

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

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26 ABSTRACT

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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 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® 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® 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.

Key words: *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

52 primarily a pest of Cucurbits in many African counties [7], *D. punctatifrons* became a
 53 prominent pest on tomatoes in the Centre and Southern regions of Cameroon in the early
 54 nineties when high infestations at times compelled some farmers to abandon entire tomato
 55 fields [8]. Since then, *D. punctatifrons* has emerged as one of the most prevalent and
 56 destructive insect pests in most tomato fields in Cameroon [6, 9]. The female fly lays a
 57 cluster of eggs in the flesh of unripe tomato fruits and the ensuing larvae feed and complete
 58 their development in the fruit pulp then drop to pupate in the soil. In view of the concealed
 59 feeding habits of the larvae of this fruit fly, the widespread trans-border tomato trade in the
 60 central African region and the non-respect/enforcement of quarantine regulations in most
 61 parts of Africa, it is likely that this fruit fly has or will spread into other tomato producing areas
 62 of central Africa. Faced with enormous fruit fly-induced tomato fruit losses and subsequent
 63 loss of market opportunities, coupled with the lack of trained local personnel in fruit fly
 64 management, farmers resorted to a widespread use of varied synthetic conventional
 65 insecticides against *D. punctatifrons* on tomatoes. However, given that at times some of
 66 the tomato fruits are consumed raw like in salads, the use of conventional chemical
 67 insecticides on the crop should be done with caution since it may lead to the accumulation of
 68 undesirable toxic residues on the fruits. The potential environmental and consumer health
 69 hazards associated with toxic insecticide residues on tomato fruits thus underpin the need to
 70 search for alternative less toxic methods to manage the high population of *D. punctatifrons*
 71 on tomatoes.

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73 Our hypothesis was therefore that cultural practices and use of potent plant extracts can be
 74 alternative or complementary eco-friendly options to integrate with judicious use of
 75 appropriately formulated synthetic insecticides to suppress the fruit fly population on
 76 tomatoes. Cultural practices like clean weeding of fields help to eliminate alternate hosts of
 77 insect pests while staking of tomato plants raises the fruits above the ground and facilitates
 78 the easy detection and collection of dropped fruits infested by fruit fly larvae. On the other

79 hand, botanical insecticides are of interest because they contain natural chemicals which are
 80 easily biodegradable and often considered safe to handle and use on food products.
 81 Derivatives of the highly aromatic and hot tasting seeds of *Piper guineense* Schum et Thonn
 82 (Piperaceae) have been reported to be potential reduced-risk pesticides against various
 83 pests [10]. Seeds of *P. guineense* are known to have several insecticidal unsaturated
 84 isobutalamides, including pipericide, piperine and guineensine [11]. The objectives of this
 85 study were therefore to document the various types of insecticides employed against the fruit
 86 fly *D. punctatifrons* and also test the efficacy of aqueous seed extracts of *P. guineense*
 87 against the pest compared to conventional insecticides, as well as determine the effects of
 88 staking tomato plants, collection and destruction of fallen fruits on the fruit fly population on
 89 tomatoes in Buea, Cameroon as potential components of a multi-pronged management
 90 approach for the fruit fly.

91 92 **2. MATERIALS AND METHODS**

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95 **2.1. Study Site:** The study was carried out from October 2010 to September 2011 in Buea
 96 situated at 247.89°N, 58.24°S, and 530m above sea level in South West Cameroon. The site
 97 is on the eastern slope of Mount Cameroon and 30 km from the Atlantic Ocean. It has a
 98 temperature range of 18-30°C, an annual rainfall of above 4,090 mm and an equatorial
 99 climate, with a long rainy season from April to mid-November and a short dry season from
 100 mid-November to March. Tomato production in this region is done mostly during the dry
 101 season.

102
 103 **2.2. Survey of insecticides used against the fruit fly:** A structured questionnaire was
 104 used in the study. A total of 110 tomato farmers in the study site and its environs were
 105 involved in the survey. Each farmer was asked how long s/he had been growing tomatoes;
 106 when the crop was planted and harvested; the main insect pests of the crop and the

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

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110 **2.3. Testing of Plant Extract and Cultural Practices**

111 The tomato variety “Rio grande” known to be susceptible to *D. punctatifrons* was used in the
112 study. Seeds of the variety were purchased and nursed for four weeks under shelter prior to
113 transplanting to field plots. The experiment was laid out in a randomized block design with
114 four treatments each replicated four times. The treatments were: plots treated biweekly with
115 10% *P. guineense* aqueous seed extracts from full bloom stage till harvest; plots sprayed
116 once bi-weekly with the insecticide Parastar[®] 40EC (20g/l imidachlopride+20g/l
117 lambdacyhalothrine); Plots in which the plants were staked, pruned and all dropped fruits
118 regularly removed from the field (cultural practice) and plots which were neither treated with
119 the plant extract or insecticide nor cultural practices applied (untreated control). The
120 insecticide was sprayed with a conventional knapsack using the recommended rate of the
121 chemical.

122 To prepare 10% *P. guineense* aqueous seed extract, 500g of seed powder was weighed,
123 soaked in 3 litres of cold water and allowed to stand for 24 hours. Thereafter, 1.5 litres of
124 water were added to the mixture and then filtered through a fine cloth (mosquito net folded
125 over). Then 20% each of detergent and starch solutions (500mL) were added to the filtrate.
126 The detergent or starch solution was prepared by dissolving 50mg of the detergent or starch
127 in 250mL of water). The aqueous seed extract was applied on the tomato plants to runoff
128 once every two weeks using a conventional knapsack sprayer.

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130 **2.4. Count of *Dacus punctatifrons*-induced Damaged Fruits**

131 At 50% fruit ripening, ten plants from each plot were tagged and then the total numbers of
132 fruits as well as those with *D. punctatifrons* damage symptoms counted separately. The
133 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.

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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.

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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.

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2.6. Statistical Analysis

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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

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162 3. RESULTS

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164 3.1. Insecticides used against tomato pests

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

169 The majority of farmers (92(83.64%)), used only conventional insecticides to control tomato
170 insect pests and 18 (16.36%) used other non-chemical methods. For non-chemical
171 methods, 14 (12.73%) used wood ash, 3(2.73%) used intercropping and 1(0.91%) removed
172 (rouged) insect infested plants and fruits. Out of the 18 farmers who used non-chemical
173 methods against insect pests, 13 (72.22%) used the alternative because of their low costs,
174 3(16.67%) because of low risk of intoxication and 2(11.11%) because they were readily
175 available.

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

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

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

207 reported that the pesticides were often not readily available. When spraying insecticides,
208 92(83.6%) of the farmers did not use appropriate protective clothing, nose masks or goggles
209 while 18(16.4%) did.

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

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216 **3.2. Effects of various treatments on fruit damage**

217 Plots treated with either the Parastar[®] 40EC insecticide or *P. guineense* aqueous extract still
218 had fruits with tiny black oviposition spots of *D. punctatifrons* which served as good signs of
219 the fruit fly damage. There was no significant difference in fruit fly damage ($P=.05$) between
220 plots treated with the conventional insecticide and *P. guineense* aqueous seed extract.
221 However, plots treated with either the insecticide or the botanical had significantly fewer
222 fruits damaged by *D. punctatifrons* compared to the control plots and those where cultural
223 practices were applied (Table 2). A similar trend was observed for the total number of fruit
224 flies that emerged, number per fruit and percentage of emerged adults after the laboratory
225 incubation of fruits.

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

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239	Treatment	Number of	Emerged	Percentage of	Adults per
240		Fruits	adults	emerged adults	fruit
241					
	Plants staked at full bloom	76.25 $\pm$ 20.77b	21.50 $\pm$ 7.19a	45.67	0.28 $\pm$ 0.04a
	stage, pruned and plot				
	sanitized				
	Plants treated with	26.25 $\pm$ 4.65a	4.33 $\pm$ 1.52b	9.20	0.19 $\pm$ 0.04b
	<i>Piper guineense</i> extract				
	Plants not staked nor treated	60.00 $\pm$ 6.16b	19.00 $\pm$ 6.06a	40.36	0.31 $\pm$ 0.07a
	with botanical or insecticide				
	Plants treated with Parastar [®]	13.75 $\pm$ 4.79a	2.25 $\pm$ 1.50b	4.78	0.16 $\pm$ 0.07b
	40EC insecticide				
	F-value ($P=.05$)	26.21	14.76	-	6.89

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

244
 245 The highest number of fallen fruits was collected from plots in which the cultural practices of
 246 staking and judicious pruning were applied, and this was significantly higher ($P=.05$) than
 247 those of the other treatments, which were similar to each other. The number of *D.*
 248 *Punctatifrons* adults that emerged from fallen fruits collected from plots treated with the *P.*
 249 *guineense* extract was not significantly different from plots treated with the Parastar[®] 40 EC
 250 insecticide (Table 3).

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

256 Treatment	257 Number of Fruits	258 Emerged adults	Percentage of emerged adults	Adults per fruit
Plants staked at full bloom				
stage, pruned and plot	72.00 $\pm$ 26.05a	11.75 $\pm$ 5.91a	42.73	0.16 $\pm$ 0.04ab
sanitized				
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 [®]				
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

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

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

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

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272 Treatment	273 Number of Fruits	274 Mass (Kg) of Fruits	Mass (Kg) of one fruit
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 (<i>P</i> =0.05)	7.81	9.49	2.06

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

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278 3.3. Fruit flies from crop residues

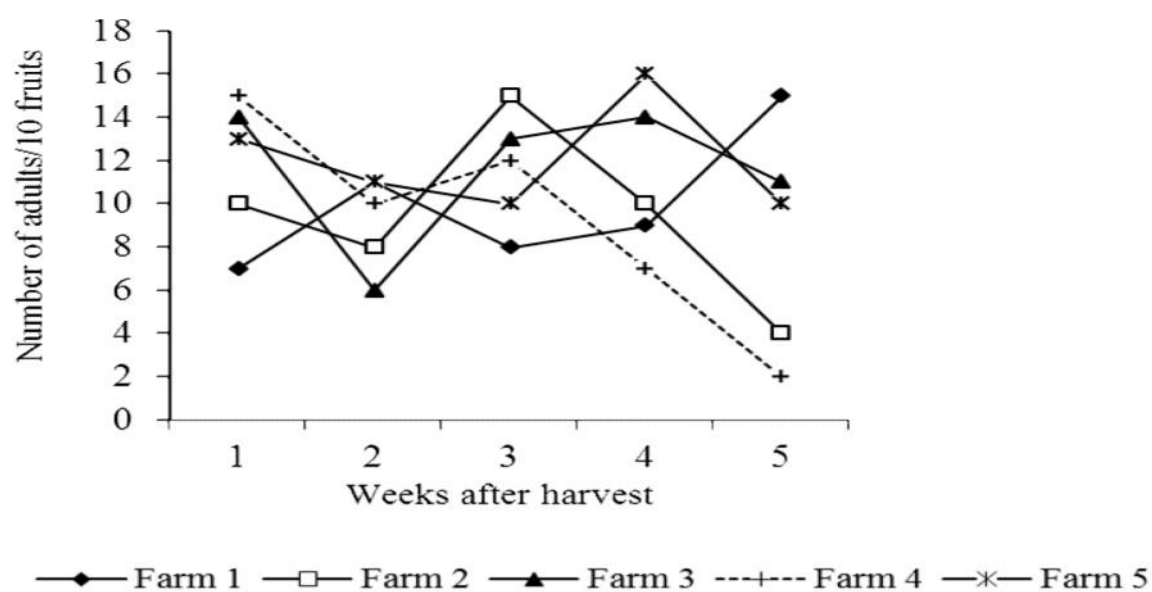
279 Tomato fruit leftovers harvested from various farms even up to five weeks after farmers had

280 harvested all their marketable fruits and abandoned the farms to fallow still contained larvae

281 of *D. punctatifrons* that eventually completed their development to emerge as adults after the

282 laboratory incubations. The number of adults that emerged varied from one farm to another

283 and also over time (Fig. 1).



284

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

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4. DISCUSSION

289 Most farmers indicated that *D. punctatifrons* was the major biological constraint of tomato
 290 production in this study; though this fruit fly is a known pest of tomatoes in Cameroon [6, 8],
 291 its appropriate control measures on the crop have not been implemented. Also, in the study
 292 area, tomatoes are often intercropped with okra (*Abelmoschus esculentum*), pepper
 293 (*Capsicum* spp) which also serve as alternative host plants for *D. punctatifrons* [12]. The
 294 availability of these alternate plants may thus contribute to a high fruit fly population build-up
 295 since these alternate food sources may enable the pest to breed continuously round the
 296 year.

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298 All the tomato farmers sprayed liquid formulations of synthetic insecticides to combat insect
 299 pests on their crop though this pest management strategy may not properly target the
 300 damaging larvae of fruit flies which feed and develop while concealed inside the tomato fruit

301 pulp. Bait-based insecticide applications against fruit flies are more effective since the bait
302 attracts the adults to the point of application where they ingest the insecticide during feeding
303 and subsequently die [13]. The bulk of the survey respondents indicated that they start
304 applying insecticides on tomatoes from the nursery or one to two weeks after transplanting
305 which suggest that these chemicals are not only deployed solely against fruit flies but also to
306 suppress other insects. Hence there is need for the design and implementation of a proper
307 fruit fly management strategy targeted against the exposed adult flies so as to prevent them
308 from ovipositing on the fruits. The repeated indiscriminate and injudicious use of insecticides
309 such as the synthetic pyrethroids (cypermethrine, lambdacyhalothrine) and neonicotinoids
310 (imidachlopride, acetamypid) may kill beneficial natural enemies of the fruit flies [14] or
311 hasten the development of resistance to these chemicals by *D. punctatifrons* and also cause
312 environmental and health problems occasioned by a build-up of toxic insecticide residues on
313 tomatoes. The fact that most of the farmers did not even respect pre-harvest intervals
314 further increases the likelihood of accidental human insecticide intoxication. Some of the
315 farmers were actually aware of the potential negative effects of insecticides since a few of
316 them did not use insecticides alluding to high cost, unavailability and risk of human toxicity
317 as well as environmental pollution as reasons for adopting other options of controlling the
318 fruit flies. This is indicative of the readiness of these farmers to embrace more
319 environmentally-friendly methods such as the destruction of infested plants or fruits and use
320 of botanical extracts to control fruit flies on tomatoes. Plots treated with *P. guineense*
321 aqueous seed extracts were not significantly different from those treated with the
322 neonicotinoide (Parastar[®]) insecticide in terms of the fruit fly damage signs thus suggesting
323 that the extract is effective in suppressing *D. punctatifrons* populations due to its anti-insect
324 effects [10]. Earlier studies [15] reported that *P. guineense* has hallucinating effects against
325 insect pests, which die within 10-15 minutes of contact with the extract. The piper species
326 including *P. guineense* are reported to contain piperamides known to be neurotoxic to
327 insects [16]. Since *P. guineense* is used as a culinary spice in food without any reported

328 toxic effects to humans, it could also be used in the field as a low-risk insecticide to protect
329 tomato fruits, which are often also eaten raw in salads.

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

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

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355 **5. CONCLUSION**

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

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370 **COMPETING INTERESTS**

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372 Authors declare that no competing interest exists.

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374 **AUTHORS' CONTRIBUTIONS**

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376 Author NNN designed the study, wrote the experimental procedures and the first draft of the
 377 manuscript. Author DNSN performed the studies supervised by authors EBF and LAF.
 378 Author LAF also performed the statistical analysis. All authors read and approved the final
 379 manuscript.”

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