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## Ant-hemipteran associations in a market-gardening based agro-system in a Yaoundé suburb, Centre Region (Cameroon)

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### ABSTRACT

Tritrophic plant-hemipteran-ant relationships are poorly documented in tropical African market-garden agro-systems despite its agronomic importance. The present study aimed at characterizing ant-hemipteran associations on five market crop species at Nkolondom (north-western suburb of Yaoundé): *Abelmoschus esculentus*, *Capsicum annum*, *Solanum lycopersicum*, *Solanum melongena* and *Solanum scabrum*. From July to October 2013, twice per week, feeding activities of ants were examined and the occurrence of each ant/hemipteran association recorded per plant species. As result, ants preferentially harvested honeydew excreted by hemipterans. However, *Myrmecaria opaciventris* and *Camponotus flavomarginatus* also collected plant sap from wounded organs. Among hemipterans, *Aphis fabae*, *Aphis gossypii*, *Aulacorthum solani*, *Macrosiphum euphorbiae*, scale insects and mealybugs were the most recurrent. The most frequent associations were *M. opaciventris*-*A. fabae* and *C. flavomarginatus*-*A. fabae* on *S. scabrum*, *C. flavomarginatus*-*M. euphorbiae* on *S. lycopersicum*, *C. flavomarginatus*-*A. solani* on *C. annum*, *M. opaciventris*-*A. gossypii* and *Technomyrmex* sp.-*A. gossypii* on *S. lycopersicum*. Some moderately frequent associations *viz.* *C. flavomarginatus*-*M. euphorbiae* and *M. opaciventris*-*M. euphorbiae* were recorded on *S. melongena*. For these associations, highly significant and positive correlations was raised between ants' and aphids' populations, suggesting potential mutualistic interactions between the two taxa.

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**Keywords:** Aphids, bugs, feeding behavior, Formicidae, interactions, market crops.

## Associations fourmi-hémiptère dans un agrosystème à base de cultures maraîchères dans une banlieue de Yaoundé, Région du Centre (Cameroun)

### RESUME

Les relations tritrophiques plante-hémiptère-fourmi sont peu étudiées dans les agrosystèmes maraîchers d'Afrique tropicale, malgré leur importance agronomique. La présente étude visait à caractériser les associations fourmi-hémiptères sur cinq espèces de cultures maraîchères à Nkolondom (banlieue nord-ouest de Yaoundé): *Abelmoschus esculentus*, *Capsicum annum*, *Solanum lycopersicum*, *Solanum melongena* et *Solanum scabrum*. De juillet à octobre 2013, deux fois par semaine, les activités d'alimentation des fourmis ont été examinées et la présence de chaque association fourmi/hémiptère enregistrée sur chaque espèce végétale. Comme résultat, les fourmis récoltaient principalement le miellat excrété par les hémiptères. Cependant,

*Myrmecaria opaciventris* et *Camponotus flavomarginatus* prélevaient également la sève issue des organes végétaux blessés. Parmi les hémiptères, *Aphis fabae*, *Aphis gossypii*, *Aulacorthum solani*, *Macrosiphum euphorbiae* et les cochenilles étaient les plus récurrents. Les associations les plus fréquentes étaient *M. opaciventris*–*A. fabae* et *C. flavomarginatus*–*A. fabae* sur *S. scabrum*, *C. flavomarginatus*–*M. euphorbiae* sur *S. lycopersicum*, *C. flavomarginatus*–*A. solani* sur *C. annuum*, *M. opaciventris*–*A. gossypii* et *Technomyrmex* sp.–*A. gossypii* sur *S. lycopersicum*. Quelques associations modérément fréquentes telles que *C. flavomarginatus*–*M. euphorbiae* et *M. opaciventris*–*M. euphorbiae* ont été enregistrées sur *S. melongena*. Des corrélations hautement significatives et positives ont été établies entre les populations de fourmis et de pucerons, suggérant des interactions mutualistes potentielles entre les deux taxons.

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**Mots clés :** Comportement de nutrition, cultures maraîchères, Formicidae, interactions, pucerons, punaises.

## INTRODUCTION

Since the early 1990's in Cameroon, market gardening has become one of the main contributors to food self-sufficiency (Temple, 2001). Its intensification in urban and suburban areas has led to an increase and diversification of pest insects. Among others, hemipterans, especially aphids and true bugs, have been pointed out as one of the main constraints of cultivated plants worldwide (Djiéto-Lordon et al., 2007; Tendeng et al., 2017), although their damage are not always obvious. In addition to sap spoliation, damage due to hemipterans, namely aphids, include localized chlorosis near the feeding site caused by chloroplast disruption, growth distortions on leaves, leaf curling, and sometimes but seldom, galls or tumours (Guerrieri and Digilio, 2008). Sometimes, once infested leaves curl upward, they turn brown, and eventually die and fall down. As for whiteflies, they can directly damage plants by depleting sap, inducing premature defoliation, stunted growth, and potentially death of the plant during population outbreaks (Nasruddin and Stocks, 2014). Damage are vicious when true bugs feed on seedlings and newly transplanted market crops. The feeding punctures are characterised by marks appearing as white patches starting on the edges of leaves as it expands (Palumbo and Natwick, 2010). True bugs such as mirids are well known for abortions they induce on cherelles in cocoa plantations (Mahob et al., 2014, 2018). Other hemipterans, such as aphids, by inserting their mouthparts into plant tissues during sap depletion, inject toxic

saliva or pathogens in the plant tissue (Guerrieri and Digilio, 2008). They might be very harmful since they are highly prolific and usually determine outbreaks on growing plants (Guerrieri and Digilio, 2008). Furthermore, by the saliva bearing pathogen injections, hemipterans could act as vectors of some pathogenic microorganisms (Blackman and Eastop, 2000, Jones, 2003; Ng and Perry, 2004; Hampton et al., 2005; Brault et al., 2010). Such threats usually affect plant growth, productivity and, may have a real impact on leaves and fruit yield.

Some hemipterans, especially those living in more or less large colonies, are often associated with one or several ant species (Steiner et al., 2004). Anyway, poor flying hemipterans such as aphids and coccids depend on their tending ants for dispersal. Ants might then play an important role in their dissemination and their spray in and within gardens (Delabie, 2001). They can also amplify or reduce populations and protect them from natural enemies (Stadler and Dixon, 2005; Oliver et al., 2007). In turn hemipterans provide considerable amounts of honeydew, a highly energetic food reward for various insect taxa, especially ants. Moreover, in the absence of ants, the honeydew could negatively affect the growth of hemipteran colonies as well as the fitness of the host-plants due to accumulation of honeydew that favour the development of sooty mold (Lehouck et al., 2004).

Hemipterans and ants have been inventoried on some market-crop species (Aléné et al., unpublished data). These data

are used in the present study to characterize ant-hemipteran associations. To achieve this, the main food resources exploited by ants on these plants was identified; the diversity and the occurrence of ant-hemipteran associations on each plant species was assessed and the strength of the interaction between ants and hemipterans was characterized.

## MATERIALS AND METHODS

### Study site and period

The present study was carried out at the campus of the University of Yaoundé 1 (03° 51' 35,3" N; 11° 30' 0,06"E; 770 m asl) and at Nkolondom (03° 57' 07" N, 11° 29' 27"E; 645 m asl) a north-western suburb of Yaoundé.

Field works were conducted from June 21<sup>st</sup> to October 12<sup>th</sup> 2013. However, the data collecting, was effectively done from July 25<sup>th</sup> to October 12<sup>th</sup> 2013, including the short dry season and the great rainy season.

### Vegetal material

The biological material involved five market-crop species; four from the family Solanaceae, *Capsicum annuum* L. (hot pepper), *Solanum lycopersicum* L. (tomato), *Solanum scabrum* Mill. (African nightshade), *Solanum melongena* L. (sweet eggplant) and one from the family Malvaceae, *Abelmoschus esculentus* (L.) Moench (okra). These plant species were chosen on the base of their high prevalence in the basin and their permanent production in different local market-oriented cropping zones of Cameroon.

For the experimental plants, seeds of *S. lycopersicum*, *S. scabrum*, *S. melongena* and *C. annuum* were produced and conditioned by Technisem. Varieties used were "roma savanna" for the tomato, Estrella F1 for pepper, "F1 kalenda" for the sweet eggplant and "royale" for the African nightshade. For okra (var paysan), seed locally produced were bought from Mokolo market in Yaoundé.

### Data collecting

Data were collected twice per week. For each sampling, 30 plants per species were

chosen and examined. The inventory was conducted on the base of presence/absence of each ant or hemipteran species on a given host-plant species. Ants' feeding behaviour was surveyed with special references to plant products collected either from plants or hemipterans. Their associated hemipteran species were also recorded when it was the case.

### Identification of the collected insects

At the laboratory, the identification of the collected insects were done by comparing specimens to those in the collection of the Laboratory of Zoology of University of Yaoundé 1 and using the following keys: Blackman and Eastop (2000) for aphids, Hölldobler and Wilson (1990), Bolton (1994) and Taylor (<http://www.antbase.org/>, April, 06<sup>th</sup>, 2015) for ants. These identifications were later confirmed by comparing specimens to those in the Voucher collection of the Royal Museum for Central Africa (RMCA) at Tervuren (Belgium) during an internship of DCA. Some other hemipterans such as mealybugs were determined with the help of taxonomists of the CIRAD-CBGP at Montpellier (France) during an internship of DCA.

### Food resources exploited by ants

Once different food resources targeted by ant species in the farms identified, the occurrence of each harvested resource was computed with reference to the number of time a given ant species was observed feeding on it on a given host-plant species.

### Variation of the occurrence of ant-hemipteran associations

Occurrences of each pair of ant and hemipteran species on different host-plants was computed. According to their global occurrence on host-plant species, associations were grouped in three categories *viz*: most frequent (relative frequency of occurrence  $\geq 10\%$ ), less frequent ( $1\% \leq$  relative frequency of occurrence  $< 10\%$ ) and rare (relative frequency of occurrence  $< 1\%$ ).

The effect of host-plant species on the variation of the most occurring associations was tested using Chi-squared test (GLM proc); then binomial family was applied for adjustment as recommended by Crawley (2007) for the proportion data. TurkeyHSD pairwise comparison test was also applied when necessary in order to find out the variation source between occurrences of associations on a pair of host-plant species. Values of probabilities were adjusted by using the sequential Bonferroni procedure for pairwise comparisons and the results were appreciated at the 5% threshold.

### Characterization of ant fauna and relationships with hemipterans

Interactions between hemipteran and ant species on a given host-plant was studied using spearman correlation test ( $r$ ). Analysis were done using package Corrplot (Wei and Simko, 2017) for R. With  $r \geq 1$  or  $\leq -1$ , ant and hemipteran species were either positively or negatively associated on a given host-plant species; with  $r = 0$ , there was no relationship between ants and hemipterans on a given host-plant. The results were appreciated at the 5% confidence interval.

## RESULTS

### Hemipteran and ant faunas

The hemipteran fauna associated with studied plants was relatively diversified (Aléné et al. unpublished data), with five families interacting with ant species. These included Aphididae represented by *Aphis fabae*, *Aphis gossypii*, *Macrosiphum euphorbiae*, and *Aulacorthum solani*, Aleyrodidae represented by *Bemisia tabacci*, Membracidae (*Centrotus globifer*, *Leptocentrus bolivari*, *Trichoceps cf varipennis*), Cicadellidae (*Jacobiasca* sp., *Empoasa* sp., *Amrasca* sp.) and mealybugs (Coccoidea) (*Planococcus* sp., *Phenacoccus* sp., *Orthezia insignis*) (Table 1).

Their associated ant fauna included three subfamilies: Dolichodinae represented by three species (*Axinidris* sp., *Tapinoma* sp., *Technomyrmex* sp.), Formicinae with three

species (*Camponotus maculatus*, *Camponotus flavomarginatus*, *Lepisiota* sp.) and Myrmicinae with eight species (*Cardiochondyla* sp., *Monomorium bicolor*, *Myrmecaria opaciventris*, *Pheidole magacephala*, *Pheidole* sp., *Pheidole speculifera*, *Tetramorium sericeiventre*, *Tetramorium* sp.) (Table 2).

### Plant food resources exploited by ants

Apart from their predatory behaviour, ant diet in the present study included various plant fluids among which sap directly extracted from host-plant tissues and honeydew indirectly obtained through hemipterans.

The sap diet (18 observations) was mainly observed in *M. opaciventris* with eight occurrences (44.44%) on *Solanum melongena* and *C. flavomarginatus* with five occurrences (27.78%) on *S. melongena*. The species *M. opaciventris* was sometimes observed feeding on sap from wounded parts of *Abelmoschus esculentum*.

The honeydew regime was observed in all the ant species recorded. For this purpose, they were closely associated with hemipteran species.

### Variation of the occurrence of ant-hemipteran associations

Among the 38 ant-hemipteran associations pointed out from this survey (Table 3), 11 of them, involving aphids, presented the highest occurrences ranged from 10 (i.e. relative frequency of 7.52%) to 48 (i.e. relative frequency of 36.09%); 17 of them, involving aphids and mealybugs, were less frequent with occurrences ranged from 2 (1.50%) to 9 (6.77%); and finally 10 associations involving aphids and other hemipterans namely mealybugs, membracids and cicadellids, were rare with occurrences of 1 (0.75%). The occurrences of the most frequent associations showed highly significant variations from one plant species to another ( $P < 10^{-3}$ ). For instance, the most recurrent associations included *C. flavomarginatus*–*M. euphorbiae* occurring

mostly on eggplant with a relative frequency of 100% and on tomato with a relative frequency of 70.83%, *M. opaciventris*-*M. euphorbiae* occurring mostly on eggplant (100%), seldom on tomato (29.17%) and on okra (12%), *M. opaciventris*-*A. fabae* solely encountered on African nightshade (100%), *P. megacephala*-*M. euphorbiae* occurring mostly on eggplant (56.67%), sometimes on tomato (29.17%), *C. flavomarginatus*-*A. fabae* occurring merely on African nightshade (70%), *C. flavomarginatus*-*A. solani* occurring mostly on hot-pepper (66.67%) and occasionally on eggplant (13.33%), *Tapinoma* sp.-*M. euphorbiae* exclusively on eggplant (60%), *M. opaciventris*-*A. gossypii* mostly recorded on okra (44%) and sometimes on African nightshade (10%), *M. opaciventris*-*A. solani* on hot-pepper (29.17%) and on eggplant (23.33%), *Technomyrmex* sp.-*M. euphorbiae* on tomato (37.50%) and on okra (16%), *Technomyrmex* sp.-*A. gossypii* exclusively recorded on okra (40%).

Among the less frequent associations, the occurrences of some of them varied highly significantly from one plant to another, they were *M. opaciventris*-Mealybugs exclusively recorded on eggplant (30%), *T. sericeiventris*-*M. euphorbiae* recorded on eggplant (23.33%) and on tomato (4.17%), *Technomyrmex* sp.-*A. fabae* only recorded on African nightshade (20%), and *C. flavomarginatus*-Mealybugs exclusively encountered on eggplant (20%).

Among the rare associations, those involving *M. opaciventris* and Membracidae (*T. varipennis* and *C. globifer*) were exclusively recorded on eggplant with very weak occurrences, 1 (3.33%). This was also the case with *Tetramorium* sp.-Cicadelidae on eggplant.

In terms of diversity, the number of ant-hemipteran associations was the highest on eggplant (20), then on okra (10), on pepper (8), on African nightshade (7), and lastly on tomato (6). However, the associations

recorded on okra were mostly among the less frequent and rare whereas those on tomato were mainly among the most frequent. The associations hosted by the eggplant belonged to the three categories, most frequent, less frequent and rare.

### Ant-aphids relationships

Owing the importance of ant-aphid associations, the analysis of relationships amongst the two groups revealed different pattern of interaction between ants and aphids (Table 4). So, positive and significant correlations were observed between the aphid *M. euphorbiae* and five ant species, *C. flavomarginatus*, *M. opaciventris*, *P. megacephala*, *Tapinoma* sp. and *T. sericeiventris* on eggplant. The same trend was observed between the aphid *A. solani* and three ant species, *C. flavomarginatus*, *M. opaciventris* and *P. megacephala* on *S. melongena* too. Correlations were also positive and significant between *A. gossypii* and two ant species, *C. flavomarginatus* and *P. megacephala* on okra. The same trend was observed on African nightshade between *A. fabae* and ant two ant species, *C. flavomarginatus* and *M. opaciventris*. On hot pepper, positive and significant correlations were raised out between *A. solani* and two ant species, *M. opaciventris* and *Pheidole* sp. On tomato, *M. euphorbiae* determined positive and significant correlations with four ant species *M. opaciventris*, *M. bicolor*, *P. megacephala* and *Technomyrmex* sp.

For some other aphid species, the correlations with ant species were either positive and non-significant or negative and non-significant, especially when the aphid was not on its favourite host-plant (Table 4), suggesting that their simultaneous presence on these host-plants was not compulsory. This could also be due to the vagrant behaviour of some ants whose food resources were not derived from a single hemipteran species.

**Table 1:** List of hemipterans encountered with ants in the trap garden at Nkolondom.

<b>Families</b>	Aphididae	Aleyrodidae	Coccoidea	Membracidae	Cicadellidae
<b>Species</b>	<i>Aphis fabae</i> Scopoli 1763	<i>Bemisia tabaci</i> (Gennadius, 1889)	<i>Planococcus</i> sp.	<i>Centrotus globifer</i> Pelaez, 1935	<i>Jacobiasca</i> sp.
	<i>Aphis gossypii</i> Glover 1877		<i>Phenacoccus</i> sp.	<i>Leptocentrus bolivari</i> Pelaez, 1935	<i>Empoasa</i> sp.
	<i>Aulacorthum solani</i> Kaltenbacher 1843		<i>Orthezia insignis</i> Browne 1887	<i>Trichoceps</i> cf <i>varipennis</i> Signoret, 1858	<i>Amrasca</i> sp.
	<i>Macrosiphum euphorbiae</i> Thomas 1878				

**Table 2:** List of ants encountered with hemipterans in the trap garden at Nkolondom.

<b>Sub-families</b>	<b>Species</b>
Formicinae	<i>Camponotus flavomarginatus</i> Mayr, 1862
	<i>Camponotus maculatus</i> Fabricius, 1782
	<i>Lepisiota</i> sp.
Myrmicinae	<i>Myrmecaria opaciventris</i> Emery, 1893
	<i>Pheidole megacephala</i> Fabricius, 1793
	<i>Pheidole speculifera</i> Emery, 1877
	<i>Pheidole</i> sp.
	<i>Monomorium bicolor</i> Emery, 1877

	<i>Tertramurium sericiventre</i> Emery, 1877
	<i>Tertramurium</i> sp.
	<i>Cardiocondyla</i> sp
	<i>Axinidris</i> sp.
Dolichoderinae	<i>Tapinoma</i> sp
	<i>Technomyrmex</i> sp

**Table 3:** Variations of occurrence and Frequency of ant-hemipteran associations on the studied host-plants.

Ant-Hemiptera associations	Plant species					Total (n=133)	$\chi^2$ test (GLM Proc.)
	SM (n = 30)	AE (n = 25)	SSc (n = 30)	CA (n = 24)	SL (n = 24)		
	Most frequent						
<i>Camponotus flavomarginatus-Macrosiphum euphorbiae</i>	30 (100.0) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	1 (4.17) <sup>bc</sup>	17 (70.83) <sup>bd</sup>	48 (36.09)	$\chi^2= 136.66; P < 10^{-3} ***$
<i>Myrmicaria opaciventris-Macrosiphum euphorbiae</i>	30 (100.0) <sup>a</sup>	3(12.0) <sup>bc</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	7 (29.17) <sup>bd</sup>	40 (30.08)	$\chi^2= 115.34; P < 10^{-3} ***$
<i>Myrmicaria opaciventris-Aphis fabae</i>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	30 (100.00) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	30 (22.56)	$\chi^2= 142.01; P < 10^{-3} ***$
<i>Pheidole megacephala-Macrosiphum euphorbiae</i>	17 (56.67) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	7 (29.17) <sup>bc</sup>	24 (18.05)	$\chi^2= 55.54; P < 10^{-3} ***$
<i>Camponotus flavomarginatus-Aphis fabae</i>	0(0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	21 (70.00) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	21 (15.79)	$\chi^2= 79.37; P < 10^{-3} ***$
<i>Camponotus flavomarginatus-Aulacortum solani</i>	4 (13.33) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	16 (66.67) <sup>bc</sup>	0 (0.00) <sup>b</sup>	20 (15.04)	$\chi^2= 58.50; P < 10^{-3} ***$
<i>Tapinoma sp.-Macrosiphum euphorbiae</i>	18 (60.0) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	18 (13.53)	$\chi^2= 65.06; P < 10^{-3} ***$
<i>Myrmicaria opaciventris-Aphis gossypii</i>	0 (0.00) <sup>b</sup>	11 (44.00) <sup>a</sup>	3 (10.00) <sup>bc</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	14 (10.53)	$\chi^2= 35.71; P < 10^{-3} ***$

<i>Myrmicaria opaciventris-Aulacortum solani</i>	7 (23.33) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	7 (29.17) <sup>bc</sup>	0 (0.00) <sup>b</sup>	14 (10.53)	$\chi^2 = 27.94$ ; $P < 10^{-3}$ ***
<i>Technomyrmex sp.-Macrosiphum euphorbiae</i>	0 (00.0) <sup>b</sup>	4 (16.00) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	9 (37.50) <sup>bc</sup>	13 (9.77)	$\chi^2 = 31.41$ ; $P < 10^{-3}$ ***
<i>Technomyrmex sp.-Aphis gossypii</i>	0 (00.0) <sup>a</sup>	10 (40.0) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	10 (7.52)	$\chi^2 = 37.33$ ; $P < 10^{-3}$ ***
<b>Less frequent</b>							
<i>Myrmicaria opaciventris-Mealybugs</i>	9 (30.0) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	9 (6.77)	$\chi^2 = 29.20$ ; $P < 10^{-3}$ ***
<i>Tetramorium sericeiventre-Macrosiphum euphorbiae</i>	7 (23.33) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	1 (4.17) <sup>bc</sup>	8 (6.01)	$\chi^2 = 19.57$ ; $P < 10^{-3}$ ***
<i>Technomyrmex sp.-Aphis fabae</i>	0 (00.0) <sup>b</sup>	0 (0.00) <sup>b</sup>	6 (20.00) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	6 (4.51)	$\chi^2 = 18.88$ ; $P < 10^{-3}$ ***
<i>Camponotus flavomarginatus-Mealybugs</i>	6 (20.0) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	6 (4.51)	$\chi^2 = 18.88$ ; $P < 10^{-3}$ ***
<i>Camponotus flavomarginatus-Aphis gossypii</i>	2 (6.67) <sup>a</sup>	3 (12.0) <sup>bc</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	5 (3.76)	$\chi^2 = 9.58$ ; $P = 0.05$ *
<i>Tetramorium sericeiventre-Aphis fabae</i>	0 (00.0) <sup>b</sup>	0 (0.00) <sup>b</sup>	4 (13.33) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	4 (3.01)	$\chi^2 = 12.35$ ; $P = 0.01$ *
<i>Pheidole megacephala-Aphis gossypii</i>	0 (00.0) <sup>b</sup>	4 (16.00) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	4 (3.01)	$\chi^2 = 13.93$ ; $P = 0.01$ **
<i>Pheidole sp.-Aulacortum solani</i>	0 (00.0) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	4 (16.67) <sup>b</sup>	0 (0.00) <sup>b</sup>	4 (3.01)	$\chi^2 = 14.28$ ; $P = 0.01$ **
<i>Pheidole speculifera-Aphis gossypii</i>	0 (00.0) <sup>b</sup>	3 (12.00) <sup>a</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	3 (2.26)	$\chi^2 = 10.34$ ; $P = 0.04$ *
<i>Pheidole megacephala-Aphis fabae</i>	1 (3.33)	0 (0.00)	2 (6.67)	0 (0.00)	0 (0.00)	3 (2.26)	$\chi^2 = 5.22$ ; $P = 0.27$ ns
<i>Pheidole megacephala-Aulacortum solani</i>	0 (00.0) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	3 (12.50) <sup>a</sup>	0 (0.00) <sup>b</sup>	3 (2.26)	$\chi^2 = 10.60$ ; $P = 0.03$ *
<i>Axinidris sp.-Aulacortum solani</i>	0 (00.0) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	3 (12.50) <sup>a</sup>	0 (0.00) <sup>b</sup>	3 (2.26)	$\chi^2 = 10.60$ ; $P = 0.03$ *
<i>Tapinoma sp.-Aulacortum solani</i>	0 (00.0) <sup>b</sup>	0 (0.00) <sup>b</sup>	0 (0.00) <sup>b</sup>	3 (12.50) <sup>a</sup>	0 (0.00) <sup>b</sup>	3 (2.26)	$\chi^2 = 10.60$ ; $P = 0.03$ *
<i>Monomorium bicolor-Macrosiphum euphorbiae</i>	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	2 (8.33)	3 (2.26)	$\chi^2 = 6.15$ ; $P = 0.20$ ns
<i>Axinidris sp.-Aphis gossypii</i>	0 (00.0)	2 (8.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (1.50)	$\chi^2 = 6.82$ ; $P = 0.15$ ns



<i>Tetramorium sp.-Macrosiphum euphorbiae</i>	2(6.67)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (1.50)	$\chi^2 = 6.06$ ; P= 0.19 ns
<i>Tapinoma sp.-Mealybugs</i>	2(6.67)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (1.50)	$\chi^2 = 6.06$ ; P= 0.19 ns
<b>Rare</b>							
<i>Camponotus maculatus-Aphis fabae</i>	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns
<i>Lepiotas sp.-Aphis fabae</i>	0 (00.0)	0 (0.00)	1 (3.33)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns
<i>Cardiocondyla sp.-Aulacortum solani</i>	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns
<i>Tetramorium sericeiventre-Aulacortum solani</i>	0 (00.0)	0 (0.00)	0 (0.00)	1 (4.17)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.48 ns
<i>Pheidole speculifera-Macrosiphum euphorbiae</i>	0 (00.0)	1 (4.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.37$ ; P = 0.50 ns
<i>Technomyrmex sp.-Mealybugs</i>	0 (00.0)	1 (4.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.38$ ; P= 0.50ns
<i>Myrmicaria opaciventris-Tricocep cf. varipenis</i>	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns
<i>Myrmicaria opaciventris-Centrotus globifer</i>	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns
<i>Tetramorium sp.-Cicadelidae</i>	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns
<i>Pheidole megacephala</i> –Mealy bugs	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.75)	$\chi^2 = 3.00$ ; P = 0.56 ns

Legend: SM = *Solanum melongena*; AE = *Abelmoschus esculentus*; SSc = *Solanum scabrum*; CA = *Capsicum annum*; SL = *Solanum lycopersicum*; n: cumulative sampling days. In cells, the first figure is the number of occurrence and the second in brackets the relative frequency of occurrence; \*\*\* = highly significant P-value; df (degree of freedom) = 4; ns = non-significant P-value at 5 % confidence interval; different letters in superscript indicate differences or similitudes between occurrences in pairs of plant species after pairwise comparison.

**Table 4:** Relationships between ant and hemipteran populations on target host-plants.

Ants species	Host-plant species							
	SM		AE		SSc		CA	SL
	<i>M. euphorbiae</i>	<i>A. solani</i>	<i>A. gossypii</i>	<i>M. euphorbiae</i>	<i>A. fabae</i>	<i>A. gossypii</i>	<i>A. solani</i>	<i>M. euphorbiae</i>
<i>Axinidrix</i> sp.			-0,17	0,22				
<i>Camponotus flavomarginatus</i>	0.92*	0.29*	0.45*	-0,23	0.38*	0,24	0,39	0,08
<i>Myrmicaria opaciventris</i>	0.94*	0.30*	0,04	-0,1	0.62*	0,35	0.47*	0.43*
<i>Monomorium Bicolor</i>								0.44*
<i>Pheidole megacephala</i>	0.61*	0.35*	0.41*	-0,06			0,01	0.67*
<i>Pheidole speculifera</i>			0,29	0,26				
<i>Pheidole</i> sp.							0.57*	
<i>Tapinoma</i> sp.	0.63*	0,13					0,12	
<i>Tetramorium cericiveintris</i>	0.47*	0,02			0,16	-0,13		0,06
<i>Technomyrmex</i> sp.			0,37	0,11	0,13	-0,16		0.57*

Legend: SM= *Solanum melongena*; CA= *Capsicum annum*; AE= *Abelmoschus esculentus*; SSc= *Solanum scabrum*; SL= *Solanum lycopersicum*. Values in the table represent Spearman correlation test (r);

\*= significance at 5% confidence interval.

## DISCUSSION

In the present study, only two ant species consuming sap were observed, *M. opaciventris* and *C. flavomarginatus*. This suggests that honeydew was the main food resource sought by ants in our trap garden. In fact, it is known that honeydew is an important source of compensation for the high energy requirement, notably in the carbohydrate, for ant metabolism (Fischer et al., 2005). In addition, Blüthgen and Fiedler (2004) reported tritrophic interactions between ants, hemipterans and plants. Ants would prefer honeydew to sap because they are unable to feed directly on the sap (Delabie, 2001). The species *M. opaciventris*, out of our experimental garden, have often been observed chewing young parts of okra and absorbing sap (personal observation). This behavior can induce serious lesions to plant, thus letting flow the sap that it consumes. Then *C. flavomarginatus* takes advantage of these lesions. Such feeding behaviour is well studied by Blüthgen et al. (2004). Also, Kenne (2006) reported workers of *M. opaciventris* very often chewing young branches and buds of *Vernonia amygdalina* Delile in order to feed on sap from wounded tissues. Apart from these two ant species, *P. megacephala* is known to consume nectar from flower nectaries (Lach et al., 2009). On the host-plants involved in the present study, this ant was also present and would gather nectar.

In the current survey, no ant seemed to depend exclusively on the honeydew produced by a single species of hemipteran. In turn hemipterans also could do well without the presence of ants as observed by Steiner et al. (2004). In this context, it would be too pretentious to state about symbiosis in ant-hemipteran associations. It is shown from our results that a species of ant may tend several species of hemipteran as much as they provide them with honeydew; this observation has already been made by Yoo et al. (2013). These associations are mostly of the oppositionist mutualistic type described by Maravalhas and Morais (2009).

Ants that exploit honeydew may either pose more or less nuisance problems to host-plants because of the protection they supply to plant sap-suckers (Styrsky and Eubanks,

2007). Indeed, great damage such as leaf curling or necrosis was observed in the present study on African nightshade and on tomato. Ant would also protect plants from other phytophagous insects as observed by some authors (Moreira and Del-Claro, 2005; Styrsky and Eubanks, 2007).

Observed associations showed that ants were mostly attracted by aphids. The most recurrent were *C. flavomarginatus*-*M. euphorbiae*, *M. opaciventris*-*M. euphorbiae*, *M. opaciventris*-*A. fabae*, *P. megacephala*-*M. euphorbiae*, *C. flavomarginatus*-*A. fabae*. With non-aphid hemipterans, the most recurrent associations were those involving *M. opaciventris* and mealybugs or *C. flavomarginatus* and mealybugs. In fact, in trophobiotic interactions between ants and hemipterans, as pointed out by Delabie (2001), ants are likely to be more attracted by Sternorrhyncha than Cicadomorpha (Membracidae, Cicadellidae). The high frequency of ant-aphid associations would be explained either by the huge amount and the quality of the honeydew they could produce and/or by the inability for most of aphids to move by themselves from one plant to another; then ant would serve as vehicle duties for these plant-lice (Delabie, 2001). It's also to be noticed that the most recurrent associations were made up by aphids and behavioural dominant ants, *M. opaciventris*, *P. megacephala*, etc., which are known to be territorially aggressive, and some other such as *C. flavomarginatus*, which are known to behave as extirpators according to Delsinne et al. (2007). Anyhow, there is no strict specificity in these associations. Furthermore ants are considered as opportunist in the choice of the hemipteran species they tend (Delabie, 2001; Blüthgen et al., 2006).

In this study, while some ant-hemipteran associations recorded were closely related to a specific host-plant with high frequencies, the majority of these associations were present on eggplant with high or low frequencies. This might be due to the fact that eggplant, an exotic selected plant, is not among the main crops produced at the Nkolondom basin. Hence, it tends to attract more insects species which would taste this new host or because of lack of defence

features, inherent to continuous selection of the plant (Chen et al., 2018).

In our results, positive and significant correlations were observed between populations of some ant species and those of aphid species. This shows that the presence of ants contributes to the fitness of the aphids as observed by Stadler and Dixon (2005). Moreover, it has been demonstrated that for a given species of aphid, the amount of honeydew linked to the number of individuals would be a major factor determining the recruitment of more ants in the colonies (Mailleux et al., 2003). In the present study, from one plant to another, the ants' species as well as the hemipterans' species in association varied. This could be due to the specificity of aphids vis-à-vis of host-plants.

### Conclusion

From the present study, it was observed that ants fed preferentially on the honeydew excreted by hemipterans, mainly aphids with which they were associated. These associations, although very diversified, were distinctively related to specific host-plants, pointing out the oligophagous regime of these aphids. It also raised out that ants were not always specialized to a single hemipteran species, probably because of the vagrant behaviour of some of them who would forage on diverse foods without any specialization. Definitely, ants indirectly cause damage to plants by nurturing hemipteran herds whose activity spoils plants from their nutrients by sucking the sap. Consequently, further integrated management strategies of these hemipteran pests in market-oriented cropping systems should take into account the associated ant community.

### COMPETING INTERESTS

The authors do not have any competing interests to declare.

### AUTHORS' CONTRIBUTIONS

DCA and CDL conceived the project, DCA and YMM collected data and ZT did statistical analyses. DCA wrote the manuscript and all the co-authors read and approved the manuscript.

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