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## Developing an Integrated Management Approach for the Fruit Fly *Dacus punctatifrons* on Tomatoes

Nelson N. Ntonifor<sup>1\*</sup>, Divine N. S. Nsobinenyui<sup>2</sup>, Eric B. Fokam<sup>2</sup>  
and Lum A. Fontem<sup>3</sup>

<sup>1</sup>Department of Biochemistry and Molecular Biology, Faculty of Science, University of Buea, P.O. Box 63, Buea, Cameroon.

<sup>2</sup>Department of Zoology and Animal Physiology, Faculty of Science, University of Buea, P.O. Box 63, Buea, Cameroon.

<sup>3</sup>Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture and Veterinary Medicine, University of Buea, P.O. Box 63, Buea, Cameroon.

### Authors' contributions

This work was carried out in collaboration between all authors. Author NNN designed the study, wrote the experimental procedures and the first draft of the manuscript. Author DNSN performed the studies supervised by authors EBF and LAF. Author LAF also performed the statistical analysis. All authors read and approved the final manuscript.

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### ABSTRACT

**Aims:** To document the various insecticides employed and also test alternative and/or complementary less-toxic and eco-friendly management methods against the notorious fruit fly *Dacus punctatifrons* on tomatoes as potential components of a multi-pronged eco-friendly integrated approach for this pest.

**Study Design:** Random interviewing of tomato farmers and field testing of different pest management methods in a randomized block design.

**Place and Duration of Study:** Interviewed farmers in Buea and its environs. Field experiments at the Research Farm of the University of Buea, South Western Cameroon. October 2010 to September 2011.

**Methodology:** Structured questionnaires administered to 110 farmers to document how they managed *Dacus punctatifrons* on their tomatoes and testing the efficacy of *Piper*

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\*Corresponding author: Email: [ntonifor@yahoo.com](mailto:ntonifor@yahoo.com);

*guineense* aqueous extract, cultural practices like staking, pruning and farm sanitation against this pest in field studies.

**Results:** Most of the farmers, 58(52.73%) cited *Dacus punctatifrons* as their main insect pest on tomatoes. All the farmers used conventional insecticides injudiciously to control the insect pests. The synthetic pyrethroid, Cypercal<sup>®</sup> 50EC was the most popular insecticide used. The numbers of fruits with fruit fly damage signs, and number of adult flies that emerged from plots treated with *Piper guineense* seed extract were not significantly different from those of plots treated with the neonicotinoid Parastar<sup>®</sup> 40EC insecticide. These two treatments were significantly superior to the untreated control plots and those where the plants were staked, regularly weeded and judiciously pruned. Fallen fruits and those harvested from farms even up to five weeks after farmers had harvested all marketable fruits still contained *Dacus punctatifrons* larvae that eventually developed into adults which emerged after laboratory incubation.

**Conclusion:** Integrating the judicious use of appropriately formulated insecticides, *Piper guineense* aqueous seed extract, early detection, collection and destruction of fruit fly-infested tomato fruits and destruction of crop residue after harvest can be a sustainable and reduced-risk multi-trigger management system for *Dacus punctatifrons* on tomatoes.

**Keywords:** *Piper guineense*; aqueous extract; cultural practices; fruit fly management.

## 1. INTRODUCTION

Tomato, *Solanum lycopersicum* is one of the most popular vegetables grown all over the world [1]. It is a versatile fruit vegetable that can be eaten fresh or in a variety of processed forms such as tomato preserves (e.g. tomato juice, tomato paste), dried tomato fruits and tomato based foods such as tomato soup and tomato sauces [2]. Tomatoes are a good source of vitamin C, folate, pro-vitamin A and potassium. One of its micronutrients lycopene, a carotenoid that gives the red colour of the fruit helps to prevent some major diseases, such as some types of cancer and heart disease [3]. Lycopene induces cell-to-cell communication, inhibits tumour cell proliferation, represses insulin-like growth factor receptor activation and improves anti-tumour immune response [4,5]; this thus makes tomato a vital functional food source.

Tomato production provides both income and employment to small-holder and medium-scale commercial farmers in Cameroon since some of the harvest is for domestic consumption and the rest sold locally and/or exported to other countries of the central African sub-region. As an important ingredient in most diets, tomato also greatly improves the dietary habits of most Africans in general due to the increased consumption of this micronutrient-rich vegetable. In spite of the economic importance of tomato, its cultivation in Cameroon is seriously hampered by varied insect pests and diseases. The most notorious of these pests is the polyphagous fruit fly, *Dacus punctatifrons* Karsch (Diptera: Tephritidae) which causes enormous losses of marketable tomato fruits [6]. Previously reported as primarily a pest of Cucurbits in many African counties [7], *D. punctatifrons* became a prominent pest on tomatoes in the Centre and Southern regions of Cameroon in the early nineties when high infestations at times compelled some farmers to abandon entire tomato fields [8]. Since then, *D. punctatifrons* has emerged as one of the most prevalent and destructive insect pests in most tomato fields in Cameroon [6,9]. The female fly lays a cluster of eggs in the flesh of unripe tomato fruits and the ensuing larvae feed and complete their development in the fruit pulp then drop to pupate in the soil. In view of the concealed

feeding habits of the larvae of this fruit fly, the widespread trans-border tomato trade in the central African region and the non-respect/enforcement of quarantine regulations in most parts of Africa, it is likely that this fruit fly has or will spread into other tomato producing areas of central Africa. Faced with enormous fruit fly-induced tomato fruit losses and subsequent loss of market opportunities, coupled with the lack of trained local personnel in fruit fly management, farmers resorted to a widespread use of varied synthetic conventional insecticides against *D. punctatifrons* on tomatoes. However, given that at times some of the tomato fruits are consumed raw like in salads, the use of conventional chemical insecticides on the crop should be done with caution since it may lead to the accumulation of undesirable toxic residues on the fruits. The potential environmental and consumer health hazards associated with toxic insecticide residues on tomato fruits thus underpin the need to search for alternative less toxic methods to manage the high population of *D. punctatifrons* on tomatoes.

Our hypothesis was therefore that cultural practices and use of potent plant extracts can be alternative or complementary eco-friendly options to integrate with judicious use of appropriately formulated synthetic insecticides to suppress the fruit fly population on tomatoes. Cultural practices like clean weeding of fields help to eliminate alternate hosts of insect pests while staking of tomato plants raises the fruits above the ground and facilitates the easy detection and collection of dropped fruits infested by fruit fly larvae. On the other hand, botanical insecticides are of interest because they contain natural chemicals which are easily biodegradable and often considered safe to handle and use on food products. Derivatives of the highly aromatic and hot tasting seeds of *Piper guineense* Schum et Thonn (Piperaceae) have been reported to be potential reduced-risk pesticides against various pests [10]. Seeds of *P. guineense* are known to have several insecticidal unsaturated isobutalamides, including piperidine, piperine and guineensine [11]. The objectives of this study were therefore to document the various types of insecticides employed against the fruit fly *D. punctatifrons* and also test the efficacy of aqueous seed extracts of *P. guineense* against the pest compared to conventional insecticides, as well as determine the effects of staking tomato plants, collection and destruction of fallen fruits on the fruit fly population on tomatoes in Buea, Cameroon as potential components of a multi-pronged management approach for the fruit fly.

## **2. MATERIALS AND METHODS**

### **2.1 Study Site**

The study was carried out from October 2010 to September 2011 in Buea situated at 247.89°N, 58.24°S, and 530m above sea level in South West Cameroon. The site is on the eastern slope of Mount Cameroon and 30 km from the Atlantic Ocean. It has a temperature range of 18-30°C, an annual rainfall of above 4,090 mm and an equatorial climate, with a long rainy season from April to mid-November and a short dry season from mid-November to March. Tomato production in this region is done mostly during the dry season.

### **2.2 Survey of Insecticides used against the Fruit Fly**

A structured questionnaire was used in the study. A total of 110 tomato farmers in the study site and its environs were involved in the survey. Each farmer was asked how long s/he had been growing tomatoes; when the crop was planted and harvested; the main insect pests of

the crop and the synthetic insecticides as well as constraints linked to the insecticide use and any other methods used to combat the pests.

### 2.3 Testing of Plant Extract and Cultural Practices

The tomato variety “Rio grande” known to be susceptible to *D. punctatifrons* was used in the study. Seeds of the variety were purchased and nursed for four weeks under shelter prior to transplanting to field plots. The experiment was laid out in a randomized block design with four treatments. Each treatment was allocated to a plot of 3 x 3 m and replicated four times. The treatments were: plots treated biweekly with 10% *P. guineense* aqueous seed extracts from full bloom stage till harvest; plots sprayed once bi-weekly with the insecticide Parastar<sup>®</sup> 40EC (20g/l imidachlopride+20g/l lambdacyhalothrine); Plots in which the plants were staked, pruned and all dropped fruits regularly removed from the field (cultural practice) and plots which were neither treated with the plant extract or insecticide nor cultural practices applied (untreated control). The insecticide was sprayed with a conventional knapsack using the recommended rate of the chemical.

Based on previous laboratory studies of different concentrations of *P. guineense* extracts on various nagging pests [12,13] and on *D. punctatifrons* [D. Nsobinyui, University of Buea, Cameroon, unpublished results] which revealed that 10% extracts were highly potent, this concentration was used in the field experiment. To prepare the 10% *P. guineense* aqueous extract, 500g of seed powder was weighed, soaked in 3 litres of cold water and allowed to stand for 24 hours. Thereafter, 1.5 litres of water were added to the mixture and then filtered through a fine cloth (mosquito net folded over). Then 20% each of detergent and starch solutions (500mL) were added to the filtrate. The detergent or starch solution was prepared by dissolving 50mg of the detergent or starch in 250mL of water). The aqueous seed extract was applied on the tomato plants to runoff once every two weeks using a conventional knapsack sprayer.

### 2.4 Count of *Dacus punctatifrons*-Induced Damaged Fruits

At 50% fruit ripening, ten plants from each plot were tagged and then the total numbers of fruits as well as those with *D. punctatifrons* damage symptoms counted separately. The fruits with fruit fly damage symptoms were harvested and all dropped fruits in each plot also collected. Each set of fruits was counted and put in a bucket whose bottom was lined with about 2 cm-thick sand layer that served as a pupation medium and also to absorb juice that oozed out of the fruits. The bucket was covered with plastic mesh fastened with a rubber band. The bucket and its contents were kept in the laboratory at ambient conditions to incubate for 20 days during which all *D. punctatifrons* adults that emerged were counted. The mean number of flies that emerged per fruit was then calculated as well as the percentage of adults that emerged per treatment as follows: (number of adult flies in a treatment/total number of flies in all treatments) x 100.

To assess the tomato fruit yield, all ripe fruits in each plot were harvested weekly, counted, weighed and at the end of the study the various numbers and weights of fruits were each summed up to have respectively, the total numbers of fruits and yield of each plot. The average mass of one fruit was also obtained by dividing the total mass of fruits from each plot by the total number of fruits from that plot.

The fruit yield and the total cost incurred in implementing each fruit fly management method were used to calculate the cost benefit ratio of each management option in order to determine the most effective and economical method.

## 2.5 Fruit Flies Sampling in Crop Leftovers

After farmers had harvested their marketable tomato fruits and left the fields to fallow, five farms were randomly selected in the study area for weekly sampling for fruit flies. Each week and for five consecutive weeks, ten fruits per farm were harvested, transported to the laboratory and incubated as described earlier for the emergence and counting of *D. punctatifrons* adults. The data was used to elucidate the population dynamics of fruit flies in tomato crop residues.

## 2.6 Statistical Analysis

Data collected was analyzed by one-way analysis of variance (ANOVA) using Minitab. Means were compared using Fisher (F-test) set at  $P=.05$  significant level

## 3. Results

### 3.1 Insecticides Used against Tomato Pests

Tomatoes were always grown in association with other crops. In order of decreasing importance, tomatoes were often intercropped with pepper>cabbage>okra>eggplant and green spices like leek and other Allium species. Among the pests, 58(52.73%) farmers indicated that fruit flies were the most important biological constraint.

The majority of farmers (92(83.64%)), used only conventional insecticides to control tomato insect pests and 18 (16.36%) used other non-chemical methods. For non-chemical methods, 14 (12.73%) used wood ash, 3(2.73%) used intercropping and 1(0.91%) removed (rouged) insect infested plants and fruits. Out of the 18 farmers who used non-chemical methods against insect pests, 13 (72.22%) used the alternative because of their low costs, 3(16.67%) because of low risk of intoxication and 2(11.11%) because they were readily available.

Each farmer used more than one type of insecticide against insect pests. In some cases, one insecticide containing the same active ingredient and concentration was sold to farmers under different trade names during the same cropping season; for example, Cypercal<sup>®</sup> 50 EC, Cigogne<sup>®</sup> 50EC and Cypalm<sup>®</sup> 50EC all contain 50g/l cypermethrine as active ingredient. Cypercal<sup>®</sup> 50 EC was the most widely used insecticide while Grethoate<sup>®</sup> was the least (Table 1).

**Table 1. Different insecticides used against fruit flies and other insect pests of tomatoes in Buea**

Trade name	Active ingredient(s)	Frequency
Cypercal <sup>®</sup> 50EC	50g/l cypermethrine	67
Parastar <sup>®</sup> 40EC	20g/l imidachlopride + 20g/l lambdacyhalothrine	65
Dimex <sup>®</sup> 400EC	400g/l dimethoate	49
Callidim <sup>®</sup> 200EC	200g/l dimethoate	37
Pacha <sup>®</sup> 25EC	10g/l acetamiprid + 15g/l lambdacyhalothrine	30
Pyriforce <sup>®</sup>	600g/l chlorpyriphos-ethyl	25
Cofresh-P <sup>®</sup> 100EC	100g/l cypermethrine	16
Cicogne <sup>®</sup> 50EC	50g/l cypermethrine	15
Karate <sup>®</sup> 45EC	45g/l lambdacyhalothrine	11
Callisulfan <sup>®</sup> 350EC	350g/l endosulfan	7
Malathane <sup>®</sup> 50EC	500g/l malathion	4
Cyplandim <sup>®</sup> 260EC	20g/l cypermethrine + 240g/l dimethoate	3
Plantac <sup>®</sup> 60	Alpha cypermethrine	3
K-optimal <sup>®</sup>	15g/l lambdacyhalothrine + 20g/l acetamipride	3
Plantima <sup>®</sup> 700WG	700g/Kg imidachloprid	3
Cypalm <sup>®</sup> 50EC	50g/l cypermethrine	2
Thionex <sup>®</sup> 35R EC	350g/l endosulfan	2
Cypercot <sup>®</sup>	50g/l cypermethrine	2
Grethoate <sup>®</sup>	400g/l dimethoate	1

*Active ingredients are as per the label of each insecticide.*

As regard the limitations of using these insecticides, 100 (90.9%) farmers indicated that they were expensive, 6(5.5) claimed the chemicals were not always effective while 4(3.6) reported that the pesticides were often not readily available. When spraying insecticides, 92(83.6%) of the farmers did not use appropriate protective clothing, nose masks or goggles while 18(16.4%) did.

As concerns when farmers started spraying against insects, 79(71.82%) stated that they started when the tomato was still in the nursery while the rest started treating at one to four weeks after transplanting. After the last insecticide application, 77(70.0%) farmers observed a pre-harvest period of less than one week, 31(28.18%) harvested between one to two weeks later while 2(1.82%) waited for a month before harvesting.

### 3.2 Effects of Various Treatments on Fruit Damage

Plots treated with either the Parastar<sup>®</sup> 40EC insecticide or *P. guineense* aqueous extract still had fruits with tiny black oviposition spots of *D. punctatifrons* which served as good signs of the fruit fly damage. There was no significant difference in fruit fly damage ( $P=0.05$ ) between plots treated with the conventional insecticide and *P. guineense* aqueous seed extract. However, plots treated with either the insecticide or the botanical had significantly fewer fruits damaged by *D. punctatifrons* compared to the control plots and those where cultural practices were applied (Table 2). A similar trend was observed for the total number of fruit flies that emerged, number per fruit and percentage of emerged adults after the laboratory incubation of fruits.

**Table 2. Mean number ( $\pm$ SD) of harvested tomato fruits with signs of *Dacus punctatifrons* infestation and adults that emerged after laboratory incubation**

Treatment	Number of fruits	of Emerged adults	Percentage of emerged adults	Adults per fruit
Plants staked at full bloom stage, pruned and plot sanitized	76.25 $\pm$ 20.77b	21.50 $\pm$ 7.19a	45.67	0.28 $\pm$ 0.04a
Plants treated with <i>Piper guineense</i> extract	26.25 $\pm$ 4.65a	4.33 $\pm$ 1.52b	9.20	0.19 $\pm$ 0.04b
Plants not staked nor treated with botanical or insecticide	60.00 $\pm$ 6.16b	19.00 $\pm$ 6.06a	40.36	0.31 $\pm$ 0.07a
Plants treated with Parastar <sup>®</sup> 40EC insecticide	13.75 $\pm$ 4.79a	2.25 $\pm$ 1.50b	4.78	0.16 $\pm$ 0.07b
F-value ( $P=.05$ )	26.21	14.76	-	6.89

Means with the same lower case letter in a column are not significantly different ( $P=.05$ )

The highest number of fallen fruits was collected from plots in which the cultural practices of staking and judicious pruning were applied, and this was significantly higher ( $P=.05$ ) than those of the other treatments, which were similar to each other. The number of *D. Punctatifrons* adults that emerged from fallen fruits collected from plots treated with the *P. guineense* extract was not significantly different from plots treated with the Parastar<sup>®</sup> 40 EC insecticide (Table 3).

**Table 3. Mean number ( $\pm$ SD) of dropped tomato fruits and *Dacus punctatifrons* adults that emerged after laboratory incubation**

Treatment	Number of fruits	of Emerged adults	Percentage of emerged adults	Adults per fruit
Plants staked at full bloom stage, pruned and plot sanitized	72.00 $\pm$ 26.05a	11.75 $\pm$ 5.91a	42.73	0.16 $\pm$ 0.04ab
Plants treated with <i>Piper guineense</i> extract	27.50 $\pm$ 7.59b	4.25 $\pm$ 3.20bc	15.45	0.16 $\pm$ 0.11ab
Plants not staked nor treated with botanical or insecticide	30.25 $\pm$ 6.29b	9.75 $\pm$ 5.56ab	35.45	0.32 $\pm$ 0.15b
Plants treated with Parastar <sup>®</sup> 40EC insecticide	33.75 $\pm$ 13.33b	1.75 $\pm$ 1.71c	6.36	0.06 $\pm$ 0.08b
F-value ( $P=.05$ )	7.36	4.40	-	4.07

Means with the same lower case letter in a column are not significantly different ( $P=.05$ )

The highest number of marketable fruits (223.25) was harvested from plots treated with the Parastar<sup>®</sup> 40EC insecticide and this was significantly different from the other treatments ( $P=.05$ ). The number of marketable fruits harvested from the plots treated with the *P. guineense* extract (126.25) was significantly higher than those of the plots where the cultural practices (82.25) were applied as well as the control plots (76.00) which were not different from each other. There were no significant differences between the treatments regarding the total fruit mass and mass of one fruit (Table 4).

**Table 4. Mean marketable tomato fruit yield from various treatments at harvest**

Treatment	Number of fruits	Mass (Kg) of Fruits	Mass (Kg) of one Fruits
Plants staked at full bloom stage, pruned and plot sanitized	82.25±27.16c	4.47±0.92a	0.057±0.009a
Plants treated with <i>Piper guineense</i> extract	126.25±65.81b	6.01±3.38a	0.048±0.003a
Plants not staked nor treated with botanical or insecticide	76.00±43.88c	3.51±1.83a	0.047±0.003a
Plants treated with Parastar® 40EC insecticide	223.25±52.32a	11.63±2.50a	0.052±0.007a
F-value (P=0.05)	7.81	9.49	2.06

Means with the same lower case letter in a column are not significantly different (P=.05)

The lowest cost benefit ratio (1:-0.14) was recorded in the cultural control where plants were staked, pruned and all dropped fruits removed regularly from the plots. The cost benefit ratio of plots treated with *P. guineense* aqueous extract (1:2.35) and that of the Parastar® 40EC insecticide (1:2.72) were similar (Table 5).

**Table 5. Cost: benefit analysis for the various treatments based on the projected sales of harvested tomato fruits in Central African Francs (frs CFA)**

Treatment	Yield (Kg/ha)	Yield increase (Kg/ha)	Price increase (frs CFA)	Cost incurred (frs CFA)	Profit	Cost benefit ratio
Plants staked at full bloom stage, pruned and plot sanitized.	4966.67	1077.78	431112	500,000	-68888	1:-0.14
Plants treated with <i>Piper guineense</i> extract.	6677.78	2788.89	1115556	333,333	782222	1:2.35
Plants not staked nor treated with botanical or insecticide (control).	3888.89	-	-	-	-	-
Plants treated with Parastar® 40EC insecticide.	12922.23	9033.34	3613336	972,222	2641114	1:2.72

Tomatoes sold at 400frs CFA per kilogram in 2012; \$1=500frs.

### 3.3 Fruit Flies from Crop Residues

Tomato fruit leftovers harvested from various farms even up to five weeks after farmers had harvested all their marketable fruits and abandoned the farms to fallow still contained larvae of *D. punctatifrons* that eventually completed their development to emerge as adults after the laboratory incubations. The number of adults that emerged varied from one farm to another and also over time (Fig. 1).



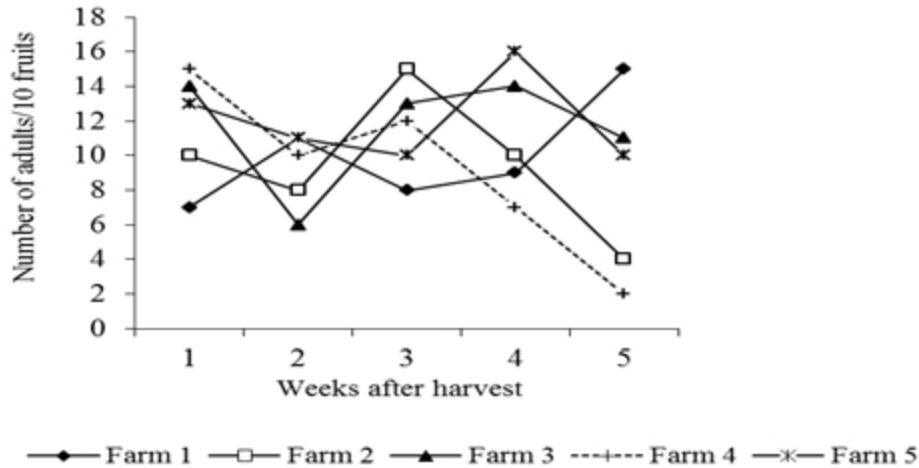


Fig. 1. Number of *Dacus punctatifrons* adults that emerged from tomato fruit leftovers collected from various farms after harvest

#### 4. DISCUSSION

Most farmers indicated that *D. punctatifrons* was the major biological constraint of tomato production in this study; though this fruit fly is a known pest of tomatoes in Cameroon [6, 8], its appropriate control measures on the crop have not been implemented. Also, in the study area, tomatoes are often intercropped with okra (*Abelmoschus esculentum*), pepper (*Capsicum* spp) which also serve as alternative host plants for *D. punctatifrons* [14]. The availability of these alternate plants may thus contribute to a high fruit fly population build-up since these alternate food sources may enable the pest to breed continuously round the year.

All the tomato farmers sprayed liquid formulations of synthetic insecticides to combat insect pests on their crop though this pest management strategy may not properly target the damaging larvae of fruit flies which feed and develop while concealed inside the tomato fruit pulp. Bait-based insecticide applications against fruit flies are more effective since the bait attracts the adults to the point of application where they ingest the insecticide during feeding and subsequently die [15]. The bulk of the survey respondents indicated that they start applying insecticides on tomatoes from the nursery or one to two weeks after transplanting which suggest that these chemicals are not only deployed solely against fruit flies but also to suppress other insects. Hence there is need for the design and implementation of a proper fruit fly management strategy targeted against the exposed adult flies so as to prevent them from ovipositing on the fruits. The repeated indiscriminate and injudicious use of insecticides such as the synthetic pyrethroids (cypermethrine, lambda-cyhalothrine) and neonicotinoids (imidachlopride, acetamypid) may kill beneficial natural enemies of the fruit flies [16] or hasten the development of resistance to these chemicals by *D. punctatifrons* and also cause environmental and health problems occasioned by a build-up of toxic insecticide residues on tomatoes. The fact that most of the farmers did not even respect pre-harvest intervals further increases the likelihood of accidental human insecticide intoxication. Some of the farmers were actually aware of the potential negative effects of insecticides since a few of them did not use insecticides alluding to high cost, unavailability and risk of human toxicity as well as

environmental pollution as reasons for adopting other options of controlling the fruit flies. This is indicative of the readiness of these farmers to embrace more environmentally-friendly methods such as the destruction of infested plants or fruits and use of botanical extracts to control fruit flies on tomatoes. Plots treated with *P. guineense* aqueous seed extracts were not significantly different from those treated with the neonicotinoide (Parastar<sup>®</sup>) insecticide in terms of the fruit fly damage signs thus suggesting that the extract is effective in suppressing *D. punctatifrons* populations due to its anti-insect effects [10]. Earlier studies [17] reported that *P. guineense* has hallucinating effects against insect pests, which die within 10-15 minutes of contact with the extract. The piper species including *P. guineense* are reported to contain piperamides known to be neurotoxic to insects [18]. Since *P. guineense* is used as a culinary spice in food without any reported toxic effects to humans, it could also be used in the field as a low-risk insecticide to protect tomato fruits, which are often also eaten raw in salads.

The cost benefit ratios of using the synthetic insecticide or *P. guineense* extract were similar which indicate that these options can be used alternatively to minimize the sole reliance on the potentially more hazardous conventional insecticides. Taking into consideration the tomato crop phenology, if it is inevitable to protect the fruits at one to two weeks before harvest then the comparatively safer *P. guineense* extract should be used given that the seeds of this plant are readily affordable and available in the local markets and the aqueous extract is also easy to prepare. The cost benefit ratio of the cultural practice which also involved pruning of the plants was lowest presumably because some of the pruned branches were destined to produce fruits and thus removing them resulted in lower fruit yield and hence reduced the cost benefit ratio. Therefore only staking with its associated advantages should be used.

The higher the number of fruits with tiny black spots on them, the higher the number of *D. Punctatifrons* adults that emerged confirming that the tiny black dots are reliable signs of the fruit fly infestations as earlier observed [6]. Hence farmers can exploit these signs to early detect, remove and destroy infested fruits as a cultural practice to suppress the build-up of *D. punctatifrons* populations on tomatoes. In addition, staking the plants raises the fruits from the ground thus facilitating the early detection of the infested ones for harvesting and destruction. The numbers of dropped fruits from plants that were staked and plots sanitized were significantly higher than from those that were not staked understandably so because staking together with clean weeding eased the detection and collection of all fallen fruits. Therefore, early detection and harvesting of tomato fruits with fruit fly infestation signs coupled with regular and timely collection of all fallen fruits for destruction or burial can be complementary cultural measures to minimize the pest population build-up.

Furthermore, since *D. punctatifrons* adults consistently emerged from tomato fruit leftovers harvested from plants even up to five weeks after farmers had harvested and abandoned the farms implies that the flies keep on breeding on the fruit leftovers during the tomato production off season. Such continuous breeding obviously enables this fly to develop a large carry-over population that subsequently reinvades farms during the next planting season since the prevailing tropical environmental conditions are conducive for insect survival and breeding all year round. Consequently, gathering up and burying or destroying all tomato crop residues after harvest can be a vital supplementary cultural measure to alleviate the fruit fly problem on tomatoes.

## 5. CONCLUSION

Despite the widespread use of varied conventional insecticides by farmers to suppress the fruit fly problem on tomatoes, this pest remains the most important biological constraint to increased production of the crop. Application of the synthetic insecticide and aqueous extract of *P. guineense* each was only able to partially reduce the population of these fruit flies. Staking of the tomato plants and clean weeding of fields facilitated the detection and collection of infested and/or fallen fruits for destruction. Tomato crop leftovers after harvest harboured high populations of *D. punctatifrons*. Therefore, integrating the use of *P. guineense* aqueous extract, staking and clean weeding of fields to ease detection, collection and destruction of infested fruits, burning/deep burying of crop residues coupled with judicious use of appropriately formulated insecticides may enable small scale farmers to sustainably manage the build-up of *D. punctatifrons* populations in tomato farms. The efficacy of this multi-component reduced-risk approach will need to be tested in field studies.

## ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 declaration of Helsinki.

## COMPETING INTERESTS

Authors declare that no competing interest exists.

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