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Effectiveness of Four Integrated Pest Management Approaches in the Control of Fruit Flies (Diptera: Tephritidae) in Mango Agro-Ecosystems in the South-Sudanian Zone of Burkina Faso

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Abstract

This study evaluated the effectiveness of four Integrated Pest Management (IPM) approaches in the control of *Bactrocera dorsalis* (Hendel) [Diptera: Tephritidae] and *Ceratitis cosyra* (Walker) [Diptera: Tephritidae] during two consecutive mango fruiting seasons (2018 and 2019) in the south-Sudanian zone of Burkina Faso. These approaches, including sanitation + M3 bait station (SM), sanitation + protein GF-120 bait (SG), sanitation + Timaye + M3 bait station (STM) and sanitation + Timaye + GF-120 bait (STG), were implemented in 12 mango orchards in three provinces of the country. In each province, one mango orchard was used as control. Flies per trap per week (FTW) and damage indices were assessed in treated orchards compared to the control orchards. The efficacy rate of each IPM approach in protecting mango against fruit fly attacks was also determined. The STG approach was the most effective in reducing both *B. dorsalis* and *C. cosyra* FTW with the best efficacy rate. Further research should emphasize indigenous and affordable attract-and-kill tools for resource poor farmers.

Keywords

Bactrocera, *Ceratitis*, Control, IPM, Mango, Burkina Faso

1. Introduction

In Africa, exotic and indigenous fruits play an important role in food and nutrition [1]. Among exotic fruits, mango (*Mangifera indica* L.) is cultivated across much of Africa [1]. It is one of the most economically important tropical fruits in sub-Saharan Africa. Africa exported US$239.1 million worth of mangoes in 2017 [2], indicating the importance of fruit production in the region. Mango producing areas are located mostly in the subtropical and tropical zones of Burkina Faso, most of which are under phytosanitary management [3]. In Burkina Faso, mango is grown in over 33,701 ha, providing an annual production of approximately 400,000 tons [3].

Among factors that limit or affect mango production and marketing are insect pests, with fruit flies being the most devastating. They cause direct damage by reducing yields and indirect damage by disrupting national and international trade [4]. The crop loss due to fruit fly attack is higher during the wet season (late June to July) in Burkina Faso [5] and can reach 100% in late varieties, such as Keitt and Brooks. The mean average attack rates range from 0% to 6% during the early-mango fruiting season (April through May) and from 12.5% to 86.67% during the late-mango fruiting season (late June through early July) depending on the varieties [5].

In Africa, fruit flies of economic importance belong to the genera *Bactrocera*, *Ceratitis*, *Dacus*, *Trirhithrum* and *Zeugodacus* [6] [7]. Twenty-four fruit fly species were inventoried by mass trapping using sexual attractants in mango orchards in Western Burkina Faso, the main commercial mango growing area [8], including fruit flies from the genus Ceratitis (12 species) and Dacus (seven species). The exotic genera Bactrocera and Zeugodacus are represented by a single species, *B. dorsalis* (Hendel) and *Z. cucurbitae* (Coquillett), respectively [8]. Among the 24 species, *B. dorsalis* and *C. cosyra*, an indigenous species, are the major fruit fly pests, especially on mango. These two species are collectively responsible for more than 97% of damage caused to mango fruits [5] [8]. In the commercial mango production area of Burkina Faso, *C. cosyra* populations are higher at the end of the dry season, attacking mainly early and mid-varieties (April-May). Populations of *B. dorsalis* are low most of the year and only increase during the mango fruiting season, when growers have to apply repeated ground bait sprays to minimize infestations.

Under the favorable ecological conditions of the south-Sudanian zone of Burkina Faso that promote fruit fly abundance, effective pest management strategies are needed to produce fruits free of fruit fly damage. Control measures used by growers include bait spray with GF-120, use of Timaye and, to a lesser extent, orchard sanitation. Despite these available control tools, mango attacks by fruit flies remain a concern for small scale farmers and stakeholders involved in mango export. An example is the interception in 2021 of eight mango containers from Burkina Faso, weighing 152 tons because of fruit fly infestation in the European Union, resulting in a loss of US$300,000 [9]. In commercial mango production in Burkina Faso, mango growers generally adopt only one, or rarely two, "attract and kill" tools to prevent or control fruit fly attacks. However, previous studies pointed out that fruit fly management based on a single management technique is unlikely to be successful [10] [11].

The present study was initiated to evaluate combinations of several control techniques in the hope of reducing fruit fly damage on mango in three important mango growing provinces of Burkina Faso. Integrated Pest Management (IPM) strategies are currently recommended for more sustainable management of fruit flies in Africa [12] [13] [14]. Control tools against fruit flies exist in the form of behavioral control methods using attractants mixed with insecticides (baits and male annihilation technique), sanitation practices, biological control and sterile insect technique [15]. It is therefore crucial to introduce a combination of effective and efficient control tools, which must be mutually compatible and economically viable for growers in the mango commercial area of Burkina Faso.

The major aim of this study is to provide mango growers with an environmentally-friendly fruit fly control approach. To achieve this goal, it was necessary 1) to evaluate the effectiveness of some IPM components in protecting mango from fruit fly attacks in commercial mango production areas in Burkina Faso, and 2) to identify the best combination of control methods capable of reducing fruit fly population's densities and mango damage to an economically acceptable threshold.

2. Materials and Methods

2.1. Sites for Experimentation of IPM Approaches

Experiments were carried out in three major mango production provinces in the south-Sudanian zone of Burkina Faso during two consecutive mango fruiting seasons (2018 and 2019). These include Houet, Kénédougou and Comoé provinces. Five mango orchards were chosen in each province for the current study. The criteria for choosing mango orchards included: orchard accessibility during the rainy season, an available area of 2 ha, the presence of late mango varieties, such as Brooks and Keitt. **Figure 1** presents the geographical location of the selected mango orchards.

2.2. Treatment Description

The following control methods were used with four combinations: orchard sanitation, bait application technique (BAT) and male annihilation technique (MAT). BAT implementation involved the use of GF-120 bait (G) or M3 fruit fly bait (M), whereas MAT implementation involved the use of Timaye (T). Orchard sanitation (S) was the standard component in all the four IPM combinations. The combinations set up for the present study were 1) orchard sanitation + M3 fruit fly bait (SM), 2) orchard sanitation + GF-120 bait (SG), 3) orchard sanitation + Timaye + M3 fruit fly bait (STM) and 4) orchard sanitation + Timaye + GF-120 bait (STG). In each province, one mango orchard served as control (CO).

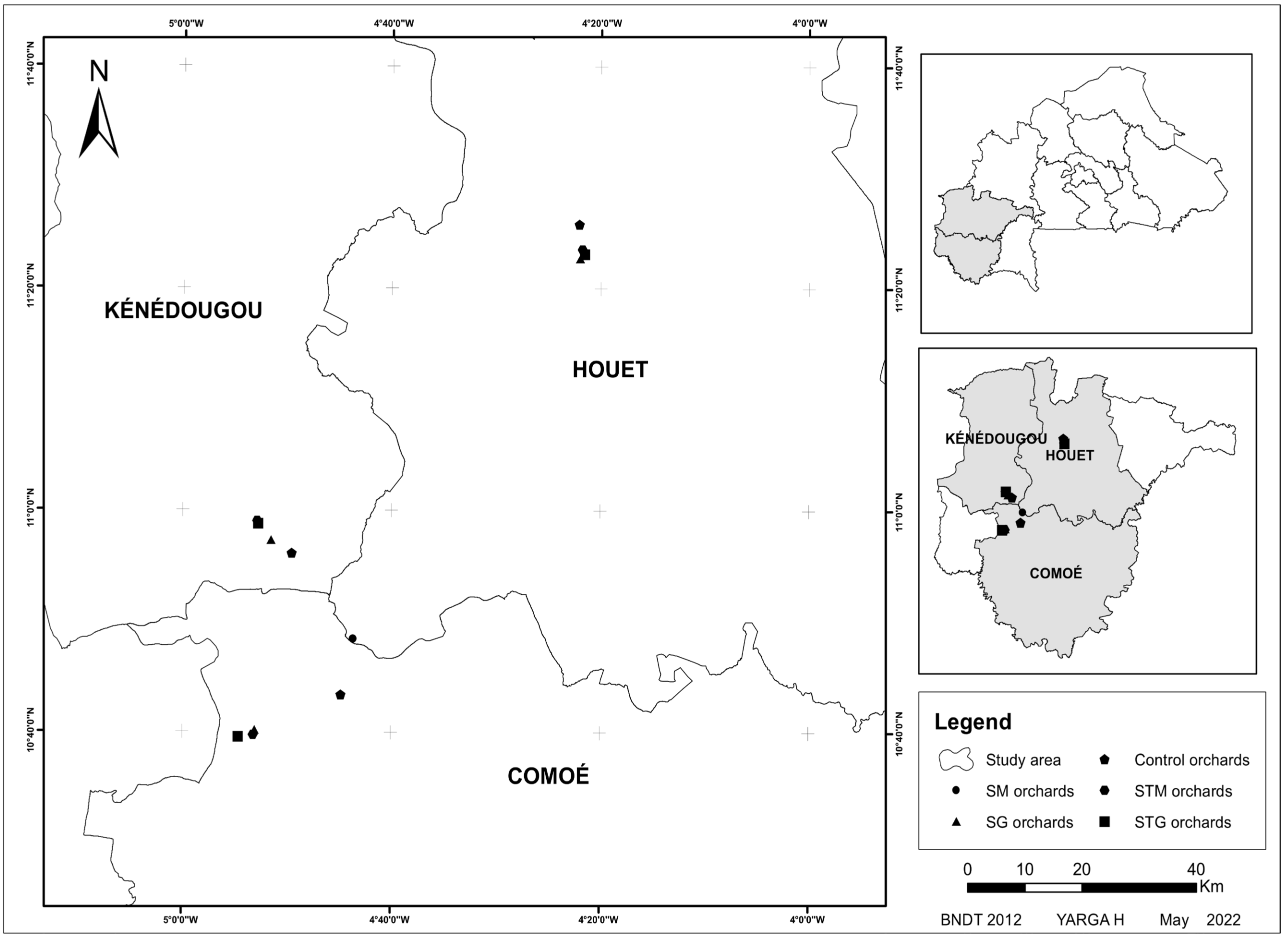

Figure 1. Location of mango orchards where IPM approach effectiveness were evaluated in each province, Western Burkina Faso.

Sanitation aims to destroy fruit fly populations at the pre-imaginal stages either in punctured fruit and/or fallen fruits. The eggs and larvae inside the fruit are destroyed through solar heating at high temperature by placing fallen fruit in sealed, black plastic bags left in the sun for seven days. This was carried out each week (during ten weeks) in trial plots in treated orchards.

Timaye (SOLEVO Suisse SA) is a killing agent that consists of a sexual attractant (methyl eugenol (100 g/kg)) associated with an insecticide (deltamethrin (0.6 g/kg)). It acts by contact and ingestion at low doses on *B. dorsalis* male adults. Timaye was used with locally made traps (water mineral bottle (1.5 liter) with four holes (1.5 cm diameter), in the upper third to facilitate the diffusion of the attractant and the entry of insects). A quantity of 10 g of timaye was placed per trap which was suspended at 1.5 - 2 m above the ground in the canopy in the shade to prevent the sun from degrading the product, close to the leaves without touching them. In mango orchards where STG and STM approaches were applied, 38 traps/ha with timaye (instead of the 45 traps/ha recommended when used alone) were hung on mango trees. The traps with timaye were hung on one out of two mango trees. Timaye was renewed once a month.

GF-120 bait (SUCCESS APPAT 0.24 CB) is a product of Dow Agrosciences

Export SAS, Canada Inc. It is a combination of protein hydrolysates and spinosad (0.24 g/l). Spinosad is formulated as a bait insecticide with hydrolyzed protein, which attracts and stimulates feeding in fruit flies [16]. Weekly spot applications of GF-120 mixture were sprayed on mango foliage at a rate of 1 liter/ha by diluting 1 liter of GF-120 in 5 liters of water. The application consisted of treating the foliage of the lower stratum of each tree during the mango fruiting season with a sprayer dispersing 4 - 6 mm diameter droplets. Treatments were carried out uniformly on the foliage using a hand-held pressure sprayer nine times during the study period.

M3 Fruit fly bait station (SAVANA 23, chemin de la Forêt-74200 Thonon-les-Bains, France) is a combination of protein hydrolysates and an insecticide, alpha cypermethrin, which targets adult fruit flies of the genera Bactrocera and Ceratitis. Its implementation consisted of placing blocks of M3 bait on mango tree stands with four units/tree. Each unit was fixed on a cardinal point of the mango tree. The density of M3 blocks recommended is 400 units per hectare when used alone. The M3 bait has an operating life of up to 10 weeks. In mango orchards where the STM and SM approaches were implemented, 300 units of M3 baits/ha were hung to the branches of mango trees. M3 fruit fly bait blocks were hung on one out of two mango trees in each mango orchard.

2.3. Experimental Layout

The study was conducted during the mango fruiting season (from May to July) in 15 mango orchards located in the three provinces. The experimental design was a dispersed block with five treatments. Each IPM approach was applied in one of the four mango orchards and the fifth was used as a control. Within the same province, mango orchards sites were at least 0.5 km apart. Each experimental orchard was subdivided into three plots of 0.5 ha, where the same approach was implemented. During the 2nd year, only the STG approach was applied to confirm its efficacy.

2.4. Evaluation of the Effectiveness of the Four IPM Approaches in the Control of Mango-Infesting Fruit Flies

Two methods were used to evaluate the effectiveness of IPM approaches, including measuring population densities and the levels of fruit fly damage in treated and control mango orchards.

In order to assess fruit fly population density, a trapping system was implemented in both treated and control mango orchards. In each mango orchard, eight McPhail traps (four traps per hectare) baited with torula yeast were implemented for monitoring fruit fly population. All traps were labeled with the name of the treatment and, the replicate number. Torula yeast was used at a dose of four tablets per 400 ml of water per trap. In each trap, an insecticide, the dichlorvos strip (DDVP), was placed to kill any insect that comes to consume the content of the trap. Monitoring and trap surveys were conducted weekly.

During each survey, the attractant (Torula) was renewed, while the insecticide was replaced after one month of operation. At each weekly check, flies were removed from the trap using a sieve and then stored in labelled pill boxes containing 70% ethanol.

In order to assess the effect of the different IPM approaches on mango infestation by fruit flies, fruits were sampled from orchards and incubated in the laboratory. The initial infestation rate was assessed by sampling mangoes prior to application of any control tool in the fifteen orchards. Fruit sampling was then made in each mango orchard every 2-week. At each sampling date, 50 mango fruits were collected randomly from five mango trees (10 fruits/tree) per block (replicate) in each orchard and packed in jute bags labeled with the following information: name of locality, type of treatment, replicate number and collection date. Fruits incubation was done following the protocol of [17].

2.5. Fruit Fly Identification

Fruit fly specimens were identified with physical [18] [19] [20] and electronic [21] identification keys.

2.6. Data Handling and Statistical Analysis

Fruit fly adults captured and mango fruits infested by fruit flies were recorded at each survey date in both the treated and control orchards. This made it possible to evaluate the following parameters: the average catch, the average damage and the efficacy rate of each treatment. The average catch of *B. dorsalis* and *C. cosyra*, reported as flies per trap per week (FTW), measures the densities of the populations of these major insect pests in the experimental orchards during the study. Damage refers to the number of mango fruits attacked by fruit flies per sample at each sampling date. The efficacy rate of each IPM approach was determined according to the following formula:

$$\mathrm{Er} = (\mathrm{U} - \mathrm{T})/\mathrm{U} * 100$$

Er = efficacy rate, U = Average damage index recorded in control orchard, T: Average damage index recorded in treated orchard.

Statistical analyses were performed with the software R 3.6.2. Bartlett' test was used to check the homogeneity of the variances, after which the Kruskal-Wallis non-parametric test was performed if $p < 5\%$. The pairwise-t-test were then used to reveal any significant difference in both, *B. dorsalis* and *C. cosyra* FTW recorded in the treated orchards in comparison to those recorded in the control ones.

3. Results

In total, 232,230 fruit fly specimens were caught in the mango orchards, of which 121,278 (52.22%), 63,767 (27.45%) and 47,185 (20.31%) in Kénédougou, Comoé and Houet provinces, respectively. The fruit fly specimens belonged to eight species including *Bactrocera dorsalis* Hendel, *Ceratitis cosyra* Walker, *C. silvestrii* Bezzi, *C. fasciventris* Bezzi, *C. quinaria* Bezzi, *C. bremii* Guérin-Méneville, *Bactrocera cucurbitae* Coquillett and *Dacus ciliatus* Loew.

In Kénédougou province, *B. dorsalis* represented 45.88% of tephritid adults while *C. cosyra* counted for 53.35%. In Comoé, *B. dorsalis* was predominant with 78.36% of the catches against 20.56% for *C. cosyra*. In Houet province, *B. dorsalis* accounted for 62.81% while *C. cosyra* was represented by 33.01%.

During the two consecutive mango fruiting seasons, the two species of economic importance represented 98.45% of the catches, of which, 58.24% (135,253 individuals) were taken by *B. dorsalis* while *C. cosyra* was represented by 93,398 individuals (40.21%).

3.1. Temporal Trend of *B. dorsalis* Catches in Mango Orchards during the 2018 Mango Fruiting Season

The average weekly catch indices (FTW) of *B. dorsalis* recorded in the 15 mango orchards during the 2018 mango fruiting season are presented in **Figure 2**. There was a highly significant difference in the mean number of *B. dorsalis* FTW among both, treatments (DF = 4, X^2 = 17.65, p = 0.001) and survey dates (DF = 8, X^2 = 137.41, p < 2.2e−16).

The weekly catch indices of *B. dorsalis* increased gradually in control orchards during the course of the study. Its population density is seen to be highest in the

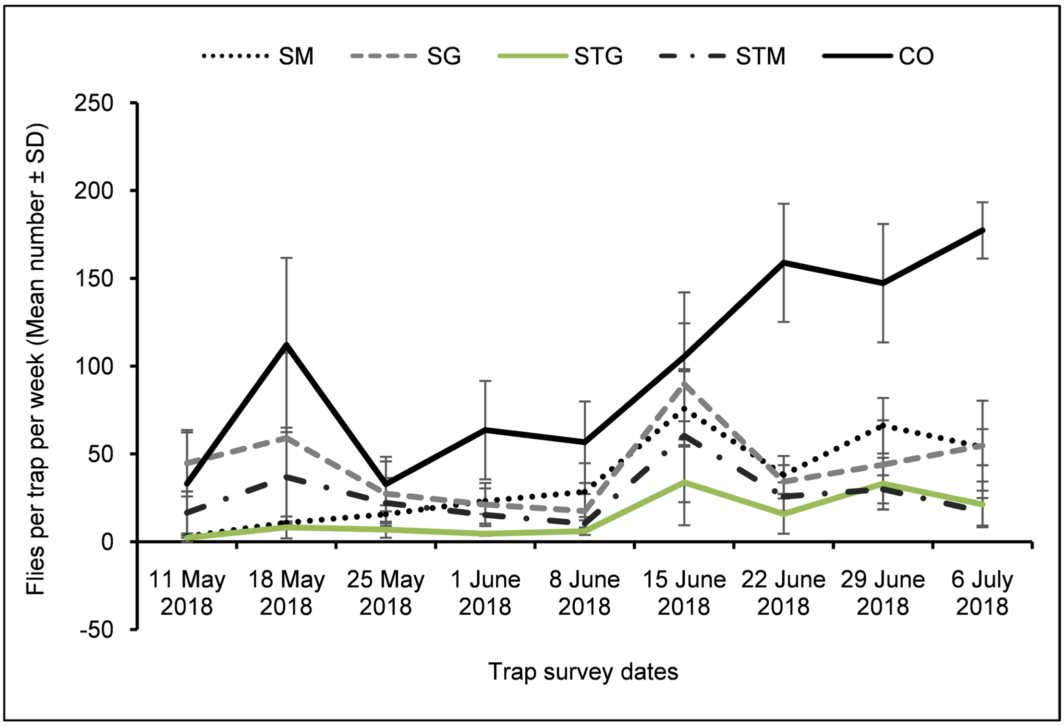

Figure 2. Evolution of the average weekly catch indices of *B. dorsalis* in treated and control orc-hards during the 2018 mango fruiting season, Western Burkina Faso. SM: Sanitation + M3 bait, SG: Sanitation + GF-120 bait, STG: Sanitation + Timaye + GF-120 bait, STM: Sanitation + Timaye + M3 bait, CO: control orchard.

control orchards compared to the treated ones during the experimentation (Figure 2). The *B. dorsalis* FTW remained very low in some treated orchards and present a low peak on June 15th, 2018. Mango orchards which were treated with the STG and STM approaches recorded, in general, the lowest weekly catch indices of *B. dorsalis*. Indeed, very significant difference was observed between the *B. dorsalis* FTW recorded in the orchards implemented with these approaches and those recorded in control orchards (Table 1).

3.2. Temporal Trend of *C. cosyra* Catches in Mango Orchards during the 2018 Mango Fruiting Season

Fluctuations of *C. cosyra* populations in experimental mango orchards are shown in Figure 3. *Ceratitis cosyra* population density was higher at the beginning of the study in early-May. The FTW then decreased as the experimentation progressed until the end of the mango fruiting season in mid-July. In general, the FTW remained slightly higher in control orchards compared to those recorded in the treated mango orchards but towards the end of the study, they became roughly equal. In the mango orchards having been treated with the IPM approaches, the average catch indices experienced the same variations and remained substantially equal during the study in the three provinces (Figure 3). The Kruskal-Wallis test showed a significant impact of treatments on *C. cosyra* FTW in the study area (DF = 4, $X^2 = 16.473$, $p = 0.01$). Statistical analyzes revealed significant difference between *C. cosyra* FTW recorded in orchards where the STG and SG approaches were applied compared to those observed in control orchards (Table 2).

3.3. Temporal Trend of *B. dorsalis* and *C. cosyra* Catches during the 2019 Mango Fruiting Season

During the 2019 mango fruiting season, the study was conducted to confirm the effectiveness of the IPM approach STG in controlling *B. dorsalis* and *C. cosyra* in

Table 1. Results of pairwise-t-test performed with average mean of FTW of *B. dorsalis* in treated and control orchards, Western Burkina Faso.

T-tests	Variables		
	DF	T	P
CO-SM	8	2.21	0.052^{ns}
CO-SG	8	3.54	0.08^{ns}
CO-STG	8	3.71	0.001**
CO-STM	8	3.60	0.001**

CO: control orchard, SM: sanitation + M3 bait, SG: sanitation + GF-120 bait, STG: sanitation + Timaye + GF-120 bait, STM: sanitation + Timaye + M3 bait. ns: No significant difference, **Very significant difference.

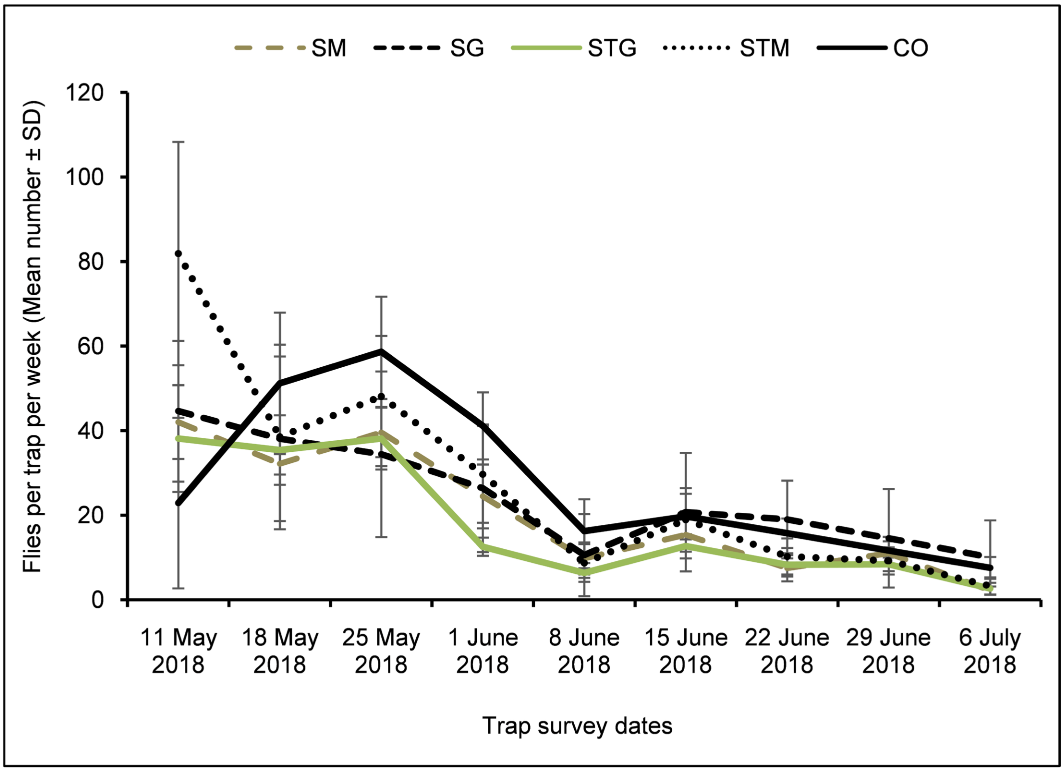

Figure 3. Evolution of the average weekly catch indices of *C. cosyra* in treated and control orchard during the 2018 mango fruiting season, Western Burkina Faso. SM: orchard sanitation + M3 bait, SG: orchard sanitation + GF-120 bait, STG: orchard sanitation + Timaye + GF-120 bait, STM: orchard sanitation + Timaye + M3 bait, CO: control orchard.

Table 2. Results of pairwise-t-test performed with average mean of FTW of *C. cosyra* in treated and control orchards, Western Burkina Faso.

T-tests	Variables		
	DF	T-value	P-value
CO-SM	8	0.03	0.97^{ns}
CO-SG	8	2.76	0.04*
CO-STG	8	3.10	0.01*
CO-STM	8	3.58	0.12^{ns}

CO: control orchard, SM: sanitation + M3 bait, SG: sanitation + GF-120 bait, STG: sanitation + Timaye + GF-120 bait, STM: sanitation + Timaye + M3 bait. ns: No significant difference, *significant difference.

mango orchards. Figure 4 presents the fluctuations of the populations of both *C. cosyra* and *B. dorsalis* during the 2019 mango fruiting season. It can be seen that the FTW of *B. dorsalis* gradually increased during the experiment, while those of *C. cosyra* gradually decreased until the end of the study.

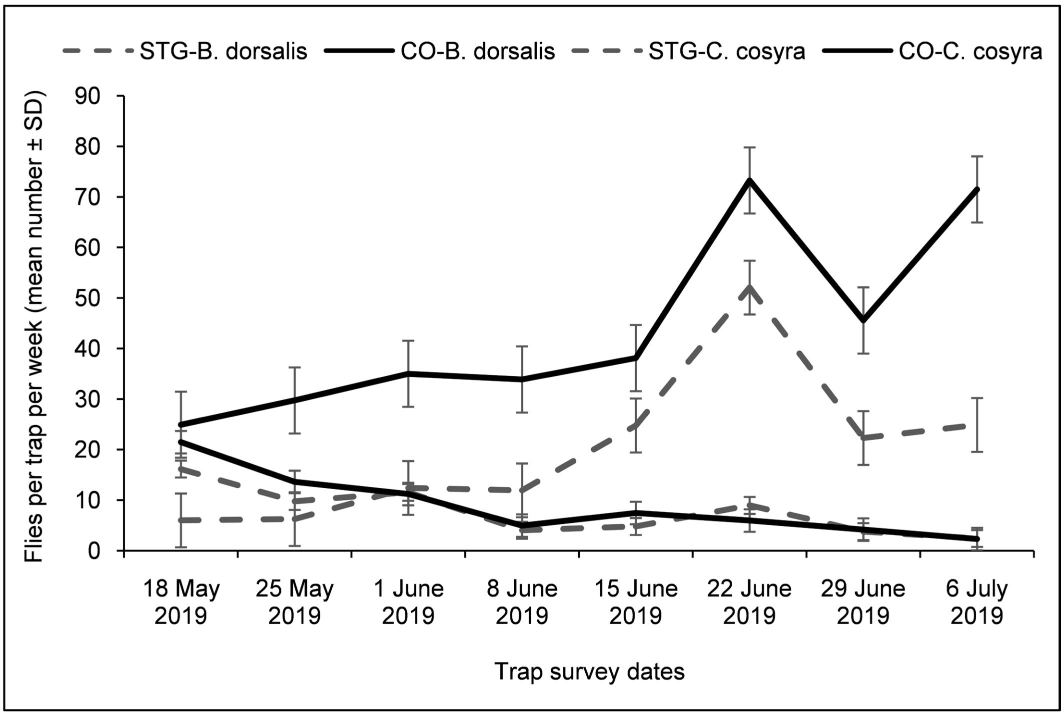

Figure 4. Evolution of FTW of *B. dorsalis* and *C. cosyra* in treated and control orchards during the 2019 mango fruiting season, Western Burkina Faso. STG: orchard sanitation + Timaye + GF-120 bait, CO: control orchard.

The Kruskal-Wallis test reveals a significant difference between the weekly catch indices of *B. dorsalis* recorded in control orchards and in treated ones. At the last survey date *B. dorsalis* FTW were 24.89 ± 17.32 in STG orchard against 71.48 ± 41.58 in the control one.

The population density of *C. cosyra* was substantially similar in both, control and treated orchards using the STG approach during the experiment. According to the survey dates, statistical analyzes revealed highly significant difference in *C. cosyra* FTW ($F = 16.52$; $P = 0.0001$ and $F = 9.69$; $P = 0.0001$) observed in STG and control orchards, respectively.

3.4. Effect of the Various IPM Approaches in Controlling Mango Fruits Infestations by *B. dorsalis* and *C. cosyra*

A total of 13,300 mango fruits for a total weight of 3977.85 kg were collected in the 15 orchards selected in the three provinces for laboratory rearing procedures. Following incubations, 9704 tephritid specimens emerged from the 14,639 pupae collected. Of the emergent adults, the invasive species *B. dorsalis* was the most numerous with 5770 individuals (59.76% of emergences) followed by *C. cosyra* represented by 3930 specimens (40.49%). The third fruit fly emerged, *C. fasciventris*, was almost absent, as it was represented by only four individuals.

The results in relation to the effects of IPM approaches on mango infestation by fruit flies during the 2018 mango fruiting season are summarized and presented in Figure 5. The initial level experienced a low attack rate in both, treated and control orchards except for the SM orchards which recorded an average attack rate of over 5%. The average damage indices were relatively low in the 15 orchards at the start of the experiment in early-May. They then experienced a slight increase depending on the IPM approach applied in the mango orchards. In the weeks following the implementation of the different IPM approaches, the average damage indices decreased slightly in some treated orchards in comparison to the control ones. The average attack rates then increased in mango orchards on June 15 with the highest observed in control orchards (37.43% ± 4.52%) (**Figure 5**). Among the treated orchards, the SM orchard recorded the highest average attack rate (17.93% ± 9.50%) while the STG orchard showed the lowest average attack rate (10.65% ± 5.47%).

Mango orchards implemented with STG approach recorded the best average efficacy rate (55.08% ± 33.57%) followed in sequence by STM (54.52% ± 19.68%), SG (41.77% ± 42.69%) and SM (34.51% ± 42.32%).

Mango attacks by fruit flies during the 2019 mango fruiting season are illustrated by **Figure 6**. Average attack rates were low at the beginning of the study in control orchards as well as in treated orchards. In general, fruit fly damage on mangoes remained relatively low in treated orchards throughout the experiment. They ranged from 7.22 ± 1.00 to 17.35 ± 17.39 in treated orchards while in the control orchards, the average damage indices increased over the course of the study. In fact, they ranged from 8.33 ± 2.10 to 52.50 ± 19.12 (**Figure 6**). The average efficacy rates observed with the STG approach during the 2019 mango fruiting season were 74.75% ± 31.36%.

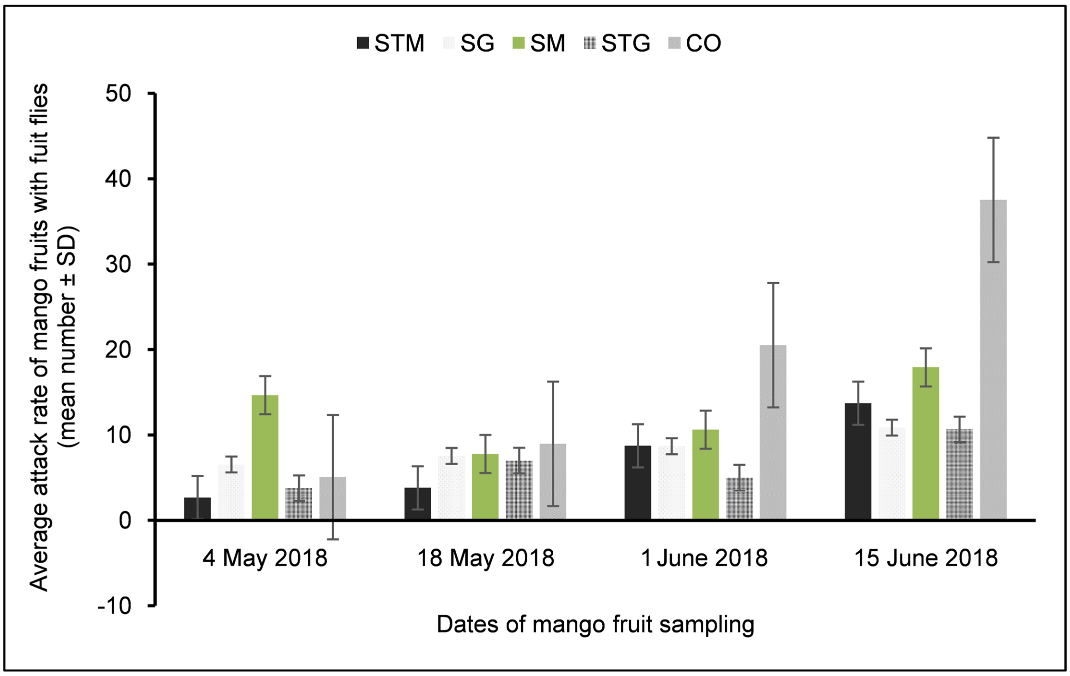

Figure 5. Average damage indices of fruit flies during the 2018 mango fruiting season, Western Burkina Faso. SM: Orchard sanitation + M3 bait, SG: Orchard sanitation + GF-120 bait, STM: Orchard sanitation + Timaye + M3 bait, STG: Orchard sanitation + Timaye + GF-120 bait, CO: control orchard.

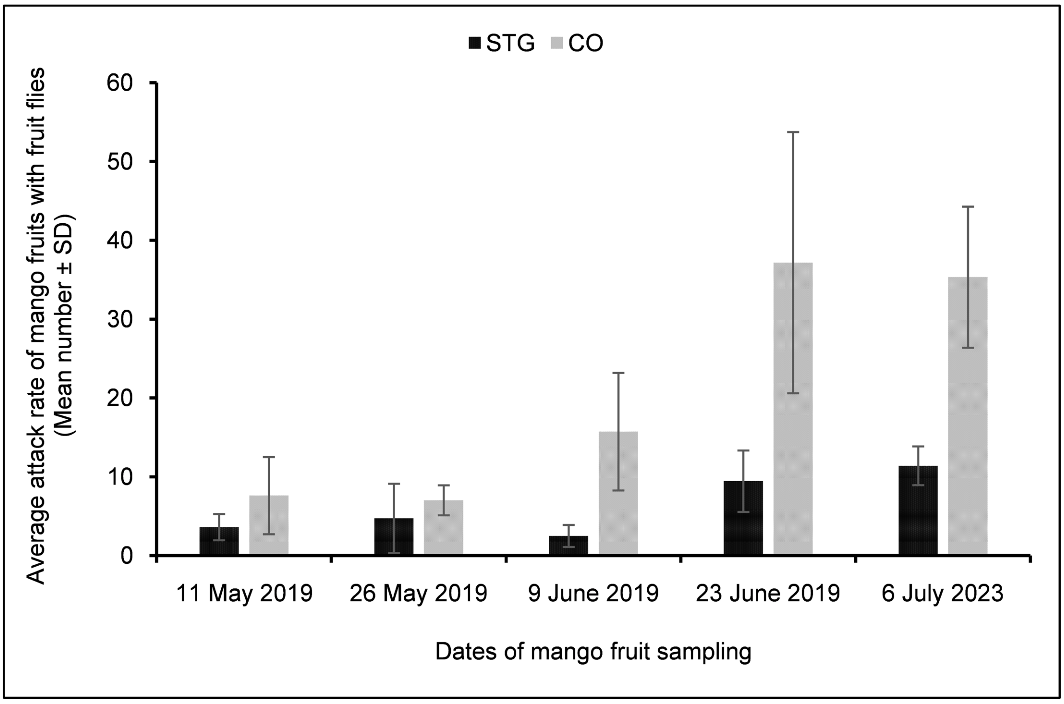

Figure 6. Average damage indices of fruit flies during the 2019 mango fruiting season, Western Burkina Faso. STG: orchard sanitation + Timaye + GF-120 bait, CO: control orchard.

4. Discussion

Monitoring with McPhail traps baited with torula yeast in both, control and treated orchards made it possible to identify eight fruit fly species, of which, *B. dorsalis* and *C. cosyra* were the most important and represented more than 98% of the captures. The presence of these fruit fly species in mango orchards in Western Burkina Faso was reported by [8]. Moreover, the dominance of *B. dorsalis* and *C. cosyra* in mango growing areas in sub-Saharan Africa was highlighted by many studies [8] [22] [23] [24] [25] [26]. Results from mango incubations showed that *B. dorsalis* represented 59.76% of emergence whereas *C. cosyra* occupied 40.49% of adult fruit flies recorded. Recent work has pointed out the relatively stable co-existence between these two major insect pests in mango fruits in Western Burkina Faso [5].

Bactrocera dorsalis population presented a low density at the beginning of the experimentation corresponding with the end of the dry season in the study zone. Its population increased then in mango orchards with the onset of the rainy season. Our findings are similar to those of [13] [24] [26] and [5] who stated that this invasive species is low/absent during the dry season and its population implodes with the first rains in mango orchards.

With regard to the African native fruit fly, *C. cosyra*, its catch indices were higher at the beginning of the experimentation in early May. Its population density then decreased gradually as the rainy season progressed until it ended in late July corresponding to the peak of the rainy season in the study zone. According to [24] and [8], *C. cosyra* population peaks during the dry season before experiencing a drop following the installation of the wet season. Therefore, the decrease in *C. cosyra* population density observed during the course of the study could not be attributed only to the control tools applied in mango orchards but also to the insect pest ecology that supports better dry environmental conditions according to [24] and [8].

As far as mango infestation by fruit flies is concerned, damage indices were low at the beginning of the study in both, control and treated orchards. They increased gradually as the mango fruiting season progressed. These results could be explained by the fact that during the early mango fruiting season, mango cultivars are attacked only by *C. cosyra* before the implosion of *B. dorsalis* [5]. The increase in mango infestation with fruit flies towards the end of mango fruiting season is justified by the abundance of *B. dorsalis* coupled with the maturity of the late cultivars, such Keitt and Brooks which are favorable to fruit fly females' egg-laying [5].

Results revealed that among the four IPM strategies tested, the STG approach was more effective in reducing *B. dorsalis* FTW in mango orchards followed in sequence by STM, SM and SG approaches. The population density of *C. cosyra* was more reduced by the STG approach, following in sequence by SG, SM and STM approaches. The best average efficacy rates were observed with the STG approach followed by STM, SG and SM approaches, respectively. These observations could be explained by several factors. Sanitation operated in all treated orchards plays an important role in reducing fruit fly populations including *B. dorsalis* [27] [28]. In fact, for commercial fruit like mango and papaya, infestation by *B. dorsalis* was found to be higher in fruit on the ground than in fruit on the trees [27]. In Hawaii, [29] found that high to moderate sprays of the spinosad-based bait, GF-120, reduced *B. dorsalis* female numbers and fruit infestation in papaya orchards when combined with orchard sanitation. The same result was observed in Benin by [28] who noted a reduction in fruit infestations by *B. dorsalis* in orchards treated with GF-120 compared to untreated orchards, although male numbers of this insect pest species in treated and untreated orchards were not significantly different. The author [30] reported that the combination "orchard sanitation + GF-120" provides a better control of *B. dorsalis* populations in mango orchards in Guinea Bissau. In Kenya, [31] reported the effectiveness of the combination "parasitoids release + Sanitation + bait sprays" in protecting mango from fruit fly attacks.

The IPM approaches STG and STM were more effective in controlling *B. dorsalis* than *C. cosyra*. These approaches combined MAT and BAT techniques in addition to the orchard sanitation. In this experiment, MAT consisted in the application of Timaye, whereas baiting agents used were GF-120 and M3 bait in STG and STM approaches, respectively. Timaye is formulated with sexual attractant, the methyl eugenol. The pheromone, methyl eugenol (1,2-dimethoxy-4-(2-propenyl) benzene), a phenylpropanoid compound naturally occurring in many plant species, attracts strongly *B. dorsalis* males, like many other *Bactrocera* species [4]

[32] [33] [34]. No "attract and kill" tool applied in the trials targeted specifically fruit flies of the genus Ceratitis.

The author [35] pointed out the pivotal role of the combined use of MAT and bait sprays in eradicating *B. dorsalis* in 2000 and 2013 in Mauritius. In South Africa, these combined techniques successfully eradicated *B. dorsalis* in the Limpopo province following its first report in the northern borders in 2010 [36]. The successful eradication of *B. dorsalis* in the Vhembe District Municipality was accomplished through the use of MAT, BAT and orchard sanitation [37]. Furthermore, in Cameroon, MAT was reported to have reduced mango infestations by fruit flies by 46.8% [38].

The approaches with three components were in general more effective in reducing both, fruit fly population density and mango fruit infestations by fruit flies than those including with two components. Such a result can be explained by the fact that STG and STM contained male lures while SG and SM are made with food baits. According to [4], food baits are not species-specific and are known to have low efficiency compared to male lures. Food baits can attract both sexes but have a limited range of attractiveness [7].

The relative low efficacy of various IPM approaches could be explained by several factors. In fact, GF-120 bait mixture was sprayed weekly on mango tree foliage. Therefore, following rainfall, GF-120 can become unattractive for the oriental fruit fly (*Bactrocera dorsalis*) and the melon fly, *B. cucurbitae* as well as for some *Anatrepha* species [39] [40] [41] [42]. The rainfall factor comes in addition to the fact that volatiles from host fruit, in particular mature fruit, were reported to be highly attractive to *B. dorsalis* females [43] [44] [45]. Moreover, the responses of *B. dorsalis* to protein baits were found to be influenced by female age and degree of protein starvation [43] [46]. The M3 bait was placed for a period of 10 weeks, so its effectiveness could decrease over time under the effect of rain, sunrays and wind. In addition, the high number of wild fruit species including Shea tree, *Landophia* spp., *Uvaria chamae*, *Spondias mombin* found in plant formations around mango orchards [17] could influence the effectiveness of fruit fly control strategy. At this regard, [47] stated that the efficacy of mass trapping technique is related to the target pest population density and geographic isolation of treated crops.

5. Conclusion

The results of this experiment show that fruit fly issues can be managed successfully. However, consistent efforts are necessary to achieve optimal effectiveness of fruit fly control. Fruit fly control in the study area requires a holistic approach that cannot be completed with partial measures. The coordinated mobilization and awareness of the entire population of growers including small-scale farmers and commercial producers is necessary. The wild fruit species found in plant formations and hosts for fruit flies around mango orchards must be taken into account in the development of sustainable fruit fly control strategies. The role of fruits and vegetables sold in large cities such as Bobo-Dioulasso, Banfora and Orodara and along roadsides in the maintaining of residual fruit fly populations must be investigated. Mango orchard sanitation can be improved by replacing the black bags with augmentoria to promote conservation biological control. In addition, a specific attract-and-kill tool should be developed to control the populations of the native insect pest species *C. cosyra*. Therefore, research for a better proteinaceous bait targeting specifically *C. cosyra* adults should be undertaken.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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