

# Reducing losses inflicted by insect pests on cashew, using weaver ants as a biological control agent

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- Abstract**
- 1 In Benin cashew plantations, yields and nut quality are lost mainly as a result of insect pests. In the present study, we investigated the effectiveness of the African weaver ant *Oecophylla longinoda* as a biocontrol agent against Beninese cashew pests.
  - 2 In a 2-year study, nut yield and quality were compared among: (i) trees with weaver ants *O. longinoda*; (ii) trees where weaver ants were sugar-fed; (iii) integrated pest management (IPM) trees with weaver ants combined with fruit fly bait spray; and (iv) control trees receiving no control measures.
  - 3 All treatments with ants showed significantly higher yields than the control, with the IPM treatment leading to the highest yield. Compared with the control trees, the ants, ant sugar-fed and the IPM trees produced 78%, 122% and 151% more nuts, respectively. Nuts produced on control trees were of a higher quality on average because they were less damaged by thrips (probably because the fruit fly bait worked as a contact poison on thrips); this was also the case for the IPM treatment. In absolute numbers, however, trees in ant treatments produced more first-quality nuts.
  - 4 To achieve a broader and effective control of both coreid bugs and thrips, a combination of weaver ants and supplementary compatible control measures is recommended.

**Keywords** Biocontrol, cashew yield, nut quality, *Oecophylla longinoda*, pest damages.

## Introduction

Cashew *Anacardium occidentale* Linnaeus (Sapindales: Anacardiaceae) is native to Brazil and was introduced to Africa by the Portuguese in the 16th Century (Goujon *et al.*, 1973). Worldwide, the annual production of cashew raw nuts, increased from 3 982 640 tonnes in 2008 to 4 279 738 tonnes in 2011 (FAOSTAT, <http://faostat.fao.org/>). The top 10 countries growing cashew are Vietnam (28% of total world production), India (25%), Nigeria (10%), Brazil (8%), Tanzania, Indonesia, Guinea-Bissau, Ivory Coast, Mozambique and Benin (Ionescu *et al.*, 2012). In Benin, the cashew sector represents a huge agricultural export opportunity. Raw nut exports rose from 36 487 tonnes in 2001 to 116 398 tonnes in 2008 (Tandjiékpon, 2010). The sector accounted for 13.5% of Benin's exports earnings in 2008 and

replaced cotton as being Benin's top one agricultural export product (Tandjiékpon, 2010).

Worldwide, cashew yields and nut quality is severely affected by the infestation of several insect pests (Devasahayam & Nayar, 1986; Peng *et al.*, 1997a; Dwomoh *et al.*, 2008; Olotu *et al.*, 2013). In Benin, the branch borer *Apate terebrans* P. (Coleoptera: Bostrichidae), the leaf miner *Acrocercopos syngamma* M. (Lepidoptera: Gracillariidae) and the sap sucking bugs *Helopeltis* sp. (Hemiptera: Miridae), *Anoplocnemis curvipes* F. (Hemiptera: Coreidae), *Pseudothaptus devastans* D. (Hemiptera: Coreidae) are major pests on cashew trees (F. Ouessou, unpublished data). At the fruiting stage, coreid bugs (*A. curvipes* and *P. devastans*) are the key insect pests on nuts. Bug infestations can result in more than 75% shoot damage and 98% flower dropping, giving a yield loss of up to 80% (Boma *et al.*, 1997). Apart from these cashew pests, in an emerging participatory survey of on-going research in Benin in 2012–2013, it was found that also thrips [*Frankliniella schultzei* Trybom, *Scirtothrips mangiferae*

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Preisner, *Scirtothrips aurantii* Faure (Thysanoptera: Thripidae) and *Haplothrips* sp (Thysanoptera: Phlaeothripidae)] played a key role as a pest by inflicting damage symptoms on the surface of raw nuts (R. Wargui, unpublished data). In Australia, cashew nuts showing thrips damage on more than 51% of the nut surface had a 17–32% reduction in the weight of the raw nut and a 35–53% reduction in kernel weight compared with undamaged nuts (Peng *et al.*, 2008). Thus, thrips may also significantly affect cashew yields and/or quality.

Weaver ants *Oecophylla longinoda* Latreille and *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae) can protect several tropical crops against more than 40 species of pests (Way & Khoo, 1992; Peng *et al.*, 1995; Van Mele, 2008) because the ants prey on and/or deter other insects. Dejean (1991) estimated that worker ants from 12 weaver ant nests captured 45 000 insects per year and studies have shown that semiochemicals deposited by the ants may also deter pests (Offenberg *et al.*, 2004; Adandonon *et al.*, 2009). For example, pest control by weaver ants has been observed in coconut (Vanderplank, 1960; Sporleder & Rapp, 1998), citrus (Van Mele *et al.*, 2002; Offenberg *et al.*, 2013), mahogany (Peng *et al.*, 2011) and mango (Peng & Christian, 2004; Van Mele *et al.*, 2007). In addition, cashew plantations have been observed to benefit from the presence of weaver ants. In Northern Australia, cashew is protected against *Helopeltis* spp. bugs by *O. smaragdina* (Peng *et al.*, 1997b, 2005). In Ghana (Dwomoh *et al.*, 2009) and Tanzania (Olotu *et al.*, 2013), *O. longinoda* provides efficient protection against sap sucking bugs. In some settings, however, weaver ants may not be effective for managing the whole insect pest complex attacking cashew. In such cases, control by weaver ants should be integrated with other compatible methods. For example, Peng and Christian (2005) reported that weaver ants used in an integrated pest management (IPM) programme with soft chemicals (white oil and potassium soap) proved to be more profitable than using the weaver ants alone because the ants were unable to reduce scale insect populations (Peng & Christian, 2005). In the present study, we evaluated the yield quantity and quality as a result of implementation of an IPM programme composed of biological control by weaver ants and spot application of bait. Such a programme may include the control of additional pests of cashew, such as thrips that are not affected by the former.

## Materials and methods

A cashew orchard in the Parakou area (09°22'13"N/02°40'16"E) of Benin was used for the present study. The orchard had an average of 100 trees/ha at an even spacing (10 × 10 m<sup>2</sup>). The trees were between 20 and 25 years old. In a 2-year experiment from October 2012 to April 2014, observations were carried out on 6-ha cashew trees divided into three blocks and each block was divided into four treatments: (i) a plot of trees colonized by weaver ants (ants); (ii) a plot of trees colonized by weaver ants fed with sugar solution (ants feeding); (iii) a plot of trees colonized with weaver ants and spot application of GF-120 (ants + GF-120) containing 0.02% Spinosad (Dow AgroSciences LLC, Indianapolis, Indiana); and (iv) a plot of trees not subjected to any form of insect pests control (control).

By contrast to many other African countries, powdery mildew is not problematic in Benin (Afouda *et al.*, 2013) and, according to farmers and other stakeholders, cashew diseases do not jeopardize the production. Therefore, none of the treatments included control measures against these diseases. Moreover, because most farmers in Benin do not control insect pests, it was impossible to compare weaver ants with traditional control practices. Blocks and treatments were set up in a randomized block design with 24 trees per replicate and three replicates, totalling 72 trees per treatment. Randomization was carried out once in the beginning of the experiment. A block design were used to avoid the effect of variation in soil quality and other spatial variation. Two rows of cashew trees were used as a buffer zone between two consecutive treatments.

## Treatments

In the ant treatments, trees with naturally occurring weaver ant colonies were selected at the beginning of the experiment. Because weaver ants from different colonies fight, aggression tests were used to identify individual colonies (Peng *et al.*, 2008). Trees belonging to the same ant colony were connected with twisted polystrings (diameter 3 mm) to facilitate ant migration (Van Mele & Cuc, 2003; Vayssières, 2012), whereas tree branches connecting trees between different colonies were pruned to avoid fighting between neighbouring ant colonies. Ants were kept out of control trees by applying a sticky band (Oecotak 5; Oecos Ltd, U.K.) around the trunk of the trees and ensuring that weeds did not bridge this barrier. In the ant-feeding treatment, a 30% sucrose solution was provided to the ants in small plastic bottles, plugged with a cotton plug. The sugar feeders were placed upside down on a tree trunk with a busy ant trail. Sugar solution (60 mL) was provided in each tree once a week as a supplement to naturally-occurring food to boost colony growth and performance. In addition, water was provided *ad libitum* in a bottle on each of the trees in the ant-feeding treatment.

In the ant + GF-120 treatment, a combination of spinosad (neurotoxin) and protein bait (Salgado, 1998; Salgado *et al.*, 1998) was used to spray the trees (GF-120 NF Naturalyte fruit fly bait; Dow AgroSciences LLC). This contained 0.02% spinosad (active ingredient) and 98.8% inert ingredients consisting of water, sugars and attractants. The recommended dose (1.5 l/ha) was used. Before application, this dose was mixed with water at the ratio of 1 : 5 (Dow Agrosciences, 2001) and was freshly applied, as a foliar spot spray, using an Apollo 16-AF manual sprayer (Berthoud Spayers Ltd, U.K.) with a conventional conical nozzle (aperture of 1–2 mm to deliver droplets of 2–6 mm) (Vayssières *et al.*, 2009). One square metre of each tree was sprayed at head height in an area without fruits (Vayssières *et al.*, 2009). The weekly application was carried out six times, from February to March in the beginning of the harvest each year. The ant + GF-120 treatment was used: (i) because GF-120 may control fruit flies that can damage cashew apples and, in this way, cashew may act as a reservoir for fruit flies that subsequently can cause considerably damage in mango and (ii) because GF-120 may control thrips and other pest species, yet be compatible with organic production.

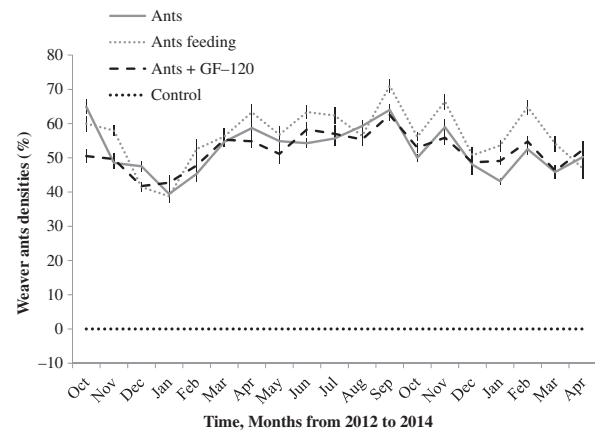
On each tree in the ant treatments, weaver ant abundance was monitored fortnightly using the Forager Density Index (Offenberg & Wiwatwitaya, 2010) from October 2012 to April 2014. The index is based on the proportion of the main trunks on the tree occupied by weaver ant trails, weighted by the density of the trails. Trails were categorized into four density levels: (i) trails without ants (zero density); (ii) trails with 1–9 ants/m (low density); (iii) trails with 10–50 ants/m (medium density); and (iv) trails with > 50 ants/m (high density). As described by Offenberg and Wiwatwitaya (2010), the FDI then equals  $[(0)(Z) + (L)(1/3) + (Me)(2/3) + (H)]/M$ , where FDI is the Forager Density Index,  $M$  is the total number of main trunks on the tree and  $Z$ ,  $L$ ,  $Me$  and  $H$  represent zero, low, medium and high density trunks, respectively. The mean index value was calculated for each treatment and plotted by month to assess the abundance of ants in different treatments.

#### Nut yield, quality and damage assessment

Data collection took place during the cashew harvest period from February to April 2013 and 2014. During this period, the total number of nuts falling to the ground was counted each day under each tree to obtain the yearly yields. In addition, nut weight was registered and mean nut weight was calculated. Furthermore, nut quality was assessed using specific criteria for export: grade 1 (first quality) = good mature nuts with shiny and clean skin and no black sooty mould and no damage symptoms from insect pests; grade 2 (second quality) = satisfactory mature nuts with less shiny and clean skin, with few spots but without major damage symptoms from insect pests; and rejected nuts = scorched mature and immature nuts with large spots and deformed shape as a result of heavy insect pest damage (Peng *et al.*, 2008). For each tree, the percentage of nuts in each category was calculated at the end of the harvest. For the two latter categories, the origin of damage on the harvested nut was also assessed and classified as damage caused by thrips, sap-sucking bugs and unknown damage to allow calculation of the percentage of nuts damaged by each type.

#### Statistical analysis

The percentages of grade 1 nut and nut damaged by thrips were normally distributed and showed variance homogeneity.  $\text{Log}_{10}[x + 1]$  and  $\arcsin\sqrt{x}$  transformations were used respectively on count variables (total number of nuts and nut weight produced per tree) and variables in percentage (percentage of nuts in grade 2, reject and percentage of nuts damaged by sap-sucking bugs) to stabilize the variance and achieve normality of the data before analysis. A multivariate repeated measures analysis of variance (MANOVA) was performed to compare means of the variable with treatments (ants, ants feeding, ants + GF-120, control) and seasons (2012–2013, 2013–2014) as the main effects along with an interaction term. In addition, yield (number of nuts and nut weight) per tree was compared between blocks by one-way ANOVA. A regression of the percentages of grade 1 nuts on thrips damage was also performed. All analyses were conducted using JMP, version 10.0.0 (SAS Institute Inc., Cary, North Carolina).



**Figure 1** The dynamics of weaver ant (*Oecophylla longinoda*) densities (mean  $\pm$  SE) in cashew trees in the four different treatments from October 2012 to April 2014.

## Results

### Weaver ant densities

Throughout the seasons, weaver ants were abundant in all the ant treatments and no ants were observed in the control treatment (Fig. 1). Weaver ant mean densities (mean  $\pm$  SE) were  $52.4 \pm 1.58\%$ ,  $56.5 \pm 1.88\%$  and  $51.9 \pm 1.21\%$  in the ant, ant-feeding and ant + GF-120 treatments, respectively, with a significant difference among the three treatments ( $F_{2,498} = 25.76$ ;  $P < 0.0001$ ). This trend was similar for the 2-year experiment.

### Effect of ants on cashew yield

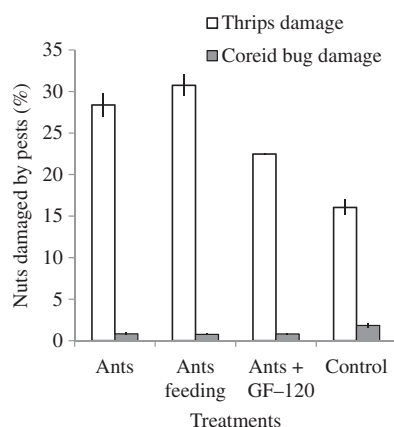
There was no significant difference in yield among the three blocks in the plantation (numbers of nuts:  $F_{2,545} = 0.87$ ;  $P = 0.42$ , nut weight:  $F_{2,545} = 0.87$ ;  $P = 0.42$ ); however, yields differed among treatments. The number of cashew nuts harvested ( $F_{3,261} = 10.38$ ;  $P < 0.0001$ ) and the mean nut weight per tree ( $F_{3,261} = 10.79$ ;  $P < 0.0001$ ) was significantly different among the four treatments (Table 1). Cashew yields (number of nuts and nut weight) in the control treatment were significantly lower compared with those in all other treatments, whereas higher numbers were recorded in the ant + GF-120 treatment. Compared with the control treatment, trees in the ants, ant sugar-fed and IPM treatments produced, respectively, a 78%, 122% and 151% increase in the number of nuts and a 73%, 118% and 141% increase in nut weight. Cashew yields were not affected by year (numbers of nuts:  $F_{1,261} = 0.99$ ;  $P = 0.32$ , nut weight:  $F_{1,261} = 3.69$ ;  $P = 0.06$ ) (Table 1).

### Effect of ants on cashew nut quality

The highest damage levels on nuts were caused by thrips ( $24.61 \pm 0.63\%$ ), with much lower damage caused by coreid bugs ( $1.05 \pm 0.08\%$ ). Thrips damages were highest in the ant-feeding treatment and lowest in the control treatment, with the control treatment showing significantly lower damage levels than all other treatments ( $F_{3,261} = 30.75$ ;  $P < 0.0001$ ) (Fig. 2). It thus

**Table 1** Cashew yields (mean  $\pm$  SE) and nut quality by treatment after the harvest of mature nuts from a plantation in Parakou, Benin, in 2013 and 2014

Treatments	Number of nuts		Weight (g)		Grade 1 nuts (%)		Grade 2 nuts (%)		Rejected nuts (%)	
	Mean $\pm$ SE	MANOVA	Mean $\pm$ SE	MANOVA	Mean $\pm$ SE	MANOVA	Mean $\pm$ SE	MANOVA	Mean $\pm$ SE	MANOVA
Ants	644.1 $\pm$ 56.1		3872.2 $\pm$ 395.6		59.5 $\pm$ 1.5		29.8 $\pm$ 1.2		10.6 $\pm$ 0.7	
Ants feeding	802.3 $\pm$ 70.4	$F_{3,261} = 10.38$ $P < 0.0001$	4886.9 $\pm$ 378.6	$F_{3,261} = 10.79$ $P < 0.0001$	57.5 $\pm$ 1.4	$F_{3,261} = 25.83$ $P < 0.0001$	31.7 $\pm$ 1.1	$F_{3,261} = 29.34$ $P < 0.0001$	10.8 $\pm$ 0.7	$F_{3,261} = 5.19$ $P = 0.0017$
Ants + GF-120	906.9 $\pm$ 61.0		5409.8 $\pm$ 349.8		69.4 $\pm$ 1.2		22.9 $\pm$ 1.1		7.7 $\pm$ 0.5	
Control	361.4 $\pm$ 27.7		2241.7 $\pm$ 175.5		72.4 $\pm$ 1.3		18.7 $\pm$ 1.0		8.9 $\pm$ 0.7	
Seasons		$F_{1,261} = 0.99$ $P = 0.3213$		$F_{1,261} = 3.69$ $P = 0.0558$		$F_{1,261} = 21.53$ $P < 0.0001$		$F_{1,261} = 4.34$ $P = 0.0382$		$F_{1,261} = 218.62$ $P < 0.0001$
Treatments $\times$ seasons		$F_{3,261} = 1.52$ $P = 0.2106$		$F_{3,261} = 1.07$ $P = 0.3615$		$F_{3,261} = 6.57$ $P = 0.0003$		$F_{3,261} = 6.04$ $P = 0.0005$		$F_{3,261} = 2.74$ $P = 0.0435$

**Figure 2** Effects of weaver ants (*Oecophylla longinoda*) treatments on pest damages on mature harvested cashew nuts from a cashew plantation in Parakou, Benin from two harvests (2012–2014). Bars indicate the mean  $\pm$  SE.

appears that the weaver ants had a positive effect on thrips. By contrast to thrips, coreid bug damages were significantly higher on control trees compared with the other treatments ( $F_{3,261} = 8.70$ ;  $P < 0.0001$ ) (Fig. 2).

The damage incurred by the pests affected the grading of nuts, resulting in significant differences among treatments (Table 1). The percentage of grade 1 nuts was the highest in the control and ant + GF-120 treatments and the lowest in the ant and ant-feeding treatments ( $F_{3,261} = 25.83$ ,  $P < 0.0001$ ), whereas the percentage of grade 2 nuts was lower in the control treatment compared with the ant and ant-feeding treatments ( $F_{3,261} = 29.34$ ,  $P < 0.0001$ ). Similarly, the lowest quality grade (i.e. the percentage of rejected nuts) was lower in the control and ant + GF-120 treatments compared with the ants and ant-feeding treatments ( $F_{3,261} = 5.19$ ,  $P = 0.0017$ ). In absolute numbers, however, trees in ant treatments produced more first- and second-quality nuts compared with the control treatment (Table 2). Moreover, the effect of thrips damage on nut quality is demonstrated by the significant negative correlation between the proportion of first-quality nuts and the amount of thrips damage (Fig. 3).

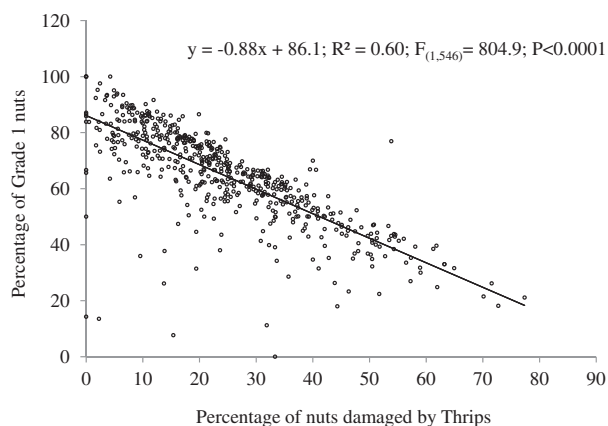
The mechanisms behind the observed effects of ants were not assessed systematically in the present study, although ants were regularly seen carrying various bugs and caterpillars to their nests, suggesting that their protective effect is partly based on predation. By contrast, ants were never seen carrying thrips.

## Discussion

Cashew yields increased almost two-fold in all the treatments with ants (from 72% to 150%) compared with the control treatment without pest control measures (Table 1). Moreover, the increased amount of nuts in the treatments with ants consisted of nuts of lower quality because they were more damaged by thrips. However, net gains were still achieved in the ant treatments because 25% of thrips damage still leaves farmers with a higher proportion of grade 1 nuts when yields are doubled. Despite low levels of bug damage, the higher yields in ant treatments were probably caused by the efficient ant control of coreid bugs as

**Table 2** Cashew yields (mean  $\pm$  SE) in relation to nut quality and treatment after the harvest of mature nuts from a plantation in Parakou, Benin, in 2013 and 2014

Treatments	Number of nuts			Weight (g)		
	Grade 1 nuts Mean $\pm$ SE	Grade 2 nuts Mean $\pm$ SE	Rejected nuts Mean $\pm$ SE	Grade 1 nuts Mean $\pm$ SE	Grade 2 nuts Mean $\pm$ SE	Rejected nuts Mean $\pm$ SE
Ants	395.6 $\pm$ 38.4	186.8 $\pm$ 17.3	61.6 $\pm$ 6.8	2832.7 $\pm$ 263.7	1128.9 $\pm$ 118.4	360.5 $\pm$ 40.5
Ants feeding	460.6 $\pm$ 40.3	249.8 $\pm$ 23.1	91.9 $\pm$ 11.3	2819.8 $\pm$ 225.8	1526.4 $\pm$ 126.31	540.7 $\pm$ 59.5
Ants + GF-120	635.4 $\pm$ 43.6	201.4 $\pm$ 15.3	70.1 $\pm$ 7.4	3786.4 $\pm$ 248.1	1206.5 $\pm$ 88.0	416.9 $\pm$ 42.7
Control	263.5 $\pm$ 21.0	68.7 $\pm$ 6.3	29.2 $\pm$ 2.8	1645.8 $\pm$ 135.4	419.1 $\pm$ 37.9	176.8 $\pm$ 16.6

**Figure 3** Relationship between thrips damage and nut quality on mature cashew nuts harvested from a cashew plantation in Parakou from February to April in 2013 and 2014.

observed in previous studies (Peng *et al.*, 2005, 2008; Dwomoh *et al.*, 2009; Olotu *et al.*, 2013; see also the review by Way & Khoo, 1992) and as reflected by the significantly higher bug damage found in the control treatment (Fig. 2). The low bug damage recorded in the present study results from bug damage on young developing nuts leading to their abortion and thus reduced yields (Peng *et al.*, 2008; Olotu *et al.*, 2013). Most of this type of damage is therefore not apparent on the mature nuts found during the harvest season because those nuts that were damaged early, never developed to maturity. Accordingly, bug damage mainly appears as a reduced yield. During flowering and fruiting, bug damage symptoms are much higher than the damage registered on the harvested nuts. Thus, higher yields can be present in ant treatments without a necessarily associated and similar lower amount of bug damage. In summary, the ants controlled bugs leading to higher yields and higher absolute numbers of first-quality nuts (Table 2). However, they also benefitted thrips, resulting in higher relative damage on ant attended nuts compared with the control treatment (Table 1).

As noted above, the positive effect of weaver ants as biocontrol agents in cashews is in accordance with previous studies. In Ghana, there were more than four-fold higher cashew yields on ant trees compared with control trees without ants and ant yields were found not to differ significantly from treatments where chemical insecticides were used (Dwomoh *et al.*, 2009). Peng and Christian (2004) found Australian weaver ant *O. smaragdina* to be even more effective than chemical

insecticides because the ants were able to increase yields by 49% compared with plots protected with chemicals. Lastly, weaver ants in Tanzanian cashew plantations reduced bug damage (Miridae and Coreidae) considerably compared with control trees without ants (Olotu *et al.*, 2013).

By contrast, the lower quality of cashew nuts associated to the presence of ants in the present study (Table 1) is not in accordance with previous findings. The reduced quality was mainly caused by thrips (Figs 2 and 3), suggesting a positive influence of weaver ants on thrips. In Vietnamese and Australian cashew, *O. smaragdina* were able to reduce thrips damages (yellow thrips *Rhynchothrips* sp. and the chilli thrips *Scirtothrips dorsalis* Hood); however, this was not sufficiently efficient to reduce damage below economic injury levels (Peng *et al.*, 2008). Furthermore, red-banded thrips *Selenothrips rubrocinctus* Giard have been reported to be efficiently controlled by *O. smaragdina* on Australian mango trees (Peng & Christian, 2004). This discrepancy between studies suggests that the interaction outcomes between weaver ants and thrips are species-dependent or depend on the ecological context. A positive relationship between thrips and weaver ants, as found in the present study, is interesting because, to our knowledge, mutualisms or trophobiosis do not exist between ants and thrips. The higher thrips damage in the ant-feeding treatment compared with the treatment where ants were not fed could have been a result of the slightly higher ant densities in this treatment (Fig. 1). At present, we have no explanation for this peculiar positive association between ants and thrips damage. The nature of this interaction therefore deserves further study.

Weaver ants reduced quantitative losses as a result of coreid bugs and led to higher absolute numbers of first-quality nuts, although the percentage of nuts damaged by thrips was higher in ant treatments. Reduced nut quality, however, was eliminated (Table 1) and thrips damage was reduced (Fig. 2) when weaver ants were used in combination with Spinosad in the IPM treatment. Thus, Spinosad in the form of GF-120 may be a promising IPM component for use as a supplement in the management of weaver ants when aiming to achieve a broader pest control. Figure 1 suggest that Spinosad, at least in the present formulation, is fully compatible with thriving weaver ant colonies. Furthermore, it is known to control thrips (Cloyd & Sadof, 2000; Workman & Martin, 2002) and other pests (Wang *et al.*, 2005; Vayssières *et al.*, 2009) and, at the same time, it is approved for use in organic production (Burns *et al.*, 2001; Vargas *et al.*, 2001; Vayssières *et al.*, 2009; Sparks *et al.*, 2012). However, before considering its use as part of an IPM package, its

direct role and cost efficiency need further clarification. Despite it being evident that ants + GF-120 lead to the highest gains, its real profit is unknown because GF-120 is expensive and may not be applicable to resource-poor farmers. The question of whether increased incomes as a result of improved yields and quality outweigh the costs associated with GF-120 will need to be addressed in future studies. Similarly, the costs associated with ant-feeding and its associated gains need to be compared with the treatment without ant-feeding to determine whether ant-feeding is cost effective. A need for the incorporation of weaver ants in IPM approaches has been documented in previous studies. For example, Peng and Christian (2005) combined the use of weaver ants with 'soft chemicals' (1.5% potassium soap and 2% white oil, which were harmless to the ants but detrimental to pests) to obtain efficient pest control in Australian mango. This IPM approach led to returns that were significantly higher than in plots where conventional chemical insecticides were used and it not only increased returns, but also was compatible with organic certification. Offenberg *et al.* (2013) described the need to apply additional control measures to supplement weaver ants to control leaf hopper damage in a Thai mango plantation. Finding alternative control measures against thrips that are compatible with weaver ants and less costly than GF-120 also remains to be addressed in the future.

On the one hand, it was surprising to find that rather sessile plant cell feeding thrips were affected by spot spraying because they are not expected to actively visit and forage on the bait. On the other hand, during the weekly applications, rotations around the trees were used. Thus, a large part of the canopies eventually became contaminated by the toxin, potentially leading to the reduction of the thrips population. More intensive spraying, rather than spot spraying, may reduce thrips damage even further in the IPM treatment. However, additional studies are needed to clarify the mode of action of GF-120 on the thrips and to test whether thrips control can be further enhanced via more efficient formulations. Alternatively, as indicated above, a search for alternative compatible control measures should be initiated.

In accordance with previous studies, the present study reports that weaver ants are highly beneficial in controlling major cashew pests such as sap sucking bugs. However, it is also shown that the ants may have an unexpected positive effect on thrips in Benin cashew. This positive association not only deserves further studies to clarify its nature, but also demands the need to identify IPM techniques that may be compatible with weaver ants and, at the same time, are detrimental to thrips.

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