systems is established for different fruit producing areas within the region in order to provide guidance to fruit growers on the necessary control actions to achieve fruit fly free consignments.

4 Future Prospects

Although trapping systems have been developed for most major fruit fly species in and outside of Africa, the trapping systems for some important *Dacus* pest species are yet to be developed and optimised. Effective olfactory attractants should be sought for those *Dacus* species that do not respond to commercially-available lures. For fruit fly pests that respond to known lures, new improved attractants have been developed, but are yet to be tested on African fruit fly species.

With regards to exotic fruit fly pests, plant health organisations in each country within the African region should prioritise the establishment and maintenance of detection-focussed trapping systems and should encourage participation of the fruit industry to ensure sustainability. Ideally there should be sharing, co-ordination, collaboration and transparency between countries to enable a more regional approach to fruit fly detection in Africa.

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