# Effectiveness of Spinosad Bait Sprays (GF-120) in Controlling Mango-Infesting Fruit Flies (Diptera: Tephritidae) in Benin

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**ABSTRACT** Effectiveness of GF-120 (Dow Chemical) Fruit Fly Bait containing the insecticide spinosad in controlling mango-infesting fruit flies (Diptera: Tephritidae) was assessed by comparing treated orchards with untreated orchards. Twelve mango, *Mangifera indica* L., plantations located in six villages (two similar orchards per village: one orchard treated and orchard untreated) scattered in the Borgou department (northern Benin) were monitored weekly with fly traps, and the fruit was sampled twice for larval infestation at the beginning and in the middle of May in both 2006 and 2007. The two main mango fruit fly pests are *Ceratitis cosyra* (Walker) and *Bactrocera invadens* Drew, Tsuruta & White, an invasive species that recently spread throughout West Africa. In both the 2006 and 2007 seasons, *C. cosyra* had the earliest peak of abundance, and the difference between treated and untreated orchards, in terms of mean number of flies trapped per week and per trap, was significant only in 2007. *B. invadens* populations quickly increased with the onset of the rains, from mid-May onward, with no significant difference between treated and untreated orchards. In 2006 and 2007, the larval infestation by *B. invadens* was significantly lower in plots treated with GF-120 than in untreated control plots. GF-120 provided an 81% reduction in the number of pupae per kilogram of fruit after weekly applications for 7 wk in 2006 and an 89% reduction after 10 wk of weekly applications in 2007. The possibility of integrating GF120 bait sprays in an integrated pest management package is discussed in relation to market requirements.

**KEY WORDS** *Bactrocera invadens*, *Ceratitis cosyra*, GF-120, *Mangifera indica*, Benin

West Africa is a region of growing economic importance for fruit production and export. Mango, *Mangifera indica* L., is one of the region's most important crops, and plays a major role in local, national, regional, and international markets (Vannière et al. 2004). Fruit production provides essential components to people's diet and nutrition and is also a valuable source of income in many West African countries.

The mango tree is a host for many pests. In West Africa, it is threatened by three major pests, namely, termites (Isoptera: Termitidae), mealybugs (Homoptera: Pseudococcidae), and fruit flies (Diptera: Tephritidae). However, only the latter cause wide-scale economic damage to the mango tree in the northern part of Benin, which corresponds to the North Guinean and South Sudanian zones.

Fruit flies are of major economic importance in commercial horticulture in tropical regions (White and Elson-Harris 1992). In fact, many species in this family attack and severely damage important fruit crops, especially mango fruit. In Benin, four species, namely, *Bactrocera invadens* Drew, Tsuruta & White; *Ceratitis cosyra* (Walker); *Ceratitis silvestrii* Bezzi; and *Ceratitis quinaria* (Bezzi), have been found to be significantly associated with damage to mango fruit. The first species is a fruit fly from Asia, only recently recorded in West Africa (Vayssières et al. 2005). During the 2005 and 2006 seasons, *B. invadens* and *C. cosyra* were found to be the most important species in Benin in terms of fly abundance and fruit damage. Recent research in Benin found that losses due to fruit flies exceeded 60% for 'Gouverneur', 'Eldon', 'Dabschar', 'Kent', 'Smith', 'Keitt', and 'Brooks' in the second half of the mango season (Vayssières et al. 2006). In addition to the direct losses, mango fruit flies are quarantine pests in many parts of the world, including both the European Union and the United States, and they are the reason for the current prohibition on imports of West African mangos.

However, despite its economic importance, fruit fly control in sub-Saharan Africa (not including South Africa) is still by and large at an experimental stage (N′Guetta 1994, Vayssières and Kalabane 2000, Ekesi and Billah 2006, Vayssières et al. 2007). In Africa, fruit growers lack appropriate available control methods. Small-scale growers in Benin try to avoid fruit fly infestation by picking fruit early before it matures, yet damage can still be significant (Vayssières et al. 2006). Other growers use pesticides distributed for cotton,

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*Gossypium hirsutum* L., production (Sinzogan et al. 2008) or sometimes import bait sprays (Lux et al. 2003). The result of this is that most of the pesticides currently used are ineffective and present risk to public health and to the ecological sustainability and resilience of the farming systems. Growers in Benin have requested access to effective control strategies and training in their use. It is therefore important to develop pest management strategies that do not compromise either public health or the environment. To achieve this goal, it is first necessary to assess the effectiveness of available control measures.

Recently, the spinosad bait spray GF 120 (Dow AgroSciences 2001), containing spinosad as a toxicant has emerged as an effective and environmentally safe alternative to traditional bait sprays (containing organophosphate insecticides) for the control of several pest tephritid flies (King and Hennessey 1996, Peck and McQuate 2000, Burns et al. 2001, Vargas et al. 2001). GF-120 Fruit Fly bait is a mixture of spinosad (insecticide) and a foodstuff attractant composed of various phagostimulants. The adult insects are attracted by the foodstuff and killed by the spinosad. Spinosyns are fermentation products of the soil actinomycete *Saccharopolyspora spinosa* Mertz & Yao and consist of a mixture of spinosyn A and D (Sparks et al. 1998, Thompson et al. 2000). Spinosad is a neurotoxin and acts as a contact and stomach poison (DowElanco 1994, Salgado 1998, Salgado et al. 1998).

Much is already known about the efficacy of spinosad as a commercial product because it has been used for several years throughout the world to control fruit flies, and many relevant papers have been published. For example, a study by Adan et al. (1996) indicated that spinosad fed to *C. capitata* in drinking water was very toxic. However, there have been no published studies evaluating the effectiveness of GF-120 Fruit Fly Bait containing spinosad against fruit flies in West Africa. It is therefore relevant to obtain data on the effectiveness of GF-120 in protecting mango orchards against fruit flies in Africa. The current study is part of an ongoing regional control program on the development and promotion of areawide integrated pest management (IPM) methods in West Africa. It reports on the first results from testing GF-120 on a relatively large scale in the Borgou region, the most important fruit-producing area of Benin. The objective of this study was to evaluate the toxicity of spinosad as formulated in GF-120 Fruit Fly bait and to determine its efficacy on the main fruit fly species of economic significance in mango orchards in Benin in the absence of any other control measure. At the same time, these data are the first collected on the control of *B. invadens* in West Africa with GF 120.

## Materials and Methods

**Experimental Site and Design.** The experiments were conducted during two successive mango seasons (2006, 2007) in the Borgou department, located between latitude 09.094–09.948° N and longitude 002.561–002.713° E in the Sudanian type agroclimatic zone sensu lato. This department is the major mango production area in Benin.

To evaluate the effectiveness of the "Success appat" (commercial name of GF-120 Fruit Fly Bait for fruit control in West Africa), orchards were selected in different localities by pairs (treated and control). The high mobility of the insects made it preferable to test this product by working in two neighboring orchards rather than in the same one. Two orchards (treated and control), a distance of 1–2 km from each other, were chosen in each locality. The selected orchards were required to have 1) the same grafted cultivars at a productive stage, 2) easy access by car, 3) no cotton fields within the vicinity, and 4) the agreement of their owners to avoid any kind of chemical treatment. Furthermore, treated orchards had to be no >2 ha each, whereas control orchards could be larger.

Based on these criteria, 12 orchards located in six villages (two similar orchards per village) were selected during each mango season. The chosen villages are scattered around the department, and the orchards have an average of 123 trees at a 9- by 9-m density or 100 trees at a 10- by 10-m density.

**Dilution and Spray of the GF-120 Fruit Fly Bait.** We used the recommended dose of 1.5 liter/ha and mixed with water at the ratio of 1:5 (GF-120 to water) (Dow Agrosciences 2001) before spraying. We applied the freshly made 80 ppm solution of GF-120 Fruit Fly Bait (Dow AgroSciences LLC, Indianapolis, IN). This bait spray was applied with a Berthoud Apollo 16-AF manual sprayer using a conventional conical nozzle with 1–2 mm aperture to deliver droplets of 2–6 mm from a spray mixture of 7.5 liters of water and 1.5 liters of GF-120.

Spot spraying, which consists of partially treating the foliage (Vayssières et al. 2007) with a freshly made mixture of GF-120, was used in the treated orchards. The spot treatments were made until the mixture was streaming from the leaves. All the trees in the treated orchards were sprayed with a limited quantity (≈0.07–0.09 liters) of the mixture applied at head height to a portion of the tree not bearing fruit over a surface area of ≈1 $m^2$. All the host trees (cashews and wild trees) in a range of 10 m around the mango orchards also were sprayed using the same pattern. This treatment required reapplication after a heavy or even moderate rainfall. Although GF-120 is less toxic than some other insecticides, standard safety precautions were taken during spraying.

As well as strictly following standardized application procedures, recently produced commercial product was requested from Dow to ensure that the GF-120 was fresh and at its peak effectiveness.

The first application was carried out 1 d after collecting flies from the traps, 2 wk before the beginning of the harvest period (3–5 April) in 2006, but 5 wk prior (13–15 March) in 2007. Subsequent treatments were carried out weekly, by using rotation around the tree (to avoid phytotoxicity on previously treated surfaces) until the end of May (end of the harvest in the selected orchards). In the Borgou area, the mango season generally occurs from mid-April to the end of June.

**Evaluation of GF-120 Effectiveness.** *Installing traps.* The relative abundance of insects in the selected orchards was monitored from just before the start of the season until the end of harvest by captures in baited Tephritraps (Sorygar, Spain) set up in the selected orchards.

The traps were hung on a primary branch of the lower third of the canopy at a medium distance from the center of the tree. The traps were not exposed to sunlight, and flies had free access to trap holes. The iron wire supporting the trap had been previously coated with solid grease to prevent predatory ant (*Oecophylla*) activity on the dead tephritid adults caught in the trap. Two parapheromones (IPS, Ellesmere Port, South Wirral, England) were used as bait to attract the males of fruit fly species. Methyl eugenol was used for *B. invadens,* and terpinyl acetate was used for *Ceratitis* species. Each trap contained a strip of DDVP insecticide (IPS) to kill the attracted insects.

In total, 48 traps were placed each year in the 12 selected orchards, i.e., two methyl eugenol traps (Met. trap) and two terpinyl acetate traps (Ter. trap) in each orchard. A distance of at least 40 m was kept between the traps to prevent any interaction between the attractants. Captured flies were counted once a week and removed from traps for identification. The attractants and the insecticides were renewed monthly.

*Infestation Rate.* Fruit infestation evaluations were conducted twice in the middle of the harvest period (3 and 17 May in 2006 and 4 and 18 May in 2007), that is, ≈5 and 7 wk after the initial sprays in 2006 and 8 and 10 wk in 2007. Two samples of 100 fruit each per orchard were randomly picked from the innermost 10 trees in 2006. In 2007, due to the low productivity of the trees, the orchard owners allowed only two samples of 30 fruit each per orchard to be randomly picked from the innermost six trees. In total, 2,400 and 720 mango fruit were collected for loss assessment in 2006 and 2007, respectively.

In the laboratory, each sample was weighed, the fruit were recounted, and the sample numbered per date and per orchard. In 2006, each sample of fruit (100 fruit) was divided in 10 parts (10 fruit per part), and each part was placed onto a wire hardware cloth support mounted on plastic box of 40 cm in diameter by 14 cm in height filled with wet sand at 5-cm height. This allowed mature larvae to drop into the sand and pupate. To provide more accurate data collection and statistical analysis in 2007, fruit of each sample of 30 fruit were individually placed onto mesh supports in jars (19 cm in diameter by 21 cm in height) filled with wet sand at 5-cm height. The basins or jars were stored in a large insectarium (without light).

Once a week, the sand covering the bottom of the containers was sifted to collect fly pupae, which were counted to determine the level of infestation (ratio of number of pupae per weight). Pupae were stored in small hatching boxes lined with moist blotting paper. The hatchings were checked every 3 d to collect the adults. Identification of fly species was confirmed in Cotonou by J.-F.V.

**Statistical Analysis.** The sample data were pooled per block of treated or untreated orchards and per week. $\text{Log}_{10}$ [x + 1] (x is number of flies) transformation was used for *B. invadens* or *C. cosyra* catches to achieve normality before analysis. Data were analyzed using analysis of variance (ANOVA) procedure at the $P = 0.05$ level with SAS software version 9.1 (SAS Institute 2003).

## Results

**Monitoring with Traps.** Four tephritid species were captured in the traps: *B. invadens, C. cosyra, C. quinaria,* and *C. silvestrii.* The two most frequently captured species, *B. invadens* and *C. cosyra,* represented, respectively, 18 and 65% of catches in 2006 and 19 and 79% in 2007. To avoid complication, only data on these two species are presented here.

*B. invadens* and *C. cosyra* were collected throughout the trapping period, but there was a considerable fluctuation in the number of flies trapped. Very few *B. invadens* were trapped in March and April. Catches increased toward the end of the harvesting season, from beginning of May onward, after the first heavy rains. Population abundance was relatively high in the 2006 season. *C. cosyra* was trapped in large numbers from March to mid-May. Although the number of *C. cosyra* trapped was already high at the start of the experiments (mid-March in 2007 and early April in 2006), a second peak occurred at the end of April in 2006 and in mid-May in 2007. The population was relatively abundant in the 2007 season.

Differences between fruit fly species could be observed in the population fluctuations (Tables 1 and 2). No significant differences were found between treatments in the mean number of *B. invadens* adults captured per week and per trap throughout the trapping period during both seasons, except for the periods 27–29 March, 8–10 May, and 29 May–1 June during the 2007 season (Table 1).

For *C. cosyra,* differences between treatments in the mean number of captured fly per week and per trap were not statistically significant throughout the trapping period in the 2006 mango season, except for the period 22–24 May (Table 2). However, the weekly gap between treated and untreated orchards was high, with lower number of flies captured in the treated orchards. No significant difference was observed between treated and untreated orchards during the first two periods (13–15 March and 20–22 March) in the 2007 mango season, but differences were always statistically significant from the third week (27–29 March) onward.

**Inventory of Tephritid Species Linked to the Mango Tree and Rate of Fruit Infestation.** Fruit collected during the 2006 and 2007 seasons yielded 6,758 and 3,752 fruit fly pupae, respectively. Four tephritid species, namely, *C. cosyra, C. quinaria, C. silvestrii,* and *B. invadens,* and three tephritid species, namely, *C. cosyra, C. quinaria,* and *B. invadens,* emerged from the 2006 and the 2007 samplings, respectively. Of those adults that emerged, *C. cosyra* and *B. invadens* respectively made up 75 and 19% of the 2006 season samplings and 79 and 17% of those from 2007.

**Table 1. Comparison of mean number of male of *B. invadens* captured weekly per trap in methyl eugenol traps placed in mango orchards from 3 April to 1 June in 2006 and from 13 March to 1 June in 2007**

| Collection date | Mean (± SE) no. *B. invadens* captured per trap | | | | | |
|---|---|---|---|---|---|---|
| | 2006 | | | 2007 | | |
| | Control orchards | Treated orchards | *F* and *P* values | Control orchards | Treated orchards | *F* and *P* values |
| 13–15 March | | | | 0.33 ± 0.14a | 0.06 ± 0.05a | $F_{1, 10} = 3.40$, $P = 0.09$ |
| 20–22 March | | | | 0.56 ± 0.22a | 0.17 ± 0.16a | $F_{1, 10} = 2.19$, $P = 0.14$ |
| 27–29 March | | | | 0.27 ± 0.10a | 0.00 ± 0.00b | $F_{1, 10} = 8.08$, $P = 0.01$ |
| 3–5 April | 17.17 ± 4.80a | 11.17 ± 4.75a | $F_{1, 10} = 1.46$, $P = 0.25$ | 0.72 ± 0.27a | 0.11 ± 0.11a | $F_{1, 10} = 4.00$, $P = 0.07$ |
| 10–12 April | 8.50 ± 2.75a | 4.83 ± 1.13a | $F_{1, 10} = 0.68$, $P = 0.42$ | 0.33 ± 0.27a | 0.11 ± 0.07a | $F_{1, 10} = 0.45$, $P = 0.51$ |
| 17–19 April | 10.33 ± 2.57a | 5.33 ± 1.33a | $F_{1, 10} = 2.11$, $P = 0.17$ | 0.22 ± 0.14a | 0.16 ± 0.07a | $F_{1, 10} = 0.04$, $P = 0.83$ |
| 24–26 April | 17.00 ± 4.98a | 9.83 ± 1.6a | $F_{1, 10} = 0.73$, $P = 0.41$ | 0.94 ± 0.26a | 0.72 ± 0.53a | $F_{1, 10} = 0.68$, $P = 0.42$ |
| 1–3 May | 45.83 ± 19.63a | 28.66 ± 8.36a | $F_{1, 10} = 0.04$, $P = 0.85$ | 8.22 ± 1.65a | 5.27 ± 1.95a | $F_{1, 10} = 2.29$, $P = 0.16$ |
| 8–10 May | 86.00 ± 22.30a | 53.66 ± 10.21a | $F_{1, 10} = 0.87$, $P = 0.37$ | 42.61 ± 4.17a | 28.11 ± 4.29b | $F_{1, 10} = 5.43$, $P = 0.04$ |
| 15–17 May | 130.16 ± 49.51a | 119.00 ± 18.81a | $F_{1, 10} = 0.63$, $P = 0.44$ | 127.61 ± 23.16a | 83.55 ± 7.47a | $F_{1, 10} = 3.63$, $P = 0.08$ |
| 22–24 May | 220.83 ± 60.56a | 171.50 ± 42.59a | $F_{1, 10} = 0.20$, $P = 0.66$ | 209.72 ± 35.30a | 143.16 ± 38.92a | $F_{1, 10} = 2.47$, $P = 0.14$ |
| 29 May−1 June | 188.50 ± 62.86a | 205.83 ± 55.66a | $F_{1, 10} = 0.73$, $P = 0.41$ | 250.00 ± 50.72a | 132.83 ± 33.59b | $F_{1, 10} = 5.09$, $P = 0.04$ |

Values in each row per year followed by the same letters are not significantly different at the 0.05 level, ANOVA followed by pairwise mean separation (SAS Institute 2003).

Fruit sampled in untreated orchards during the 2006 and 2007 seasons yielded 16.97 ± 1.96 and 34.5 ± 3.53 (mean ± SE) pupae per kg of fruit, respectively, compared with 3.17 ± 0.61 and 3.67 ± 0.67 for treated orchards (2006: $F_{1, 8} = 29.29$, $P = 0.000$; 2007: $F_{1, 8} = 59.06$, $P = 0.000$) (Fig. 1). Consequently, fruit infestation was reduced by 81% after 9 wk of weekly applications and 89% after 12 wk of weekly applications for 2006 and 2007, respectively. Samples collected in 2007 were significantly more infested than the samples from 2006. The number of pupae per kg of fruit was 19.08 ± 3.66 in 2007 versus 10.06 ± 2.03 in 2006 ($F_{1, 8} = 21.26$, $P = 0.001$).

The method used in 2006 to assess fruit damage by monitoring infested fruit in the laboratory did not allow us to determine from how many fruit the pupae originated. During the 2007 season, the method was modified to rear fruit flies from individual mangos, which made it possible to assess the percentage of damaged fruit and hence the damage reduction rate obtained from the use of GF-120. From 360 fruit sampled in the untreated orchards in 2007, 172 mango fruit in total were infested and yielded 3,480 pupae versus 30 mango fruit that yielded 329 pupae in treated orchards. From pupae of untreated orchards samples have emerged 946 *C. cosyra* (437 males and 509 females) versus 181 *B. invadens* (88 males and 93 females). From pupae of treated orchards samples have emerged 22 *C. cosyra* (five males and 17 females) versus eight *B. invadens* (zero male and eight females). Fruit fly damage reached 48% in untreated orchards compared with 8.3% in treated orchards. Thus, during the 2007 season, GF-120 provided a reduction of 82.7% in damaged fruit after a weekly application of GF-120 during 10 wk (from 13–15 March to 16–18 May).

## Discussion

At the beginning of the experiments, fly catches in treated versus untreated orchards for both *B. invadens*

**Table 2. Comparison of mean number of male of *C. cosyra* captured weekly per trap in terpinyl acetate traps placed in mango orchards from 3 April to 1 June in 2006 and from 13 March to 1 June in 2007**

| Collection date | Mean (± SE) no. *C. cosyra* captured per trap | | | | | |
|---|---|---|---|---|---|---|
| | 2006 | | | 2007 | | |
| | Control orchards | Treated orchards | *F* and *P* values | Control orchards | Treated orchards | F and *P* values |
| 13–15 March | | | | 1,614.44 ± 432.21a | 1,188.67 ± 157.49a | $F_{1, 10} = 0.13$, $P = 0.72$ |
| 20–22 March | | | | 1,199.39 ± 269.64a | 698.61 ± 94.14a | $F_{1, 10} = 2.08$, $P = 0.17$ |
| 27–29 March | | | | 867.72 ± 218.48a | 221.61 ± 37.53b | $F_{1, 10} = 15.57$, $P = 0.002$ |
| 3–5 April | 528.33 ± 232.85a | 295.00 ± 33.10a | $F_{1, 10} = 0.34$, $P = 0.57$ | 534.44 ± 108.31a | 241.66 ± 64.24b | $F_{1, 10} = 5.03$, $P = 0.03$ |
| 10–12 April | 242.83 ± 94.19a | 147.33 ± 7.60a | $F_{1, 10} = 0.09$, $P = 0.77$ | 462.16 ± 76.13a | 196.38 ± 43.13b | $F_{1, 10} = 7.96$, $P = 0.01$ |
| 17–19 April | 163.16 ± 52.81a | 151.16 ± 30.47a | $F_{1, 10} = 0.61$, $P = 0.81$ | 373.72 ± 81.94a | 116.00 ± 16.45b | $F_{1, 10} = 13.92$, $P = 0.003$ |
| 24–26 April | 508.50 ± 124.23a | 279.33 ± 57.67a | $F_{1, 10} = 1.69$, $P = 0.22$ | 454.33 ± 86.44a | 110.05 ± 18.35b | $F_{1, 10} = 16.93$, $P = 0.002$ |
| 1–3 May | 422.50 ± 137.01a | 172.33 ± 55.30a | $F_{1, 10} = 0.01$, $P = 0.94$ | 572.50 ± 130.91a | 153.11 ± 46.77b | $F_{1, 10} = 10.37$, $P = 0.009$ |
| 8–10 May | 219.16 ± 49.35a | 128.50 ± 30.23a | $F_{1, 10} = 1.99$, $P = 0.18$ | 738.50 ± 125.56a | 219.72 ± 45.91b | $F_{1, 10} = 14.77$, $P = 0.003$ |
| 15–17 May | 270.83 ± 85.62a | 170.50 ± 37.82a | $F_{1, 10} = 0.06$, $P = 0.80$ | 954.16 ± 224.63a | 168.11 ± 32.33b | $F_{1, 10} = 23.00$, $P < 0.0001$ |
| 22–24 May | 183.00 ± 30.37a | 82.83 ± 16.38b | $F_{1, 10} = 5.76$, $P = 0.03$ | 523.61 ± 84.88a | 109.22 ± 22.25b | $F_{1, 10} = 34.47$, $P < 0.0001$ |
| 29 May−1 June | 109.60 ± 21.47a | 93.00 ± 34.76a | $F_{1, 10} = 0.76$, $P = 0.40$ | 465.33 ± 155.87a | 97.55 ± 17.39b | $F_{1, 10} = 15.83$, $P = 0.002$ |

Values in each row per year followed by the same letters are not significantly different at the 0.05 level, ANOVA followed by pairwise mean separation (SAS Institute 2003).

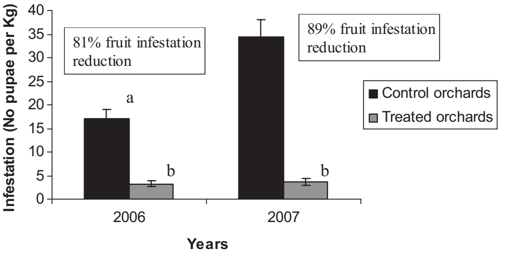


**Fig. 1.** Infestation of mangos by fruit flies during the 2006 and 2007 mango seasons. Comparison between treated and untreated orchards.

and *C. cosyra* were not significantly different for both the 2006 and the 2007 seasons, showing that the fly populations were present at similar population densities within the area under study.

From 24 to 26 April onward in 2006 and from 27 to 29 March onward in 2007, a difference in weekly catches between treated and untreated orchards was noticeable for *C. cosyra* (although it was not statistically significant during the 2006 season), whereas *B. invadens* populations were not significantly different for almost all of the sampling dates. This is probably due to the powerful attraction of the parapheromone for males of both species and to the biological characteristics of the species. Indeed, methyl eugenol is the strongest attractant within a wide area around a trap, thereby providing information on the fly abundance within a large distance surrounding the trap (Mwatawala et al. 2006, Vayssières et al. 2007). Therefore, the number of *B. invadens* trapped is more of a reflection of the population size of the production zone, which encompasses the experimental orchards and surrounding areas, and may partly mask the local effects of GF-120, whereas the number of *C. cosyra* trapped reflects the dynamics of the local populations within the orchard and probably better reflects the influence of GF-120 treatments on population density and damage. Furthermore, *B. invadens* is known for its ability as a strong flyer. The combination of a powerful attractant (methyl eugenol) and a species with good flying ability (*B. invadens*) might explain why catches of *B. invadens* were not significant between treated and untreated orchards. Because of its flying ability, *B. invadens* might be able to regularly reinfest the orchards. This raises the point of considering the production zone versus a single orchard in developing control strategies and also the issue of a permanent control system to allowing better control of reinfestations as carried out for *Oecophylla longinoda* (Van Mele et al. 2007).

*C. cosyra* populations increase during the dry season before the gradual ripening of different cultivars. This was observed here in Benin in 2005 (Vayssières et al. 2005), 2006, and 2007. This persistence (sometimes exponential growth) of fly populations is favored by the presence of wild hosts close to the mango orchards. *Annona senegalensis* Pers. (Annonaceae) and *Sarcocephalus latifolius* (Smith) Bruce (Rubiaceae) have been identified as the major wild hosts for *C. cosyra* with high number of pupae per kilogram of fruit (Vayssières et al., 2008). The authors have recorded similar observations on *B. invadens* populations close to mango orchards but throughout the rainy season period (from mid-April to mid-October) with *Sclerocarya birrea* (A. Rich.) Hochst (Anacardiaceae) and *Vitellaria paradoxa* Gaertn. (Sapotaceae) identified as the major wild hosts (high number of pupae per kilogram of fruit) for *B. invadens.*

High rates of tephritid infestation on wild hosts located close to the orchards are important factors in fruit fly population dynamics. These wild hosts should therefore be considered when developing fruit fly control programs. As a control strategy, it could be useful, for example, to include wild hosts present in the vicinity of the orchards in treatments with GF-120. This is the reason we have treated the border area trees (*A. senegalensis* and *V. paradoxa*) around the experimental orchards, with GF-120. This makes it possible to eliminate many flies before they enter the orchards. However, for a successful control strategy, it is very clear that fruit flies have to be controlled at the scale of the mango production basin (Mau et al. 2007, Vargas et al. 2008).

The objective of this study was to assess the effectiveness of GF-120 for fruit fly control. Such an assessment should ideally use a comparison of the mean number of catches per trap and per week with the economic injury level (EIL). It also should measure female capture with protein bait traps because the male lures (used in this study) generally attract flies from large distances, whereas food baits attract from short distance and should explain really the local situation in the orchard. Although the recent research carried out in Benin to determine the threshold level could lead to an improved assessment method to determine when the EIL has been reached and when spot treatment with GF-120 should be started, work needs to be performed on the capture of females with food attractants (J.-F.V. et al., unpublished) before GF-120 can be used in monitoring of fruit flies.

Damage assessment by monitoring infested fruit in the laboratory (number of fruit punctured in treated orchards versus untreated orchards) is a more accurate assessment method for evaluating the effectiveness of the product. In treated orchards, significantly fewer fruit were infested compared with the control orchards. The infestation rate in treated orchards was similar for both years, i.e., 3.17 and 3.67 pupae per kg of fruit in 2006 and 2007, respectively. GF-120 provided 81% reduction in fruit infestation after weekly applications for 7 wk in 2006 and 89% after 10 weekly applications in 2007. The difference in the reduction of infestation rates between years is probably due to both the number of applications and the date of first treatment. Indeed, the treatment started earlier in 2007 than in 2006, i.e., 3 wk before. Our results confirm the positive results obtained in other studies with bait containing spinosad, in which both field and laboratory tests of spinosad-based treatments demonstrated good control of Mediterranean fruit fly, *Ceratitis. capi-*

*tata* (Wiedemann) and Caribbean fruit fly, *Anastrepha suspensa* (Loew) (King and Hennessey 1996, Burns et al. 2001) as well as apple maggot, *Rhagoletis pomonella* (Walsh), and blueberry maggot, *Rhagoletis mendax* Curran (Pelz et al. 2005), and melon fly, *Bactrocera cucurbitae* (Coquillett) (Prokopy et al. 2003). These authors found damage reduction ranging from 67 to 98% after variable numbers of weekly applications.

Although GF-120 achieved a high degree of reduction in fruit infestation, it did not prevent the fruit from becoming infested. Similar less-than-complete suppression of fly infestations occurred in experiments conducted with spinosad formulations against the Mediterranean fruit fly (Peck and McQuate 2000, Vargas et al. 2002) or the melon fly (Prokopy et al. 2003) in Hawaii. Yet, these products are used commercially for the control of these species. Pelz et al. (2005) argued that the small size of the plots explained the incomplete suppression of fly populations in experiments. In their view, infestation of fruit in the relatively small test plots may have been due to immigration of flies from nearby untreated areas; they suggested that future tests of spinosad baits should be conducted on a larger scale. In the current study, the smallest test plot was 1 ha and the distance between untreated and treated orchards was at least 1 km. Nevertheless, the level of control of fruit fly infestations obtained can be considered as partial. Incomplete protection of fruit suggests that a series of methods (IPM package) should be integrated to obtain an effective and acceptable level of protection. With its effectiveness of reduction in fruit infestation, GF-120 seems to be a potentially useful component of an IPM package. Moreover, Thomas and Mangan (2005) showed that these bait sprays had no detectable effect on beneficial insects and especially parasitoids (*Aphytis* spp). Vargas et al. (2002) reported the same for *Fopius arisanus* (Sonan). This is very important for the introduction of the ovopupal parasitoid *F. arisanus*, which is a promising candidate for biological control of *B. invadens* in West Africa as on *B. dorsalis* in Polynesia (Vargas et al. 2007). Integration of field control methods should not necessarily aim at zero infestation but should be sufficient to meet national or regional markets. To achieve the zero infestation required by international markets, postharvest mitigations such as hot water treatment (Ducamp Collin et al. 2007) should complement field control methods.

Despite the advantages of GF-120, including effectiveness, reduced dosage of active ingredient, and reduced impact of insecticide load on the environment and nontarget insects (Vargas et al. 2001, 2002), certain difficulties of use and technical challenges must be addressed to make the use of GF-120 practical on a commercial scale and easily adopted by growers, especially by small-scale farmers in less developed countries. The equipment required and the strict respect needed for application methods could be a limit to its use by small-scale farmers. The current formulation of the bait must be applied frequently and requires reapplication after moderate to heavy rainfall. It also was noted by Prokopy et al. (2003) and Revis et al. (2004). In fact, when GF 120 was subjected to increased rainfall, Revis et al. (2004) showed that mortality rates for the melon fly were reduced by half. From this, it follows that modifications of the formulation to increase its washing resistance would greatly enhance its suitability for the control of fruit flies in tropical climates. The use of GF-120 in a bait station that protect from rain also could be an alternative.

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