

Influence of *Oecophylla longinoda* Latreille, 1802 (Hymenoptera: Formicidae) on mango infestation by *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in relation to Senegalese orchard design and management practices

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Damage caused by the fruit fly *Bactrocera dorsalis* (Hendel) (syn. *B. invadens* Drew, Tsuruta & White) (Diptera: Tephritidae) on mangoes in Senegal leads to production losses. A potential biological control agent against this pest is the weaver ant *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae). Senegalese mango-based orchards present a diversity in design and management practices that can influence the abundance of these two species in orchards. In this study we evaluated i) the ability of the *O. longinoda* ant to limit *B. dorsalis* damage in Senegalese orchards, and ii) variations in population abundance for these two species depending on orchard design and management practices. The study was conducted in Senegal in the Niayes area and the Thiès plateau. Fifteen orchards were sampled among three out of four kinds of orchards identified in this area: (1) 'No-input mango diversified orchards', (3) 'Medium-input citrus-predominant orchards' and (4) 'Medium-input large mango- or citrus-predominant orchards'. In one of the orchards we measured infestation rates and numbers of fly pupae that developed from mangoes collected from trees (cv. Kent) 'with' and 'without' *O. longinoda* colonies over three harvesting periods (May, July and August) in 2013. The abundance of *O. longinoda* and *B. dorsalis* was measured for two months in the dry season and two others in the rainy season in the 15 orchards in 2012. The presence of *O. longinoda* on trees reduced the proportion of mangoes attacked by *B. dorsalis* as well as the number of pupae that developed from infested mangoes. The abundance of *O. longinoda* and *B. dorsalis* was negatively correlated. The abundance varied depending on the orchard design and management practices. *O. longinoda* abundance was greater in orchard types 1 and 3 than in type 4. Conversely, *B. dorsalis* abundance in the rainy season tended to be greater in orchard type 4 than in types 1 and 3. This study showed that *O. longinoda* is effective in limiting mango infestations by *B. dorsalis*. It also showed that the abundance of these two species was influenced by the orchard design and management practices. Therefore, using *O. longinoda* to control fruit flies is possible in Senegalese mango-based orchards by promoting weaver ant preservation.

Key words: biological control, weaver ants, fruit flies, *Bactrocera invadens*, agroecology, farming practices.

INTRODUCTION

Fruit production accounts for a large share of the Senegalese agricultural sector. Fruits are essentially intended for the local market (Touré & Fall 2001) but they are gaining an increasingly large share of the export market, with a very favourable niche for mango (Infoconseil 2006). The latter takes first place in terms of the agricultural tonnage of exported products (Rey & Dia 2010). In

2004, the presence of a new invasive fruit fly, *Bactrocera dorsalis* (Hendel) (syn. *B. invadens* Drew, Tsuruta & White; Schutze *et al.* 2014a, b) (Tephritidae: Diptera) was signalled in Senegal (Vayssières 2004). *Bactrocera dorsalis* causes substantial damage on mango, mostly during the fruit maturation period, when flies lay their eggs on ripe fruits (Ndiaye *et al.* 2012). This fruit fly can also lay on green fruits and develop on fallen fruits and

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green, unripe fruits (Diatla *et al.* 2013). It also attacks many other fruit species belonging to numerous botanical families, which allows it to increase its reproductive potential (Vayssières *et al.* 2011).

In West Africa, the economic importance of the damage caused by *B. dorsalis* fruit fly is growing and all segments of the mango value chain suffer from this issue. In Senegalese orchards, fruit damages attributable to fruit flies were estimated at 30–50 % in the Niayes area and 60 % in the Casamance (Ternoy *et al.* 2006; Ndiaye *et al.* 2012). After a few days, infested fruits are inedible and must be discarded. Fly damage in home garden mango trees as well as in small-scale mango orchards impact food security at the local scale, since mangoes provide a fundamental nutritional intake for rural populations. This also causes heavy financial losses to the various stakeholders of the mango sector, including the producers who cannot sell these fruits but also all those who commercialize mangoes in local, national and sub-regional markets (wholesalers, retailers) or processing industries that can unwittingly purchase batches of infested fruits because mangoes recently infested are hardly detectable by inexperienced people. The financial losses of the traders have been particularly important in the first years that followed the arrival of *B. dorsalis*. The export mango market is deeply affected by this issue as well, since *B. dorsalis* is classified as a quarantine pest in most importing countries (EPPO A1 List 2013). If a single infested fruit is detected by the phytosanitary services on arrival, the whole batch is rejected and destroyed. Even worse, the exporting country may be embargoed if too many batches are found to contain fruit flies.

Of the methods used to control fruit flies, pesticide applications are the first choice of farmers. However, pesticide use is not an optimal solution. Apart from the high prices for Senegalese farmers of the chemical products currently available, their use entails a variety of negative effects: i) a health hazard for producers and consumers, ii) a harmful effect to natural enemies (Devine & Furlong 2007), iii) a lack of recommendable active ingredients for use in fruit cultivation apart from Success Appat (0.24 g/l of spinosad-based insecticide), iv) a phenomenon of fruit fly resistance to spinosad appearing, such as the one appearing in the *B. dorsalis* complex group (Hsu & Feng 2006; Jing *et al.* 2011), and v) an ineffectiveness of fruit fly

treatments against immature stages (eggs, larvae, pupae). In addition, consumers and importers are increasingly aware of the problems of pesticide residues and sanitary quality of fresh fruits and vegetables. Checks of products' compliance to Maximum Residue Limits (MRL) have become particularly strict at the entrance to the European Union, the main export market for Senegalese mangoes. Some certifications even impose MRL below the official limit and some large purchasing groups even refer to the ARfD (Acute Reference Dose) (FAO/WHO 1998, 2000) of a chemical, which for fruits of mango size is equivalent to reduce the MRL by about 2.5.

There are other alternative methods to pesticide use that are more environmentally friendly in controlling crop pests. Biological control, which focuses on using natural enemies, is one such method. The weaver ant *Oecophylla longinoda* (Latreille) (Hymenoptera: Formicidae) is a biological control agent against various insect pests (Dejean 1991; Way & Khoo 1992). Published records indicate that weaver ants were recognized in China as a biological control agent as early as 304 AD (Huang & Yang 1987; Van Mele & Cuc 2007). Their predation strategy against insects is effective due to the large number of workers per colony (Hölldobler & Wilson 1978). Recent research has demonstrated their effectiveness in controlling several pests in Beninese mango plantations where the average damage ranged from 1 to 24 % when *O. longinoda* weaver ants were either abundant or absent (Van Mele *et al.* 2007; Vayssières *et al.* 2010), in Ghanaian cashew plantations where trees colonized by *O. longinoda* had less than 6 % pest damage to shoots, panicles and fruits (Dmowoh *et al.* 2009), in Ghanaian citrus plantations where trees colonized by *O. longinoda* had between 6 % and 10 % fly infestation (Ativor *et al.* 2012) and in Tanzanian cashew plantations where shoots damaged by *Heltopeltis* spp. and nuts damaged by *Pseudopterus wayi* were reduced on average to more than 22 % and 14 %, respectively, in trees colonized by *O. longinoda* (Olotu *et al.* 2013).

In addition to reducing fruit fly infestations, *O. longinoda* ants may improve the organoleptic quality of the fruits of the tree they colonize (Sinzogan *et al.* 2008). However, to be potentially effective in controlling insect pests, weaver ant populations in an orchard have to reach a critical level (Lim 2007; Van Mele & Cuc 2007). For example, a minimum of 25 *O. smaragdina* colonies/ha

were necessary for *Hypsipyla robusta* (Lepidoptera: Pyralidae) pest control in Malaysian cashew plantations (Lim 2007).

Senegalese fruit-based agro-ecosystems present differences in their orchard designs and management practices. There are great variations in natural plant diversity and the plants grown, hedges around the orchards and management practices (e.g. irrigation, fertilization, phytosanitary practices, etc.). The abundance of pests and natural enemies is likely to be affected by orchard design and management practices. Predators, parasitoids, as well as pollinators, are recognized as beneficial insects in cropping systems. They find their food, shelter and reproduction sites in resources offered by plants, and interact with plant diversity at various scales (Landis *et al.* 2005). The structural complexity (or simplification) of the landscape, and the intensity of farming practices, are known for having effects on biotic interrelations between species (Anderson *et al.* 2013) and can affect the abundance levels of natural enemies

(predators, parasitoids) but also of phytophagous crop pests (Langellotto & Denno 2004; Margosian *et al.* 2009). Structurally complex agricultural landscapes with management based on biological methods are favourable to an increase in natural enemy populations (Östman *et al.* 2001; Öberg 2009; Simon *et al.* 2010).

In this study the aim was: i) to estimate *Oecophylla longinoda* ant effectiveness as a biological control agent to regulate mango infestations by *B. dorsalis* in Senegalese orchards, ii) to evaluate variations in the abundance of these two species depending on orchard design and management practices.

MATERIAL AND METHODS

Study area and orchard sampling

This study was carried out in the Niayes area and the Thiès plateau, in western Senegal (Fig. 1). These regions are characterized by ferralic arenosols and a Sahelian climate with unimodal rainfall from July to September (between 600 mm and

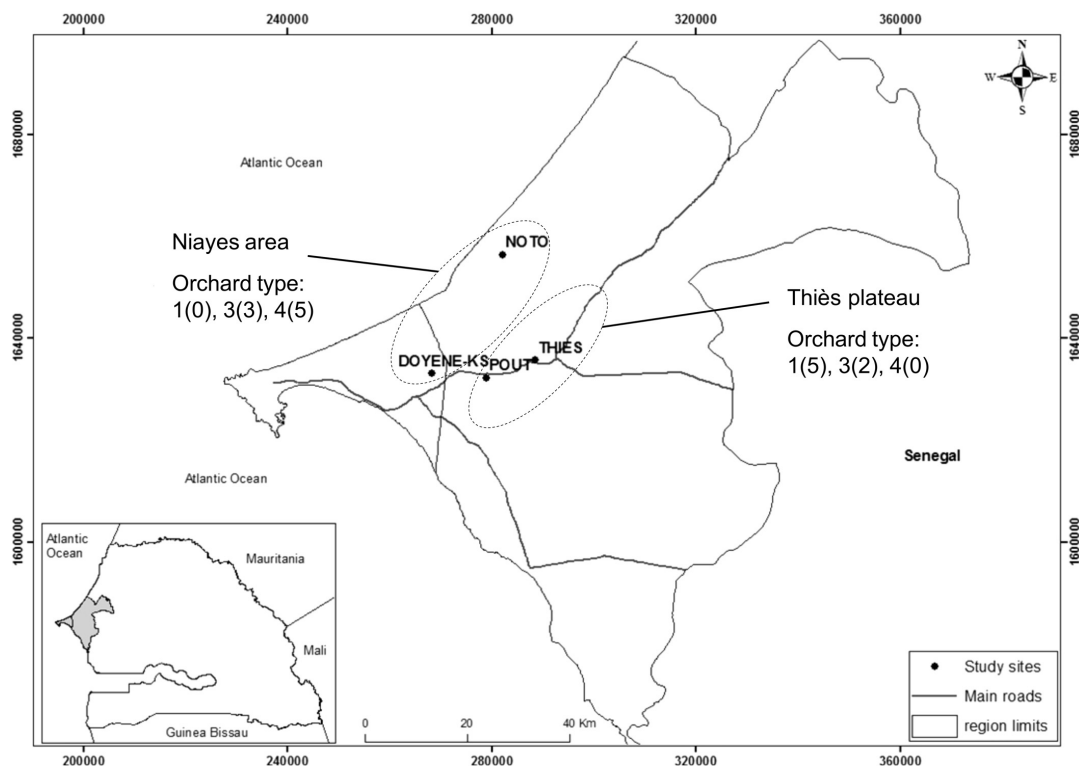


Fig. 1. Map of the study area in the Niayes and Thiès plateau zones, in Senegal. The number of orchards in each zone and per orchard type is indicated in brackets. Orchard type: (1) 'No-input mango diversified orchards', (3) 'Medium-input citrus-predominant orchards' and (4) 'Medium-input large mango- or citrus-predominant orchards'.

750 mm per year between 2008 and 2012). The favourable climate mitigated by a cool and humid trade winds during the hot season makes these two regions the major fruit- and vegetable-production areas of Senegal.

In the Niayes area and the Thiès plateau, four orchard types were identified: (1) 'No-input mango diversified orchards', (2) 'Low-input mango orchards', (3) 'Medium-input citrus-predominant orchards' and (4) 'Medium-input large mango- or citrus-predominant orchards' (Grechi *et al.* 2013). This typology was established according to orchard design arrangements (area, planting density, fruit species, and mango tree cultivars) and management practices (irrigation, fertilization, phytosanitary practices, soil management, and secondary use of the orchard). Types 1 and 2 consisted of orchards with a high composition of mango trees (86 % on average), and a high diversity in mango cultivars for those of type 1. They were mostly planted with polyembryonic mango cultivars, such as cv. Boucodiékhall, and were dedicated to the local market or subsistence production. None of orchards of type 1 was managed or supplied with water, fertilizers and pesticides. Vegetation in orchards of type 1 was dense. Type 2 orchards displayed only low management levels. Type 3 consisted of orchards with a high composition of citrus trees (65 % on average), including grapefruit, orange and mandarin, and a high species diversity. Planting density was high on average but tree spacing was irregular within the orchards. All orchards were irrigated and fertilized. Type 4 consisted of large orchards with a low diversity of species and mango cultivars and regular tree spacing. Kent was the main cultivar followed by cv. Keitt. Most of them were mango mono-specific orchards whereas the others were citrus-predominant mixed orchards. They displayed the highest management levels in comparison with those of the others types. Mango mono-specific orchards of type 4 were dedicated to the export market.

Fifteen orchards were sampled in types 1, 3 and 4 at a rate of five orchards per type (Table 1). Eight orchards were located in the Niayes area and seven on Thiès plateau (Fig. 1).

Data collection

Fruit infestation monitoring on mango trees with and without weaver ant colonies

The ability of *O. longinoda* to reduce *B. dorsalis*

Table 1. Location of the 15 orchards studied for monitoring *Bactrocera dorsalis* and *Oecophylla longinoda* abundance in the Niayes area and the Thiès Plateau, in Senegal.

Geographical zone	Orchard type	Latitude (N)	Longitude (W)
Niayes zone	4	14°58'18.4"	17°01'28.1"
	4	14°59'03.6"	17°00'16.4"
	4	14°59'19.8"	17°00'13.7"
	4	14°58'20.1"	17°00'07.9"
	4	14°58'11.0"	17°00'11.5"
	3	14°45'45.9"	17°09'08.8"
	3	14°45'39.1"	17°08'54.3"
	3	14°45'41.5"	17°08'47.3"
Thiès plateau	3	14°45'27.1"	17°03'03.5"
	1	14°45'49.2"	17°02'49.9"
	1	14°45'42.1"	17°02'46.7"
	1	14°45'30.9"	16°52'58.3"
	1	14°45'26.2"	16°52'59.7"
	1	14°47'22.8"	16°57'55.7"
	3	14°45'41.5"	17°08'47.3"

damage on mango was studied in one of the 15 orchards in 2013, over three periods (May, July and August). The orchard was a mango orchard (cv. Kent). For each time period, we harvested 200 mangoes (25 mangoes per tree) from four mango trees 'with' a weaver ant colony and four other mango trees 'without' a weaver ant colony. Fruits were kept separately in cages. A week later, attacked fruits were identified and counted to determine the mango infestation rate for each tree. Attacked fruits from the same tree were placed on a mesh support mounted over basins and incubated. The bottom of the basins was covered with wet sand, onto which larvae emerging from the fruits could drop and develop into pupae. Once a week, we sieved the sand of each container and recorded the number of pupae.

Monitoring of weaver ant and fly abundance

The abundance of weaver ants and flies was monitored in the 15 orchards in 2012.

The weaver ant abundance survey was carried out using the branch method developed by Peng & Christian (2004). Twenty trees (mango or citrus trees) chosen at random were surveyed per orchard. On each tree, observations were carried out on all the main branches situated within reach

of the observer with arms held high (~2.40 m). The main branches are those directly branching from the tree trunk but also those branching from the latter. They vary in number from three to 10 depending on the tree. This method consisted of counting the number of weaver ants moving on each main branch of the tree, which was used to determine, for each branch, an ant abundance score according to the following scale: 0, no ants; 0.5, one to 10 ants; and 1, more than 10 ants. The survey was carried out every two weeks over a period of four months in the dry season (from 31 March to 26 June 2012) and in the rainy season (from 23 July to 6 September 2012). Data were collected after 09:30 because the most active period for weaver ants is 09:30 to 18:30 (Vayssières *et al.* 2011). The weaver ant abundance on each tree was determined on each survey date and corresponded to the average scores obtained for its main branches. As ant abundance on trees was constant enough for the different survey dates of the same season (unpublished), an average abundance per orchard and per season was calculated.

Bactrocera dorsalis abundance monitoring was also carried out throughout the study by using sexual parapheromone bait. Three Tephri traps were installed in each orchard. The Tephri traps comprised plastic pots containing methyleugenol, a sexual attractant especially attracting *B. dorsalis* male fruit flies, and an insecticide which kills them. The traps were suspended from branches in the lower third of the foliage. The central coil of wire holding the trap was coated with thick grease to prevent any predatory activity by weaver ants (*O. longinoda*) on dead adult flies in the bottom of the trap (Vayssières *et al.* 2009). Trapped flies were taken from the traps and counted each week and the parapheromone cylinders and insecticide were changed every month. In each orchard, we calculated the average weekly number of trapped flies per trap. *Bactrocera dorsalis* fly abundance per orchard and per season was then calculated taking the sum of weekly orchard averages on the survey dates between 10 April and 9 June 2012 (dry season; 60 days) and between 19 July and 17 September 2012 (rainy season; 60 days).

Statistical analysis

In the orchards surveyed in 2013, we used a generalized linear model (GLM) with binomial error distribution followed by an analysis of deviance with a χ^2 -test to test the effect of the ant

factor (two levels: ant colony present and absent) on the rate of fruit infestation by *B. dorsalis*. We used a similar method to test the effect of the ant factor on fruit fly abundance in fruits (*i.e.* total number of pupae collected from 25 fruits) except that we used a Poisson error distribution.

In the 15 orchards in 2012, a Pearson correlation test between weaver ant abundance and fruit fly abundance in the dry and rainy seasons was performed. Weaver ant and fruit fly abundances, depending on the orchard type, were compared for the dry and rainy seasons using the Kruskal-Wallis test. When a significant orchard type effect was detected after a Kruskal-Wallis test, we performed multiple comparison tests to separate factor modalities.

RESULTS

Effect of *Oecophylla longinoda* presence on mango infestation by *Bactrocera dorsalis*

We evaluated *O. longinoda* potential to reduce mango infestations by *B. dorsalis* by comparing mango infestation levels on mango trees with a weaver ant colony and on mango trees without a weaver ant colony, on three different dates (May, July and August). The number of pupae for each lot of 25 mangoes was larger for trees without *O. longinoda* weaver ants than for trees with *O. longinoda* (July: $\chi^2 = 36.48$; d.f. = 1, $P < 0.001$; August: $\chi^2 = 291.94$, d.f. = 1, $P < 0.001$; Fig. 2). In May, there were no attacked fruits. In July, a total of 89 pupae was recorded from trees without *O. longinoda* colonies as opposed to 26 pupae from trees with *O. longinoda* colonies. In August, infestations had greatly increased with a total number of sampled pupae from trees without *O. longinoda* and with *O. longinoda* amounting to 392 and 53, respectively.

The mango infestation rate was also greater on trees without *O. longinoda* ants than on trees with *O. longinoda* ants (July: $\chi^2 = 4.09$, d.f. = 1, $P < 0.05$; August: $\chi^2 = 5.20$, d.f. = 1, $P < 0.05$; Fig. 3). In July there were 6 % of attacked mangoes on trees without an *O. longinoda* colony as opposed to 1 % on trees with an *O. longinoda* colony. That difference was maintained a month later, in August, with 23 % as opposed to 11 % of attacked mangoes for trees without ants and with ants, respectively.

The average number of *B. dorsalis* pupae in infested fruits was also larger on trees without *O. longinoda* than on trees with *O. longinoda*

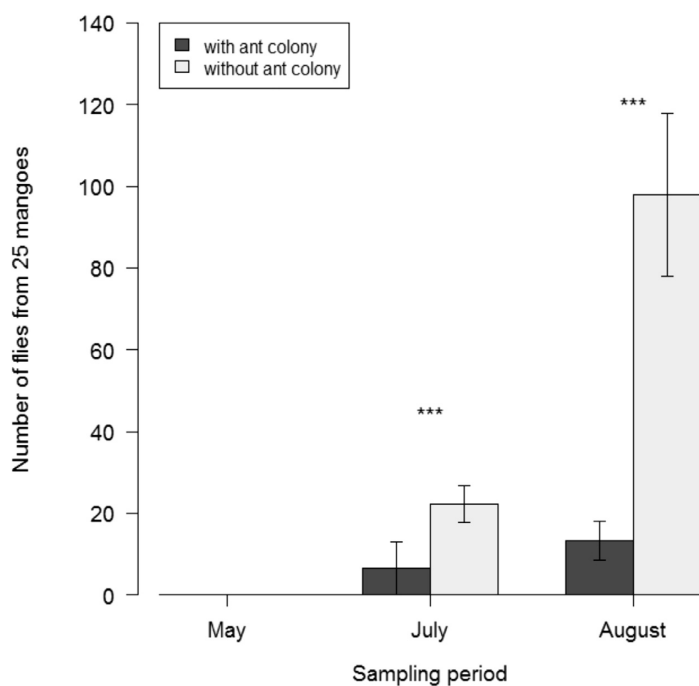


Fig. 2. Mean $\pm$ S.D. ($n=4$) total number of *Bactrocera dorsalis* pupae collected from 25 mangoes per sampling period according to the presence (■) or absence (□) of an ant colony on trees. Asterisks indicate a significant difference between ant treatments (** $P < 0.001$).

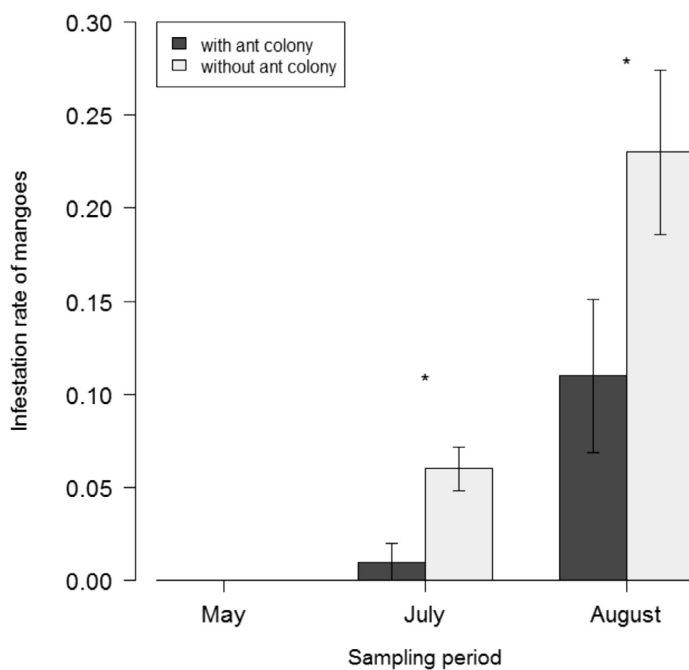


Fig. 3. Mean $\pm$ S.D. ($n=4$) infestation rate of mangoes per sampling period according to the presence (■) or absence (□) of ant colonies on trees. Asterisks indicate a significant difference between ant treatments (* $P < 0.05$).

(August: $F_{1,5} = 66.2$, $P < 0.001$). This effect could not be tested in July because there were insufficient infested fruits for the 'with' an ant colony modality. In August, there were three to four times more pupae per infested fruit on mango trees without *O. longinoda* (mean $\pm$ S.D.: 17.0 ± 2.46) than on mango trees with *O. longinoda* (mean $\pm$ S.D.: 4.9 ± 0.67).

Relations between orchard design and management practices and weaver ant and fruit fly abundance in orchards

The abundance of *O. longinoda* was significantly correlated with the abundance of *B. dorsalis* in the rainy season ($r = -0.51$, $P < 0.05$; Fig. 4). However, this correlation was not significant in the dry season ($r = 0.03$, $P = 0.54$). Overall, in the rainy season, the results showed that the more weaver ants there were in the orchard, there were fewer fruit flies. However, one orchard (32B, type 4) displayed a different tendency: fruit fly abundance was low despite the low abundance of weaver ants.

Weaver ant abundance was relatively uniform in the orchards between the dry and rainy seasons (Fig. 5), while there was a large difference for *B. dorsalis* abundance between the two seasons. Fly abundance was greater in the rainy season. On average (mean $\pm$ S.D.), *B. dorsalis* fly captures over 60 days were 27 ± 29 , 13 ± 12 and 19 ± 13 individuals per orchard respectively in the dry season in orchard types 1, 3 and 4, and then 3745 ± 970 , 4049 ± 1601 and 6503 ± 2835 , respectively, in the rainy season for the same orchard types (Fig. 6).

Orchard types 1 and 3 had higher weaver ant levels than orchard type 4 in the dry season ($\chi^2 = 6.51$, d.f. = 2, $P < 0.05$) and in the rainy season ($\chi^2 = 7.27$, d.f. = 2, $P < 0.05$). As regards *B. dorsalis* abundance, there was no significant difference according to orchard type in the dry season ($\chi^2 = 0.56$, d.f. = 2, $P = 0.76$). In the rainy season, even though there was no significant difference between orchard types ($\chi^2 = 3.5$, d.f. = 2, $P = 0.17$), a clearer tendency appeared compared to the dry season (Fig. 6): type 4 orchards tended to have higher fruit

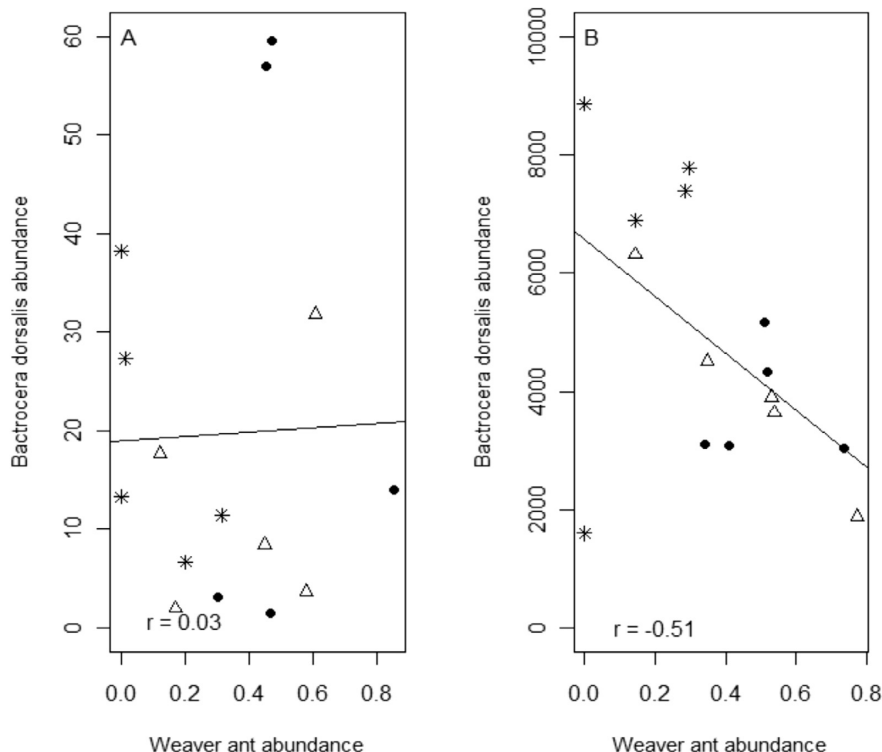


Fig. 4. Relation between *Oecophylla longinoda* and *Bactrocera dorsalis* abundance in the 15 orchards monitored in the dry season (A) and the rainy season (B). r = Pearson correlation. Symbols indicate orchard types (•: type 1, 'No-input mango diversified orchards'; Δ : type 3, 'Medium-input citrus-predominant orchards'; *: type 4, 'Medium-input large mango- or citrus-predominant orchards').

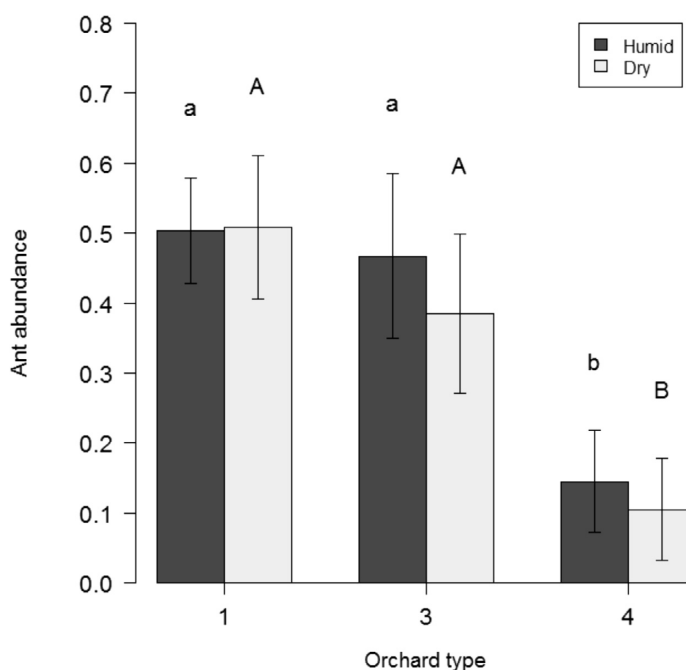


Fig. 5. Mean $\pm$ S.D. ($n = 5$) ant abundance depending on orchard type during the humid (■) and dry (□) seasons. Orchard types with different letters are significantly different (multiple comparison test after Kruskal-Wallis test; $P < 0.05$). Orchard type: (1) 'No-input mango diversified orchards', (3) 'Medium-input citrus-predominant orchards' and (4) 'Medium-input large mango- or citrus-predominant orchards'.

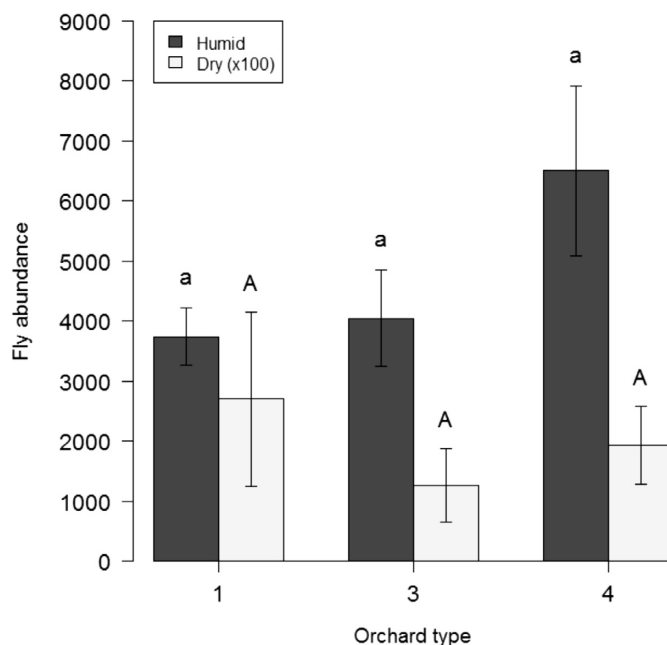


Fig. 6. Mean $\pm$ S.D. ($n = 5$) fly abundance depending on orchard type during the humid (■) and dry (□) seasons. Orchard types with the same letters are not significantly different (multiple comparison test after Kruskal-Wallis test; $P < 0.05$). Orchard type: (1) 'No-input mango diversified orchards', (3) 'Medium-input citrus-predominant orchards' and (4) 'Medium-input large mango- or citrus-predominant orchards'.

fly levels than orchard types 1 and 3. On average (mean $\pm$ S.D.), *B. dorsalis* fly captures over 60 days were 6503 ± 2835 individuals per orchard for those of type 4 against 4049 ± 1601 and 3745 ± 970 , respectively, for those of types 1 and 3.

DISCUSSION AND CONCLUSION

Our results confirmed that the presence of *O. longinoda* ants on a tree led to a reduction in mango infestation levels on that tree. They showed that lower pupa numbers from fruits on trees with weaver ants were due not only to a lower fruit infestation rate, but also to the fact that flies laid fewer eggs on those fruits and/or that the predation rate of third-stage larvae by ants was higher. In their study on the capacity of *O. longinoda* to protect mangoes against *B. dorsalis* in Benin, Van Mele *et al.* (2007) also showed that high *O. longinoda* populations considerably reduced fruit fly infestation rates.

Until now, mechanisms governing fruit fly control by weaver ants remained ambiguous. It seems, however, that the presence of *O. longinoda* ants affect fruit fly oviposition behaviour on the trees they occupy through a decreased oviposition time and number of eggs laid when *O. longinoda* have already patrolled those fruits (Vayssières *et al.* 2010, 2013). Chemical pheromone emission affecting fruit fly oviposition behaviour is the most evident supposition (Offenberg *et al.* 2004; Offenberg 2007; Adandonon *et al.* 2009; Van Mele *et al.* 2009), but the direct predation or pest deterrence are other phenomena influenced by this species (Van Mele *et al.* 2007; Aluja *et al.* 2005).

The study also highlighted a relation between the abundance of *O. longinoda* ants and that of *B. dorsalis* fruit flies in orchards. These abundances were negatively correlated. This observation confirms the results of Van Mele & Cuc (2007) showing that an orchard with abundant weaver ant populations has lower infestations of mites, leafminers and fruit flies. This relationship probably partly depends on low *B. dorsalis* reproduction when weaver ants are present on trees, as indicated by the results for fruit infestation rates on trees 'with' or 'without' an ant colony. On the other hand, the abundance of *O. longinoda* and *B. dorsalis* varied depending on the orchard types. Orchards types 1 and 3 had more *O. longinoda* ants and tended to have fewer *B. dorsalis* than the type 4 orchards. Moreover, this tendency was supported by the

first observations carried out in 2010 in other sampled orchards chosen in the same study area: over a 20-week period in the rainy season, 9720 *B. dorsalis* flies were captured per trap on average from type 4 orchards as opposed to 7230 for the other two types (Grechi *et al.* 2013). The conditions favouring abundant weaver ant populations included limited human disturbance (Van Mele & Cuc 2007). In our study, type 1 orchards were those that registered virtually no inputs and no human intervention, while higher levels were recorded in the type 3 orchards, and even more in those of type 4 (Grechi *et al.* 2013). Among the type 4 orchards, one orchard (32B) presented a different tendency in comparison to the other orchards in the rainy season. Weaver ant abundance was low, as in the other orchards of the same type; conversely, *B. dorsalis* abundance was low while it was high in the other orchards. The type 4 orchards were the ones registering the most insecticide treatments. Visibly, these insecticide applications did not reduce damage caused by fruit flies. There may be many reasons for this. First, crop pests, and precisely fruit flies, can develop resistance mechanisms against insecticides (Devine & Furlong 2007; Kakani & Mathiopoulos 2008). Second, data on farming practice intensity (e.g. pesticide application frequency or picking of fallen fruits) helping to characterize orchards did not indicate whether practices were well mastered and well applied by farmers (Grechi *et al.* 2013). So, incorrectly used insecticides may be ineffective against target pests, and may also reduce the abundance of natural enemies and their capacity to regulate pests (Van Hamburg & Guest 1997). Furthermore, treatments were carried out in general on the foliage areas of trees above eggs, larvae and pupae contained in fallen fruits. Effective pest management should take into account those fruits. Even if fallen fruits are collected, it might be ineffective if collected fruits are gathered in a corner of the orchard without sealing them in plastic bags or destroying them. This method provides greater guarantees in fruit fly management when combined with male or female pheromone trapping and also with Success® Appat applications (Verghese *et al.* 2006; Piñero *et al.* 2009; Manrakhan *et al.* 2011).

The large numbers of *B. dorsalis* in the rainy season depended on the species' biology, benefiting from good weather conditions and from the wide availability of host fruits in which to reproduce. In the dry season, which is considered as an

unfavourable period for *B. dorsalis* development, the pest was present in the three orchard types in low levels. Depending on their structural design and specific plant composition, the three orchard types displayed aspects suspected of retaining *B. dorsalis* in orchards during the dry season. Type 3 orchards had greater tree crop diversity than orchard types 1 and 4, and type 1 orchards had more fruit species and species diversity in their hedgerows than orchard types 3 and 4 (Grechi *et al.* 2013). These two elements were potentially conducive to fly reproduction and mango re-infestation during the ripening period, because *B. dorsalis* is a polyphagous pest that can infest cultivated or wild fruits of at least 46 species belonging to 23 botanical families (Goergen *et al.* 2011). In addition, Ndiaye *et al.* (2012) showed that some host plants such as *Ziziphus mauritiana* or *Capparis tomentosa*, which are generally used as protective hedges in Senegalese mango-based agro-ecosystems, sustain *B. dorsalis* flies before the mango ripening period. Type 4 orchards had greater protective species in their hedgerows than orchard types 1 and 3. The use of *B. dorsalis* host plants as protective hedges should therefore be reconsidered for the management of this fly (Ndiaye *et al.* 2012).

To conclude, the different results of this study highlighted: i) the positive impact of *O. longinoda* in limiting *B. dorsalis* mango infestations, ii) a major negative correlation between the abundance of *O. longinoda* and that of *B. dorsalis* in the orchards in the rainy season and iii) a relation

between these abundances and the orchard design and management practices. In Senegal, weaver ants are considered as harmful insects. The majority of producers consider them as pests because of the marks they leave on fruits and the painful bites they inflict during fruit harvesting. Some producers go further and eradicate them completely from their orchards (L. Diamé, pers. obs.). This kind of result may convince them of the importance of weaver ants as biological control agents and change the perception of these special ants in fruit-based agro-ecosystems.

These results are part of studies on the relationships between the management practices of growers and their effects on pests and their natural enemies. The first step was to develop a methodology and only the Niayes area and Thiès plateau regions were investigated. Now that the methodology has been finalized, it should be used in further studies to investigate these relationships in other areas of Senegal, especially the mango-rich Casamance province, and in other West Africa countries in contrasted conditions.

ACKNOWLEDGEMENTS

We would like to thank all the fruit producers in the 15 orchards in the Niayes zone and the Thiès plateau for their collaboration during the study. Thanks are due to PDMAS (Projet de Développement des Marchés Agricoles du Sénégal) for financial support. We also thank R. Blatrix (CEFE/CNRS, Montpellier, France) for his advice and P. Biggins for correcting the English.

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