# Effects of an African Weaver Ant, *Oecophylla longinoda*, in Controlling Mango Fruit Flies (Diptera: Tephritidae) in Benin

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**ABSTRACT** Six mango, *Mangifera indica* L., plantations around Parakou, northern Benin, were sampled at 2-wk intervals for fruit fly damage from early April to late May in 2005. Mean damage ranged from 1 to 24% with a weaver ant, *Oecophylla longinoda* (Latreille), being either abundant or absent. The fruit fly complex is made up of *Ceratitis* spp. and *Bactrocera invadens* Drew et al., a new invasive species in West Africa. In 2006, *Ceratitis* spp. peaked twice in the late dry season in early April and early May, whereas *B. invadens* populations quickly increased at the onset of the rains, from mid-May onward. Exclusion experiments conducted in 2006 with 'Eldon', 'Kent', and 'Gouverneur' confirmed that at high ant abundance levels, *Oecophylla* significantly reduced fruit fly infestation. Although fruit fly control methods are still at an experimental stage in this part of the world, farmers who tolerated weaver ants in their orchard were rewarded by significantly better fruit quality. Conservation biological control with predatory ants such as *Oecophylla* in high-value tree crops has great potential for African and Asian farmers. Implications for international research for development at the Consultative Group on International Agricultural Research level are discussed.

**KEY WORDS** conservation biological control, mango, fruit flies, Africa, CGIAR

Notwithstanding that integrated pest management (IPM) has been successfully applied for staple food crops in Asia and Latin-America, African resource-poor farmers are more likely to adopt IPM if it focuses on higher value commodities and enhances both sustainability and market opportunities (Orr 2003). In West Africa, fruit trees are an important, yet often neglected, component in people's livelihoods. Studies in Niger and Burkina Faso indicated that from the wide range of vitamin A-rich foods available throughout the year, including from animal sources, mango was the only one widely consumed (Blum 1997, Méda et al. 2000). Mango, *Mangifera indica* L., trees occur in the wild, in homesteads, and in plantations with varying degrees of management intensity. The choice of cultivar and composition of orchards differs from one country to the next and is influenced by the historical context and access to urban and export markets (Rey et al. 2004).

Irrespective of the cropping intensity, mangos in West Africa are threatened by three major pests, namely, termites (Isoptera: Termitidae), mealybugs (Homoptera: Pseudococcidae), and fruit flies (Diptera: Tephritidae) (Vannière et al. 2004). Although mangos play an important role in local, national, and regional markets, strict qualitative and sanitary standards are required to keep up with international trade regulations (Vannière et al. 2004). Mango fruit flies are quarantine pests in many parts of the world, including the European Union and the United States. The latter currently prohibits imports of West African mangos. Apart from export restrictions, of the 1.9 million metric tons of mangos produced in Africa annually, ≈40% is lost due to damage caused by fruit flies (Lux et al. 2003). Recent research on fruit flies in Benin indicated average losses from 12% in the beginning of April to >50% in June depending on the cultivar. This was caused by four out of the eight fruit fly species found, namely, *Ceratitis cosyra* (Walker), *Ceratitis quinaria* (Bezzi), *Ceratitis silvestrii* Bezzi, and *Bactrocera invadens* Drew et al., the latter being an invasive species from Asia, only recently observed in West Africa (Vayssières et al. 2005).

Despite its economic importance, fruit fly control in Sub-Saharan Africa (not including South Africa) is still by and large in an experimental stage (Vayssières and Kalabane 2000, Vayssières et al. 2004, Ekesi and Billah 2006). In Africa, small growers evade fruit fly infestation by picking fruit early before they mature; yet, damage can still be significant. Others use blanket pesticide sprays, or, uncommonly, imported bait sprays (Lux et al. 2003). Most of these sprays are ineffective due to a lack of farmers' knowledge about

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the biology of fruit flies and IPM strategies, including conservation biological control.

The highly organized predatory behavior of the weaver ants (Hymenoptera: Formicidae; *Oecophylla* spp.), their extensive foraging throughout the area occupied by a colony, and their potential to expand into new areas explain their success in killing or driving away many potential pests (Way and Khoo 1992). For example, to illustrate their effectiveness as biological control agents, Dejean (1991) demonstrated that a colony comprising 12 nests may capture ≈45,000 prey per year. In commercial mango plantations in northern Australia, *Oecophylla* spp. successfully controlled major pests, including fruit flies (Peng and Christian 2005).

Despite the potential of predators in keeping pests at bay, research on biological control in Africa, as opposed to Asia, has mainly emphasized parasitoids and entomopathogens. Differences in research prioritization between these continents can be partly attributed to differences in local culture, the geopolitical context of colonial research, and early failures in conservation biological control. In Asia, research conducted by national scientists on *Oecophylla smaragdina* (F.) was built on smallholder fruit farmers' knowledge, whereas in Africa, research on *Oecophylla longinoda* (Latreille) was mainly led by international researchers focusing on export-oriented plantation crops. To improve the livelihood of African smallholder farmers, insight from Asia can be valuable.

Scientists can learn a lot from farmers about the behavior of predatory ants (Van Mele and Truyen 2002, Van Mele and Cuc 2003). Some farmers also have a deep understanding of the ants' relationship to the orchard's plant and insect biodiversity (Van Mele and Cuc 2000, Van Mele and Chien 2004). Yet, farmers' knowledge also is limited by the ease of observation. With mango trees being older than 10 yr and tall, only 10% of the Vietnamese mango farmers interviewed knew about the predatory role of weaver ants in their crop. They also often wrongly attributed damage of the seed borer *Deanolis albizonalis* (Hampson) (Lepidoptera: Pyralidae) to the fruit fly *Bactrocera dorsalis* Hendel (Van Mele et al. 2001). In Bhutan, farmers attributed early fruit drop caused by fruit flies to the more easily observable stink bug *Rhynchocoris* sp. (Hemiptera: Pentatomidae) that caused similar damage (van Schoubroeck 1999). Properly diagnosing and monitoring pest populations are common practice in some countries, but these approaches are knowledge-intensive, time-consuming, and not commonly applied by smallholder fruit farmers in developing countries (Van Mele 2000). Thus, we applied two different methods to assess weaver ant abundance, and we explored which method would be the easiest for use in farmer-participatory training and research programs. We also tested to what extent weaver ants could play a role in controlling fruit flies, in the absence of any other intervention. We present data from a survey in 2005 in Benin. An exclusion experiment in 2006 compares fruit fly damage on mangos from trees with and without ants. We then present implications for research, development, and policy to boost high-value tree crops in Africa.

## Materials and Methods

**Fruit Fly Damage Survey.** During the 2005 mango season, loss assessment and weaver ant abundance were estimated in six orchards in the area of Parakou, Department of Borgou. Located in the Northern Guinea Savannah, this is a major mango-producing area in northern Benin. Orchards were selected of >6 ha containing grafted cultivars such as 'Eldon', 'Dabschar', 'Smith', and 'Gouverneur'. At 2-wk intervals, from the first week of April until late May, 10 fruits were randomly sampled per tree in five trees per cultivar, totalling 380 trees. Fruit damage was calculated as percentage fruit infested by fruit flies. From each tree, the number of ant nests was recorded. $\text{Log}10(x + 1)$ transformation was used on count variables to stabilize the variance and normalize the data (Gomez and Gomez 1984). The Pearson correlation coefficient was calculated. Repeated measures analysis using the mixed effects model analysis of variance (ANOVA) procedure was conducted to adjust for the serial autocorrelation among the repeated samples on each experimental unit (Littell et al. 1996). Fitted logit models were applied to the binomial data to test the effects and interactions of orchard, cultivar and ant nests on fruit fly damage. Data were subsequently grouped into ant abundance classes based on following criteria: absent (no weaver ants); low abundance (one to four nests); medium abundance (five to eight nests), and high abundance (more than eight nests). Data were analyzed by one-way ANOVA followed by Student-Newman-Keuls test. Analysis was done using SAS (SAS Institute 2003).

**Weaver Ant Abundance.** During the 2006 mango season, from late February to early June, an experiment was set up in a mango orchard, ≈5 km northeast of Parakou. The 40-ha orchard had abundant weaver ant colonies across blocks, each containing one main grafted cultivar. The experiments were carried out in three blocks, one with Gouverneur, a second with Eldon, and the third block containing Kent. All trees were 28 yr old and ≈8 m in height. Tree spacing was 10 by 10 m (100 plants per ha) with canopies rarely touching one another.

Weaver ant abundance was measured more precisely than in the previous year, in two different ways: the branch method and the bait method. The branch method was inspired by Peng and Christian (2004). We counted the number of main branches with ant trails. If one to 10 ants were observed walking on a main branch, only one-half ant trail was assigned. If >10 ants were observed, one ant trail was assigned. Ant abundance was expressed as percentage per tree (the sum of ant trails on main branches divided by the number of main branches of the tree multiplied by 100). The bait method was based on a method developed by Hoffmann et al. (1999) for *Pheidole* ants. A tablespoon of canned tuna fish (≈15 g) was deposited at the fork of the main branches at ≈1.5 m in height.

All ants present after 30 min in an area of 3 cm around the bait were counted. Data were collected at 2-wk intervals from the end of February to the end of June. At each sampling date, ant abundance was measured on 167 trees by using the branch method and on 18 trees by using the bait method. The Pearson correlation coefficient was calculated between both methods. We measured the time required to conduct each method and recorded the pros and cons.

To determine the best time for measuring weaver ant abundance, we recorded weaver ant activities before the exclusion experiment, on 16 February 2006. From 7 a.m. to 7 p.m., ants were counted for 30 s on each of major branches of four mango trees at hourly intervals, totalling 234 counts. Temperature and relative humidity were taken at hourly intervals.

**Fruit Fly Monitoring.** Fruit fly males were monitored during the mango fruiting and harvesting season at weekly intervals from 16 March to 8 June 2006 by using para-pheromone traps. Attractants were terpinyl acetate for *Ceratitis* spp. and methyl eugenol for *B. invadens.* For each cultivar, three traps were used for each of the attractants. Two of them were positioned in trees with ants and protected with grease to avoid ants carrying away trapped fruit flies; the third trap was positioned in a control tree where weaver ants were excluded. In total, 18 traps were used, of which six in control trees. Log10$(x + 1)$ transformation was used on count variables. Differences were calculated between traps in trees with and without ants through repeated measures ANOVA followed by *t*-test.

**Fruit Fly Damage Reduction.** The three experimental blocks containing Gouverneur, Eldon, and Kent mango were located. In each experimental block, 10 trees without weaver ants were selected as control trees. Apart from the presence of ants, the control trees had similar characteristics as the trees with ants. Grease rings were applied and regularly checked to the trunks of the control trees to avoid colonization by weaver ants. During the fruit-ripening period, on 4 May and 18 May 2006, 30 fruit from each cultivar were randomly picked from 10 trees with and 10 trees without ants. For logistic reasons, the 30 fruit were grouped together. Emerging fruit fly larvae were allowed to pupate in the laboratory and pupae were collected weekly for 4 wk. The total number of pupae was recorded for each cultivar. Log10$(x + 1)$ transformation was used on count variables, and means were compared between trees with and without ants by one-way ANOVA followed by *t*-test. Pupae were allowed to hatch for identification, and means of hatched *C. cosyra* and *B. invadens* were calculated.

## Results

**Fruit Fly Damage Survey.** Using the entire 2005 data set ($n = 380$), the Pearson correlation coefficient was $-0.59$ ($P < 0.001$), indicating a negative correlation between number of ant nests and fruit fly damage. There was no significant orchard effect on fruit fly damage and no significant cultivar × orchard interaction. Nonsignificant effects were removed from the logit model. The effect of cultivar was significant ($\chi^2 = 10.17$, df = 3, $P = 0.017$) with Eldon being most infested (22.3 ± 1.1%), followed by Dabschar (16.4 ± 1.0%) and Smith (13.0 ± 1.4%) at the same level of infestation (mean ± SE); Gouverneur was the least infested (2.9 ± 1.4%). However, when the number of ants nests was introduced as a covariate in the model the effect of cultivar disappeared ($\chi^2 = 2.26$, df = 3, $P = 0.521$), with highly significant effect of ants nest ($\chi^2 = 11.47$, df = 1, $P < 0.001$). Fruit fly damage significantly differed between ant abundance classes (Table 1). Average fruit fly damage ranged from 0.8 to 24.1% in orchards with highly abundant or no ants, respectively. At one of the orchards, damage caused by fruit flies increased to 67% toward the end of the Eldon harvesting season in the absence of weaver ants.

**Table 1. Percentage fruit fly damage (mean ± SE) across four 2-wk sampling intervals in relation to *O. longinoda* abundance in six mango orchards in the area of Parakou, northern Benin, 2005**

| | *O. longinoda* abundance level | | | |
|---|---|---|---|---|
| | Absent | Low | Medium | High |
| No. of trees | 85 | 178 | 77 | 40 |
| No. of nests per tree | None | 1–4 | 5–8 | >8 |
| Fruit fly damage | 24.1 ± 1.3a | 15.4 ± 0.9b | 7.0 ± 0.9c | 0.8 ± 0.4d |

Means followed by different letters are significantly different (ANOVA for log-transformed data followed by Student-Newman-Keuls test; $P < 0.05$).

**Weaver Ant Abundance.** On 16 February 2006, ant activity was highest during the morning and late afternoon. The activity was lowest at the hottest time of the day, between 1 p.m. and 3 p.m., when temperatures ranged between 34 and 37°C and humidity was as low as 41%. In the subsequent exclusion experiment, ant counts were avoided during this time of the day.

To measure weaver ant abundance levels, both the branch and bait methods were tested. The Pearson correlation coefficient was 0.85 ($P < 0.001$), indicating a positive correlation between both methods (Fig. 1). Nearly all trees sampled with the branch method had

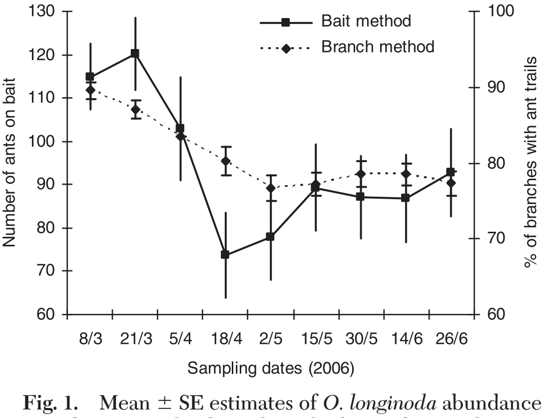


Fig. 1. Mean ± SE estimates of *O. longinoda* abundance per tree by using either branch method (SE of 167 replicates) or bait method (SE of 18 replicates) in Parakou, Benin, in 2006.

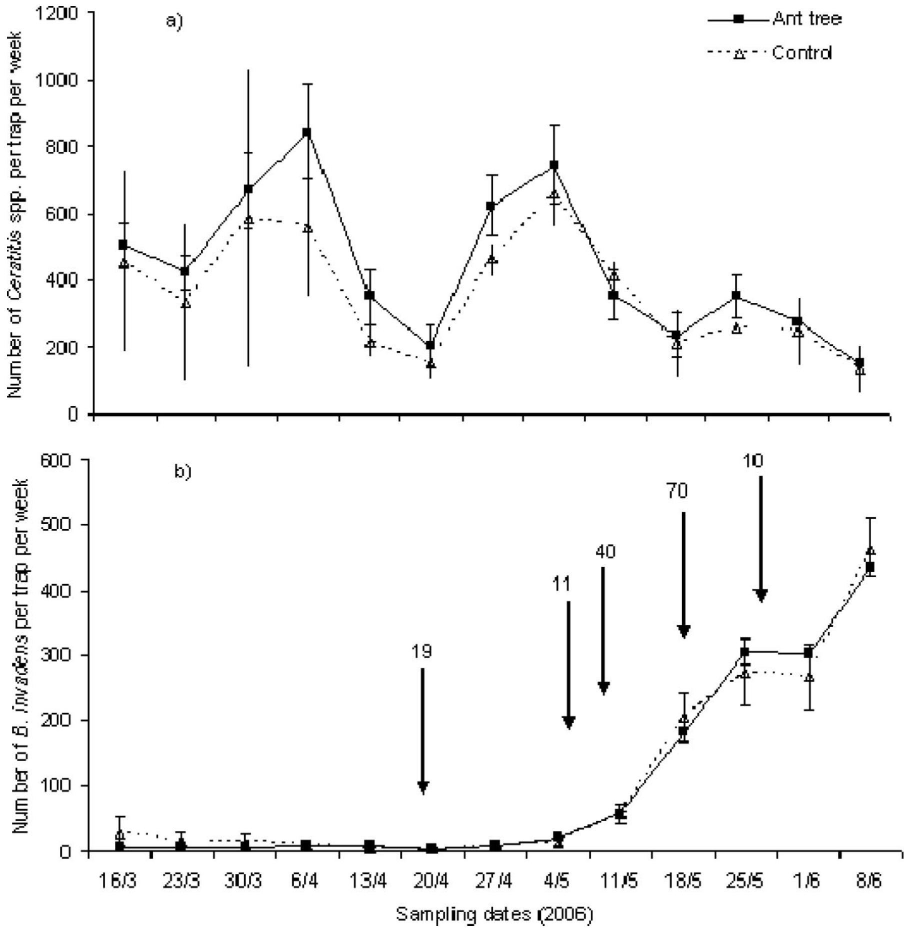


**Fig. 2.** Mean number of *Ceratitis* (a) and *Bactrocera* (b) fruit flies caught per trap per week in Parakou, Benin, in 2006. Solid lines represent traps placed in trees with *O. longinoda* (SE of six replicates). Dotted lines represent traps placed in trees without ants (SE of three replicates). Arrows indicate the recorded rainfall (millimeters).

abundance levels of >75%, indicating a good distribution of *Oecophylla* colonies across the experimental blocks. The branch method was faster and cheaper than the bait method. Once habituated, after two rounds of sampling, >50 trees could be monitored within 1 h. At the current planting density, 1 ha can be sampled within 2 h by using the branch method. With the bait method only 10 trees could be assessed within 1 h. The bait method also seemed much more prone to fluctuations between sampling days. During the fruiting season, weaver ants selected a few fruits per tree, loaded them with scales (Homoptera: Coccidae) and nursed them. They were less interested in the offered tuna, causing a drop in measured abundance levels from early April onward. Thus, we consider the branch method to be the most suitable for IPM research on *Oecophylla* spp.

**Fruit Fly Monitoring.** Clear differences could be observed in population dynamics between fruit fly species (Fig. 2). Catches differed significantly between weeks for *B. invadens* ($F = 22.37$; df = 12, 72; $P < 0.001$) and *Ceratitis* spp. ($F = 8.31$; df = 12, 84; $P < 0.001$). *Ceratitis* spp. were trapped in large numbers from March to mid-May, peaking twice, in early April and early May, before the onset of the rainy season. Very few *B. invadens* were trapped in March and April. Catches increased toward the end of the harvesting season, from mid-May to early June, after the first heavy rains. There was no interaction between traps and treatments ($F = 0.33$; df = 1, 13; $P = 0.58$). Adult fruit fly catches between trees with and without ants was not different for either *B. invadens* ($t = -0.31$, df = 6, $P = 0.77$) or *Ceratitis* spp. ($t = -1.07$, df = 7, $P = 0.32$).

**Fruit Fly Damage Reduction.** From 30 mangos collected on 4 May 2006, the number of pupae was 4.0 ± 1.0 (mean ± SE) for trees without ants compared with 0.67 ± 0.33 for trees with ants ($t = 3.74$, df = 4, $P = 0.02$). Samples collected on 18 May 2006 were much more infested for trees where ants had been excluded. The number of pupae was 77.0 ± 18.5 for mangos collected from trees without ants compared with 0.67 ± 0.33 for mangos collected from trees with ants ($t = 11.03$, df = 4, $P < 0.001$) (Fig. 3). Of the 247 pupae

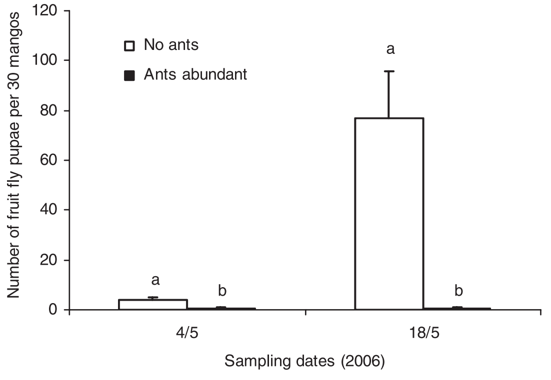


**Fig. 3.** Mean ± SE number of fruit fly pupae per 30 mangos from trees with and without *O. longinoda* in Parakou, Benin, in 2006, arranged by date. Columns followed by different letters are significantly different [*t*-test for log10($x$ + 1) transformed data, $P < 0.05$].

collected in the laboratory, 22.3% did not hatch. Of those that hatched, *C. cosyra* and *B. invadens* made up 90.0 and 10.0%, respectively, for the first sampling time (4 May 2006) and 80.8 and 19.2% for the second sampling time (18 May 2006). From the fruit collected from trees where ants were abundant, a maximum of one fruit fly pupa was collected per variety in the laboratory; hence, the infestation level could be calculated. Fruit fly damage was as low as 3.3% in Eldon and Kent and 0% in Gouverneur. However, mangos from trees where ants were excluded yielded as much as 44, 79, and 108 fruit fly pupae for Eldon, Gouverneur, and Kent, respectively. It was not possible to observe from how many fruit these pupae originated.

## Discussion

**Research and Development Implications.** To measure weaver ant abundance, 5 times more trees can be sampled with the branch method compared with the bait method within a given time; hence, we consider the branch method to be the most user-friendly method. Moreover, when we consider the results from the branch method, the outcome seems more reliable. Measuring weaver ant abundance with the branch method can be easily applied by researchers as well as in farmer training sessions such as farmer field schools (FFSs) or other methods building on participatory learning and action research (PLAR). In the 2005 survey, Gouverneur had the highest weaver ant abundance across orchards. More research is needed to clarify cultivar effect on weaver ant abundance. Also, the influence of bush fires and ecoclimatic conditions such as the annual harmattan (desert wind) on the geographical distribution of *O. longinoda* in Africa requires attention. Where ant abundance is low, complementary technologies such as fruit fly bait stations and spot treatments will need to be developed with farmers.

Both the survey and the exclusion experiment showed the drastic influence of *Oecophylla* spp. Although ants had no effect on trappable fruit flies in the tree canopy, they significantly reduced the numbers of fruit damaged. Although predation on adult fruit flies took place, deterrence and disturbance by ants during fruit fly oviposition seem to be the most important causes of reducing fruit fly damage. Although the presence of ants hinders the flies from depositing their eggs, other olfactory or visual factors may equally play a role in deterring pests.

Fruits dropped and cracked are left behind by the pickers and are an additional source of fruit fly infestation. After the harvesting season and onset of rainy season, arboreal weaver ants increasingly start patrolling on the ground, feed on third instars of fruit fly larvae exiting rotten, dropped fruit and consequently reduce future fruit fly populations. Ant predation on fruit fly larvae emerging from fallen fruit was observed, concurring with earlier findings with other ant species (Aluja et al. 2005). To assess damage by monitoring infested fruit in the laboratory, a method described by Vayssières et al. (2004), future exclusion experiments will need to rear fruit flies from individually kept mangos instead of bulking them.

Apart from the fruit quality aspects related to fruit flies, studies also are required in West Africa to assess the impact of weaver ants on other major mango pests, such as termites, scales, mealybugs, and fruit bats. Initial observations indicate weaver ants may have a significant effect on limiting damage by fruit bats. Methods to reduce dependency of weaver ants on scales and mealybugs may be required in some cases, although farmers' perception and action against these pests are yet to be documented.

Farmers in Australia did not sense ant aggressive behavior as a problem (Peng and Christian 2005). This perception is highly influenced by a range of environmental, socioeconomic, and psychological factors. In an ongoing study, we investigate the perception of various stakeholders in Benin and Guinea (smallholder farmers, plantation owners, laborers, pickers, clients) toward ants and fruit pests, in function of the cropping and marketing system. This information will increase the efficiency of future research and development interventions.

Weaver ant technology is free of costs, labor-saving, and requires relatively little intervention, making it particularly suitable for Sub-Saharan Africa. So far, few African farmers know about the benefits of weaver ants, contrary to Asia where weaver ant husbandry has a long-standing tradition. Awareness raising and participatory learning are likely to boost farmer experimentation with predatory ants. Learning tools are being developed for farmers to be used in FFS or PLAR. Opportunities for south–south exchange should be equally explored.

**Policy Implications.** The proposed research emphasis of the Consultative Group on International Agricultural Research (CGIAR) to increase income from fruit and vegetables, will contribute to 1) reducing risk and vulnerability of smallholder farmers; 2) capacity building and strengthening of producer groups; and 3) networking of actors including researchers (CGIAR

2005). The research presented in this article is a first step in systematically searching and developing appropriate IPM technologies for smallholder fruit farmers with a focus on the use of endemic predatory ants as natural enemies. Capitalizing on small research funds, various international and national research institutes, development partners, and farmer associations have started to collaborate on weaver ant research in mango and cashew (*Anacardium* spp.) in West Africa. Expertise in *Oecophylla* research is equally available in East Africa (Varela 1992, Seguni 1997), and the potential to expand partnerships across Africa is to be supported. Although the CGIAR Challenge Programs and Systemwide Programs were set up to stimulate collaboration, foundations and donors have a crucial role to play in creating flexible research funds to catalyze scaling-up of promising ongoing initiatives.

Good agricultural practices are not only an invention of scientists. Local innovations dealing with conservation biological control also are plentiful and need to be documented and validated. The role of predatory ants in sustaining agricultural systems is an underexplored research area. Smallholder farmers in countries such as Vietnam, India, and Cuba (to name a few) have generated considerable knowledge on natural pest control that may be applicable to the African context. Donors could play a proactive role in supporting south–south exchange.

Apart from the benefits for resource-poor farmers, our research shows how weaver ants improved fruit quality in commercial plantations. With an increased market demand for organically and sustainably managed crop and forest products, holistic approaches such as conservation biological control are needed. Research having disproportionally focused on parasitoids, the role of predators such as *Oecophylla* spp. in controlling major tree pests in Africa is promising and deserves more attention.

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