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Guiding farmers' choice for an integrated pest management program against the invasive *Bactrocera dorsalis* Hendel (Diptera: Tephritidae) in mango orchards in Tanzania

Maulid Walad Mwatawala [a, *], Hendry Mziray [a], Hamis Malebo [b], Marc De Meyer [c]

[a] Sokoine University of Agriculture (SUA), Department of Crop Science and Production, Box 3005, Chuo Kikuu, Morogoro, Tanzania
[b] Department of Traditional Medicine Research, National Institute for Medical Research, P.O. Box 9653, Dar Es Salaam, Tanzania
[c] Royal Museum for Central Africa (RMCA), Entomology Section, Tervuren, Belgium

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ABSTRACT

Trials were conducted in the Morogoro Region, Tanzania, to evaluate the effectiveness of three Integrated Pest Management (IPM) programs against *Bactrocera dorsalis* over five seasons. Spot application of molasses bait was compared with broadcast sprays of insecticide dimethoate/lambda cyhalothrin (Karate 5 EC) and spot application of a spinosad bait (Success, Dow AgroSciences) plus mass trapping using methyl eugenol, as components of IPM programs for *B. dorsalis*. Orchard sanitation and early harvesting of fruits were standard practices in each program. The molasses bait was formulated with crude extracts of *Derris elliptica*, water and brewery yeast waste. The effective median dose of the bait was determined by exposing adults of *B. dorsalis* to a range of concentrations of crude extracts of *D. elliptica* in a laboratory bioassay.

Each program was applied in an individual mango orchard and replicated for five seasons with populations being monitored using McPhail traps baited with torula yeast. In addition, fruits were sampled at ripening and individually placed in containers to determine the incidence and infestation rates of emerged fruit fly species. Results show that for the molasses bait 9 g of *D. elliptica* roots powder soaked in 5 L of neutral soap are required to kill 50% of a *B. dorsalis* population. The three IPM methods did not differ significantly in reducing fly incidence and infestation rates. We analyzed the three IPM methods on the basis of cost-benefit, environmental protection and health safety, in the light of purpose and market focus of the farmer. It is finally recommended that spot application of botanical bait can be used in IPM programs for fruit flies in smallholder settings. Spot application of Success bait is recommended for commercial farmers targeting organic and export market markets. Broadcast spray of Karate is recommended for commercial farmers, mostly targeting regional markets.

1. Introduction

True fruit flies (Diptera: Tephritidae) are the most important insects attacking horticultural crops (Hill and Terblanche, 2014; Shelly et al., 2014). Infestation by fruit flies is a major constraint to fruit production (Lux, 1999) as many species are of quarantine importance (Qin et al., 2015). High mobility and opening of new markets for agricultural products offer greater opportunities for the movement of pests (Griffin, 2000) including fruit flies. Presence of pests of quarantine significance in a country limits farmer's access to export markets. Strong quarantine restrictions are often imposed against exporting countries harboring quarantine pests. The detection of *Bactrocera dorsalis* (Hendel) in Africa in 2003 affected regional and international fruit trade. For example South Africa temporarily banned the importation of bananas from Mozambique, affecting business valued at about USD 20 million annually (Cugala et al., 2011)

Reliable markets can be secured by producing high quality fruits, free from pests and diseases. Management of fruit flies, in particular *B. dorsalis*, is ongoing in many African countries (Ekesi et al., 2010; Vayssières et al., 2009). However, information on the efficacy of Integrated Pest Management (IPM) programs tested in many African countries is not readily available. Most

* Corresponding author.
E-mail address: mwatawala@yahoo.com (M.W. Mwatawala).

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management programs concentrate on *B. dorsalis*, an aggressive and key fruit fly pest. The generally accepted management model comprises (1) orchard sanitation, (2) spot application of baits, (3) male annihilation/mass trapping and, (4) monitoring. The general model is complemented by biological control using parasitoids such as *Fopius arisanus* (Sonan), predators like weaver ants, *Oecophylla longinoda* (Latreille) entomopathogens especially *Metarrhizium anisopliae* (Metchinkoff) Sorokin (Ekesi et al., 2010) and applications of sexual communication in tephritids (Benelli et al., 2014).

Fruit flies are among the most important pests in the major fruit growing areas in Tanzania (Mwatawala et al., 2006a, 2006b). Heavy losses inflicted by fruit flies necessitated the formulation of ecologically based Integrated Pest Management (IPM) programs to cater for, among others, smallholder farmers who dominate mango production (Mwatawala et al., 2009, 2013).

Most synthetic products used in management of fruit flies are not affordable to smallholder farmers. Advanced paraphermone release systems like SPLAT MAT spinosad ME (Vargas et al., 2010) are not easily accessible to many farmers in Africa. Attract and kill systems using naturally occurring contact and stomach poisons (Benelli et al., 2012; Canale et al., 2013) as well as insecticide-free trapping systems should be explored (Vargas et al., 2010).

There is a need to explore cheap, locally available baits and toxicants that could fit within the generally accepted management model to be used by smallholder farmers who dominate African agriculture. Verghese et al. (2004) included a neem (*Azadirachta indica* A. Juss) product, Azadirachtin, in the IPM program for *B. dorsalis* in India. Essential oils from plants of family Lamiaceae are toxic to Diptera including mosquitoes (Conti et al., 2014) and fruit flies like *Ceratitis capitata* Wiedemann and *Bactrocera oleae* (Gmelin) (Bennelli et al., 2012; Canale et al., 2013). Most botanical insecticides are compatible with organic farming systems and have multiple modes of action, retarding the ability of insects to develop resistance. This paper presents the results of five-year trials on the effectiveness of botanically based IPM as one of the programs for managing *B. dorsalis* in mango orchards in the Morogoro Region of Tanzania.

2. Material and methods

2.1. Bioassay

We prepared a mixture of molasses, brewery yeast waste and water at a ratio of 0.05 L: 1 L: 0.05 Kg respectively. Crude extracts from the roots of *Derris elliptica* (Roxb.) Benth. (Fabaceae), were added as toxicants to the mixture, hence forming bait (hereinafter referred to as molasses bait).

Roots of *D. elliptica* were obtained from Muheza, Tanga, Tanzania. The roots were washed, and cut into pieces and dried in the shade for five days (Stoll, 2000). The content of rotenone (5%) was determined by the Normal Soaking Extraction (NSE) process using 95% Acetone (v/v) ethanol at Tanzania's National Institute for Medical Research (NIMR) laboratories in Dar Es Salaam.

We introduced 100 adults of *B. dorsalis* (sex ratio 50:50) into population cages with petri dishes containing molasses bait with various concentrations of *D. elliptica* extracts. The concentrations tested were 0, 5, 15, 30, 60 and 75 g of *D. elliptica* powder soaked overnight in 5 L of neutral soap solution. The trials were replicated four times.

We recorded number of dead adult flies at intervals of 6, 12 and 24 h. We then performed probit analysis to determine the median lethal concentration (LC_{50}) of *D. elliptica* powder that could kill 50% of the *B. dorsalis* population. The LC_{50} of *D. elliptica* was obtained by first determining the log concentration corresponding to the probit value of 5 in regression equations and then changing back the value to its exponential form.

2.2. Field experiments

Field trials were conducted in fourteen mango orchards (Table 1) for five seasons, commencing in 2008/09. For each season, six orchards were selected from these fourteen, based on fruits production. All the orchards are located in the plateau zone of the Morogoro Region (Mwatawala et al., 2006). Of these, three orchards are located in the Morogoro Municipality, five in Morogoro District (Mikese, Bigwa wards) and six in Mvomero District (Mlali, Mkundi and Mzumbe wards). The trial was arranged in a Completely Randomised Design (CRD), replicated for five years. The treatments were allocated as shown in Table 2. We tested three IPM programs, based on insecticide sprays and spot application of baits. Each program was implemented in two orchards each season. Orchard sanitation and early harvesting of fruits were standard components in all the three programs. Specific treatments were dimethoate 400 EC/Karate 5 EC, Success bait (Dow AgroSciences) and molasses bait.

Insecticides were sprayed fortnightly, starting with dimethoate (0.2%) during the first two seasons followed by Karate (lambda cyhalothrin 0.02%) in the last three seasons. Baits were applied weekly on 1 m^2 spots on tree canopies at a rate of 1 L/ha. Molasses bait 360 gm *D. elliptica* powder: 1 L molasses: 360 g of brewery yeast waste: 20 L of water. The bait was usually applied 12 h after formulation. Success bait (spinosad 0.02%) was first diluted at ratio of 1 L to 5.5 L of water. We also placed 6 traps of methyl eugenol (ME) per ha for mass trapping of males in orchards under Success bait treatment.

Populations of fruit flies in each orchard were monitored using torula yeast placed in modified McPhail traps (AgriSense, UK). Protein bait was used because it has a small radius of attraction (as compared to the stronger parapheromone attractant methyl eugenol) and therefore sufficient replicates could be maintained with minimal chances of attracting flies from nearby orchards.

The population of fruit flies was determined as the number of adult fruit flies per trap per week (FTW). Data were collected weekly for eight consecutive weeks during peak fruiting periods. Catches of flies from orchards under the same IPM program were averaged. Additionally, fifty mango fruits (varieties “Tommy” and “Red India”) were harvested from each orchard and taken to the laboratory at Sokoine University of Agriculture (SUA). Fruits were washed, weighed and placed in individual rearing containers to monitor the number and species of emerging flies. Procedures used by Mwatawala et al. (2006a) were followed.

Infestation rate was determined as the number of adult fruit flies per unit weight of fruits. Incidence was determined as the number of positive samples out of total number of samples (Cowley et al., 1992). One-way ANOVA was used to analyze the data that were first transformed to improve normality. Analytic Hierarchy Process (AHP) (Saaty, 1980) was used to determine the program that would give the greatest benefit to the farmers. A set of evaluation criteria consisted of Cost Benefit Ratio (CBR), environmental protection and consumer safety ($m = 3$). A set of alternative options among which the decision was made consisted of the three IPM programs ($n = 3$). The weights for each evaluation criterion were generated and for each criterion, the score was assigned according to the pairwise comparisons of the options (on a scale of 1–9). Finally the criteria weights and the option scores were used to compute the global score for a given option, as a weighted sum of the scores obtained with respect to all the criteria. The ranking of criteria and alternatives was based on results presented by Nyavanga (2011) and available literature.

Table 1
Description of orchards.

Farm	Location	Latitude	Longitude	Elevation	Varieties
SUA	Magadu, Morogoro	S6°50′	E37°39′	526	Tommy, Kent
Mazimbu	Mazimbu, Morogoro	S6°47′	E37°37′	500	Tommy, Kent
JKT	Tungi, Morogoro	S6°48′	E37°41′	520	Tommy, Kent
Magunguli	Mikese, Morogoro	S6°46′	E37°55′	387	Tommy, Kent
Maerere	Mikese, Morogoro	S6°46′	E37°56′	386	Tommy, Kent
Assey	Mikese, Morogoro	S6°48′	E37°55′	387	Tommy, Kent
Lasway	Mikese, Morogoro	S6°44′	E37°51′	478	Tommy, Red India
Mamiro	Mikese, Morogoro	S6°44′	E37°51′	453	Tommy, Red India
Semoka	Mlali, Morogorp	S6°58′	E37°32′	592	Tommy, Kent
Kachemela	Mlali, Morogoro	S6°57′	E37°29′	501	Tommy, Red India
Juma	Kingolwira, Morogoro	S6°49′	E37°43′	526	Tommy, Kent
Anna Temu	Kingolwira, Morogoro	S6°48′	E37°44′	514	Tommy, Kent
Urio	Mzumbe, Morogoro	S6°53′	E37°36′	516	Tommy, Red India
Sibuga	Mkundi, Mvomero	S6°39′	E37°36′	505	Tommy, Kent

Table 2
Seasonal allocation of treatments in the orchards.

Program	Farm				
	Year 1	Year 2	Year 3	Year 4	Year 5
Spinosad based IPM	Kachemela Maerere	Maerere Mazimbu	Urio Anna Temu	Mamiro Urio	Semoka Kachemela
Insecticide based IPM	Semoka Mazimbu	Semoka Kachemela	Magunguli Juma	Juma Singano	JKT Juma
Derris based IPM	Sibuga Assey	Mamiro Assey	Kachemela JKT	JKT Kachemela	Singano Mamiro

3. Results

3.1. Bioassay

Bioassay results show that the median effective dose obtained in this bioassay was 9.0 g/0.5 L (see also Fig. 1). This implies that, when 9.0 g of *D. elliptica* powder is soaked overnight in 0.5 L of neural soap solution and the solution exposed to a population of *B. dorsalis* for 6 h, half of the population of the adult fruit flies will be killed. The probability of Pearson Goodness-of-Fit-Chi Square value ($p = 0.62$, $df = 4$) is greater than confidence level (0.05) indicating that mortalities were not random, but dependent on the concentration of the toxicant (Table 3).

3.2. Incidence, infestation rates and trap catches of B. dorsalis

Incidence of *B. dorsalis* was not significantly different (LSD = 1.553, df = 12, p = 0.667) among fruits from different orchards (Fig. 1). The lowest incidence of *B. dorsalis* was recorded in fruits harvested from orchards under Success bait treatment, while the highest incidence was recorded in fruits from orchards under molasses bait treatment (Fig. 1)

Incidences ranged from 9 to 25%, 2–15.56% and 4–17.5% in mangoes harvested from molasses bait, Success bait and insecticide treated orchards respectively.

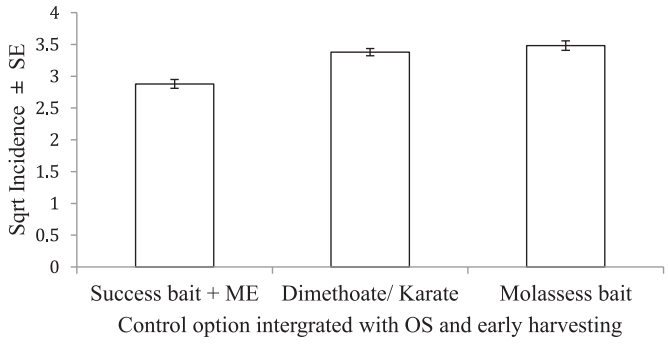

Fig. 1. Incidence of *Bactrocera dorsalis* in mango (OS = Orchard Sanitation).

Fig. 2 presents results on the effects of control methods on infestation rates. Fruits harvested from orchards under Success bait treatment were least infested by *B. dorsalis*. Infestation rates ranged from 0.58 to 2.52%, 0.004–1.7%, and 0.4–2.03% in mango from orchards under Success bait, molasses l bait and dimethoate/karate treatments respectively. However, infestation rates were not significantly different (LSD = 0.207, df = 12, p = 0.678) among fruits under different treatments (Fig. 2).

The catches of flies per trap per week were statistically similar (LSD = 77.49, df = 2, p = 0.753) among orchards under three programs (Fig. 3). The number of trapped flies per week ranged from 26.0 to 84.7, 14.5 to 186.9, and 13.7 to 150.0 in orchards under molasses bait, Success bait and insecticide treatments respectively.

The pairwise correlations between incidence, infestation and trap catches were all positive (Table 4). The correlation was highest between incidence and infestation rate and lowest between infestation rates and trap catches.

3.3. Analytical hierarchy process

Results of AHP show that, of the three criteria used to select a management option, CBR ranked highest followed by health and environmental protection. Molasses bait ranked highest in achieving the combined IPM goal of high CBR, environmental protection and consumer safety (Table 5). Insecticides ranked highest in achieving a single goal of profit maximization but ranked lowest in achieving the combined goals of environmental protection and consumer safety.

4. Discussion

This study reports the effectiveness of three IPM programs against *B. dorsalis*. The study also reports the lethal concentration of crude extracts of *D. elliptica* against the pest. *D. elliptica*, is a climbing shrub, whose roots are used for preparing insecticides. Roots of *D. elliptica* contain many compounds, such as rotenoids,

Table 3
Mortalities of *Bactrocera dorsalis* at different concentrations of *Derris elliptica*.

Log Conc.	Subjected (%) (n)	Probit	Observed response (%) (r)	Expected probit (ep)	Expected response (%) (np)	Residual (r−np)	$(r-np)^2-np(1-P)$	Prob.
0.70	100	4.69	38	4.80	42	−3.946	0.64	0.41946
1.18	100	5.36	64	5.21	58	5.551	1.26	0.58449
1.48	100	5.55	71	5.47	68	2.694	0.33	0.68306
1.65	100	5.61	73	5.62	74	−0.567	0.02	0.73567
1.78	100	5.67	75	5.73	77	−2.010	0.23	0.77010
1.88	100	5.77	78	5.82	79	−1.498	0.14	0.79498
						X^2	2.62	0.622

Chi-Square Goodness-of-Fit Chi Square (χ^2) is 2.626, df = 4, p = 0.622. Confidence interval at 95%.

isoflavones, ceramides and rotenoids (Wu et al., 2012). LC_{50} values reported in this work are higher compared to values reported from other studies (see Mangan, 2009; McQuate et al., 2005; Wang et al., 2013; Yee and Chapman, 2013; Zhang et al., 2015). The concentration and dose of toxicants used to kill 50% of a population of fruit flies are variable depending on species and insecticidal compound. Lower LC_{50} values could be attained if we used refined compounds rather than crude extracts of the toxicant.

This study showed that the three tested IPM programs do not differ significantly in reducing incidences and infestation rates of *B. dorsalis* in mango. The components of the tested IPM programs have been used in various combinations in management of fruit flies in many fruits producing regions. Methyl eugenol, a powerful parapheromone for *Bactrocera* species (Peña et al., 1998) successfully in controlled *B. dorsalis* in Ouahu (Steiner and Lee, 1959) and Pakistani (Mohyuddin and Mahmood, 1993). Parapheromones like methyl eugenol are preferred because they safer for workers and more convenient to handle and apply (Benelli et al., 2014).

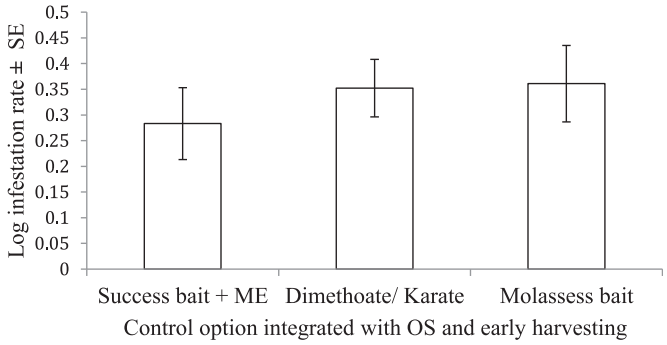

Fig. 2. Infestation rate of *Bactrocera dorsalis* in mango (OS = Orchard Sanitation).

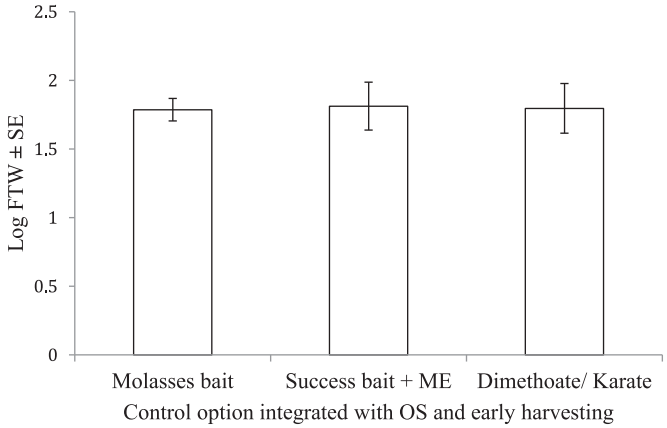

Fig. 3. Catches of adult *Bactrocera dorsalis* per trap per week (FTW = Fruit flies per trap per week, OS = Orchard Sanitation).

Synthetic insecticides were a component of a successful IPM program for *B. dorsalis* in mango in India (Verghese et al., 2004). However, conventional insecticide sprays have been associated with fly resistance, environmental pollution and health problems. Farmers targeting local, non-organic markets can use synthetic insecticides to control fruit flies.

GF 120 (Mangan et al., 2006), eco-friendly bait for fruit flies (Vargas et al., 2002) was also used successfully against *B. dorsalis* in some African countries (Ekesi et al., 2010; Vayssières et al., 2009). GF 120 is sold as Success bait in East Africa. High cost of Success bait limits its application by smallholder farmers in Africa (Vayssières et al., 2009). IPM program based on spot application of Success bait is suitable for farmers targeting export markets.

Brewery yeast waste and molasses, cheap sources of protein and sugar respectively, can be formulated and used as cheap baits for fruit flies. Brewery yeast waste was used to control of fruit flies in Australia (Lloyd and Drew, 1997) and Mauritius (Seewooruthun et al., 1998, 2000; Sookar et al., 2002). Plant extracts gave promising results as toxicants (Benelli et al., 2012; Canale et al., 2013) or attractants (Verghese et al., 2004) and can be used in formulating baits for fruit flies. Most extracts from plants do not pose health risks and degrade easily in the environment. The main disadvantages of plants extracts are lack of standard methods of processing and application, longer processing time and in large quantities used per unit area/volume.

Insecticides are not environmental friendly but gave high CBRs because of reduced labor costs and less time and frequency of application (once in two weeks). Success bait is environmental friendly although expensive, less available, and applied frequently compared to conventional insecticides. Molasses, brewery yeast waste and *D. elliptica* are cheap, easily accessible and friendly to the environment.

Nyavanga (2011) performed cost-benefit analysis of the IPM programs reported in this paper. The molasses bait based IPM program gave highest CBR followed by insecticide-based program. Orchards under an insecticide based IPM, gave the highest Net Present Value (NPV) followed by molasses bait based IPM. Orchards under Success bait based IPM had lowest NPV because benefit is outweighed by the cost.

In conclusion, the three tested IPM programs did not differ significantly in their effects on reducing flies population as well as

Table 4
Correlations of *B. dorsalis* infestation, incidence and catches.

Association	Pearson	R^2	p value
Incidence vs infestation rate	0.998	0.997	0.035
Incidence vs catches	−0.86	0.741	0.34
Infestation rate vs catches	−0.831	0.691	0.375

Table 5
Ranking of IPM programs based Cost Benefit Ratio, health and environmental benefits.

Weights (eigen vector)						Rank
Criteria		Alternatives	CBR (0.63)	Health (0.24)	Environment (0.14)	
CBR	0.625	Insecticide	0.58	0.076	0.058	0.390
Health	0.238	GF 120	0.069	0.46	0.47	0.217
Environment	0.136	Molasses bait	0.34	0.46	0.47	0.392
Maximum eigen value	3.018		3.032	3	3	
Consistency index	0.0091		0.01618	0	0	

in reducing damage to mango fruits as assessed by incidence and infestation rates. There is a potential of incorporating botanical extracts in baits for controlling *B. dorsalis*. However, further studies on simple and efficient methods of extracting botanical toxicants should be undertaken. Botanical extracts from other plants should also be tested in multiple locations, for multiple species and fruits.

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