

The coconut mite, *Aceria guerreronis*, in Benin and Tanzania: occurrence, damage and associated acarine fauna

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Abstract The coconut mite *Aceria guerreronis* (Eriophyidae) is considered the most important pest of coconut fruits in Africa; however, quantitative knowledge about its distribution and abundance is lacking. We conducted four diagnostic surveys—three in Southern Benin and one along the coast of Tanzania—to determine the distribution of *A. guerreronis* and the severity of its damage to coconut fruits, as well as the diversity and abundance of other associated mites and potential natural enemies. *Aceria guerreronis* was found in all visited plantations with the percentage of damaged fruits varying considerably among plantations—67–85% in Benin and 43–81% in Tanzania. Overall, 30–40% of the fruit surfaces were damaged by *A. guerreronis*. Damage severity increased with fruit age and negatively affected fruit weight of 7- to 12-months-old fruits. *Aceria guerreronis* was by far the most abundant mite on coconut fruits but its abundance depended on fruit age. The highest densities of *A. guerreronis* were observed on 3- to 4-months-old fruits. *Neocypholaelaps* sp. (Ameroseiidae) was the most abundant mite on inflorescences. Three species of predatory mites (Phytoseiidae)—*Neoseiulus baraki*, *N. neobaraki* and *N. paspalivorus*—were the most commonly found predatory mites beneath the coconut bracts in association with *A. guerreronis*. *Neoseiulus neobaraki* was the prevailing predator in Tanzania while *N. paspalivorus* was the most frequent predator in Benin. Other mites found beneath the bracts were the herbivore *Steneotarsonemus furcatus* (Tarsonemidae) and the detritivore and fungivore *Tyrophagus putrescentiae* (Acaridae).

Keywords *Cocos nucifera* · Eriophyidae · Phytoseiidae · Predatory mites · Mite diversity

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Introduction

Coconut, *Cocos nucifera* L. (Arecaceae), is widespread throughout the tropics. Its geographical distribution has been favored by its adaptability to wide range of climatic and vegetational regions, floatability in seawater followed by germination on beaches once washed ashore, and its usefulness to humans (Foale 2003). With approximately 11 million ha harvested worldwide in 2006 (FAO 2010), coconut palm is considered one of the ten most important trees for humankind in the world, providing food and income for hundreds of millions of people (e.g. APCC 2010).

Aceria guerreronis Keifer (Eriophyidae), commonly called the coconut mite, presently is the most important pest of coconut fruits (Howard et al. 2001). This mite pest had been known for decades from the Americas and Africa (e.g. Mariau and Julia 1970; Howard et al. 1990), but it has been detected only recently in India and Sri Lanka, two major coconut producing countries (Fernando et al. 2002; Ramaraju et al. 2002). *Aceria guerreronis*, likely originating from South America (Navia et al. 2005), is a tiny worm-like organism that typically inhabits the area beneath the perianth (i.e. the floral bracts) of coconut fruits feeding on the tender meristematic tissue (Howard and Abreu-Rodriguez 1991; Aratchige 2007; Lawson-Balagbo et al. 2007a). Physical injuries resulting from feeding develop into necrotic and suberized tissues on the fruit surface. Infested fruits later become distorted and stunted due to uneven growth, leading to reductions in copra yield and premature fruit drop (e.g. Julia and Mariau 1979; Hall 1981). Yield losses attributable to damage by *A. guerreronis* range from 10 to 70% in many countries (e.g. Hernandez 1977; Moore et al. 1989). In the 1960s in Benin, copra losses due to *A. guerreronis* ranged from 6 to 18%, with an overall average of 10% (Mariau and Julia 1970). However, this loss was likely underestimated, as damage to coconut is presently widespread and more severe in major growing areas of Benin (K. Negloh, personal observations, years 2004–2010). Results of two surveys conducted in Tanzania in 1993 and 1996 revealed that 70–100% of sampled fruits were damaged by *A. guerreronis*, with an associated crop loss of 34% (Seguni 2002). These are substantial losses in a country (Tanzania) where coconut farming is one of the most important branches of agricultural production in the coastal region (Seguni 2002). In 2006, harvested coconut areas in Tanzania were estimated at 312,796 ha (FAO 2010).

Common control measures against *A. guerreronis* were traditionally based on repeated applications of pesticides. Although some chemicals such as monocrotophos and chiono-methionate sprayed on fruit bunches significantly reduce mite damage (Hernandez 1977; Mariau 1977; Julia and Mariau 1979), the need of repeated applications renders chemical control economically and environmentally non-feasible in the long run. Several researchers therefore recommended biological control as an environment-friendly alternative to pesticides (e.g. Moore 2000; Moraes and Zacarias 2002; Perring 2002; Lawson-Balagbo et al. 2007a, b). Various predatory mites, particularly from the family Phytoseiidae, have been found associated with *A. guerreronis* (Moraes and Zacarias 2002; Moraes et al. 2004; Aratchige 2007; Lawson-Balagbo et al. 2007a, b, 2008) but their effect on *A. guerreronis* populations has not been extensively addressed (Reis et al. 2008; Negloh et al. 2010). Entomopathogenic fungi such as *Hirsutella thompsonii* Fisher have been found infecting *A. guerreronis* (Julia and Mariau 1979; Hall et al. 1980; Cabrera 2002; Moore 2000; Gopal and Gupta 2001; Gopal et al. 2002; Fernando et al. 2007). Recent efforts to develop *H. thompsonii* as a biopesticide against *A. guerreronis* show promising results but the duration of spore viability remains a major obstacle (Edgington et al. 2008).

In the present study, we report on diagnostic surveys conducted in coconut growing areas in southern Benin and along the coast of Tanzania to assess the current status of *A. guerreronis*. These surveys are essential components of a multi-institutional research project on the development of biological control strategies against the coconut mite in Africa and elsewhere in the world. Our objectives were to determine the occurrence and abundance of *A. guerreronis*, the incidence and severity of damage caused by this pest, and the diversity of mites associated with it on coconut fruits with emphasis on potential natural enemies.

Materials and methods

Three diagnostic surveys were conducted in 66 plantations of the three major growing areas of southern Benin,—Mono, Atlantique and Oueme provinces (located between 06°15'20" N, 01°42'54" W and 05°50'50" N, 02°36'39" W),—from July to August 2004, February to March 2005, and June to July 2005 (Fig. 1a). These periods corresponded respectively with the onset of the short dry season, the end of the long dry season and the long rainy season in all provinces. The Beninese plantations were selected randomly at distances of 2–10 km, depending on plantation frequency. In August 2005 one diagnostic survey was conducted in Tanzania, along the Indian Ocean coast from Manza (04°49'17" S, 039°08'59" E) (district of Tanga in the north) to Ziwani (10°20'90" S, 040°14'99" E) (district of Mtwara in the south) (Fig. 1b). This period coincided with the end of the rainy season in the north (from Manza to Saadani) and the dry season from Bagamoyo, at approximately mid-coastal zone, to Ziwani (Mtwara) in the south. The eighteen Tanzanian plantations were selected randomly at 10–45 km distance from each other. The longer distances between plantations in Tanzania were necessary due to the much bigger length of the coastal areas in Tanzania compared with Benin. In most surveyed plantations, minimal management was applied, mainly including weeding. In few plantations, farmers tethered cows to the palms in order to fertilize the soil with their excrements or they dug holes around the palm trees and dumped dead organic matter such as shed palm leaves and cut weeds in the hole. In all plantations, mature coconut fruits were harvested at intervals of 3–4 months.

Incidence and severity of damage caused by *Aceria guerreronis*

Incidence and severity of fruit damage caused by *A. guerreronis* were assessed in situ on 10 randomly selected palms per plantation by classifying all coconut fruits on each tree on the basis of the extent of characteristic *A. guerreronis* damage visible on fruit surfaces. Binoculars were used where trees were not reachable by a ladder. Coconut fruits were grouped into four grades—based on the percentage of fruit surface damaged by *A. guerreronis* (Moore et al. 1989): grade 1 (0%), grade 2 (1–10%), grade 3 (11–25%), grade 4 (26–50%), grade 5 (>50%).

Distribution and abundance of *Aceria guerreronis* and identification of associated mites

In each plantation, coconut fruits were sampled from 10 and 12 palms in Benin and Tanzania, respectively, to assess the distribution and abundance of *A. guerreronis* and identify other mites inhabiting coconut fruits and inflorescences. Fruit sampling was based on fruit bunch age classes (FBA_S) defined as follow: FBA₁ (fruit bunches 1–3); FBA₂ (fruit

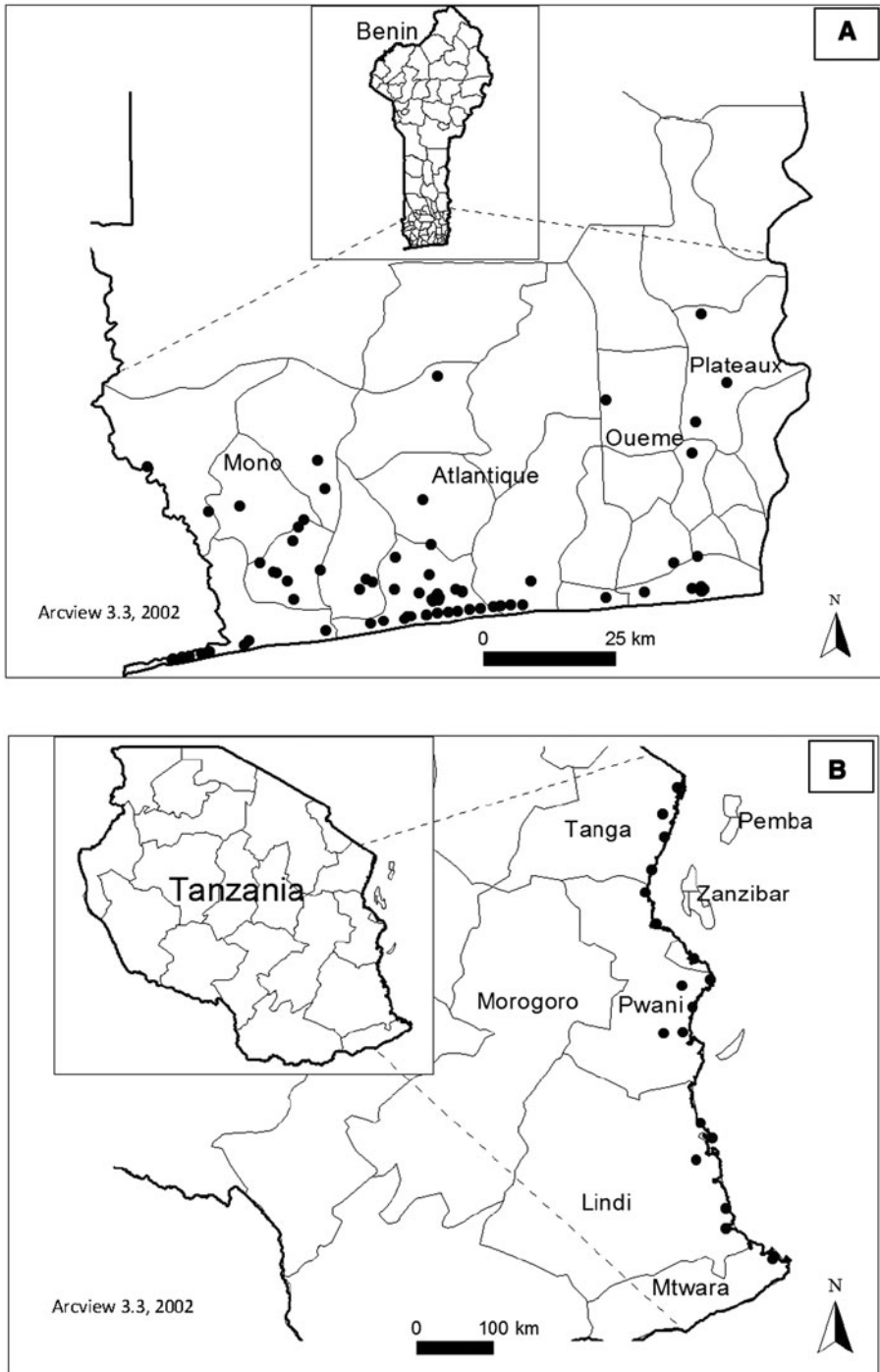


Fig. 1 Sites sampled from July 2004 to July 2005 in Benin (a) and in August 2005 in Tanzania (b) (Mapped with Arcview 3.3, 2002 by K. Negloh, IITA)

bunches 4–6); FBA₃ (fruit bunches 7–9) and FBA₄ (fruit bunches 10–12) (Negloh et al. 2010). The number of a particular bunch corresponds approximately to its age in months. Fruit classification was based on the knowledge that a new inflorescence (the prospective bunch) is produced approximately every month (Moore and Alexander 1987; Foale 2003; K. Negloh personal observations). Each succeeding bunch, from the top of the palm, is therefore a month older than the previous one. Bunch 1 is that of just fertilized fruits (approximately 1 month). Inflorescences were not included in FBAs but sampled separately. Fruit samples were collected from FBA_{1–3} in Tanzania and from FBA_{1–4} in Benin. We considered only the first 3 FBAs in Tanzania because of the long travel distances, the limited time allotted to the survey and the fact that previous observations in Benin indicated that older fruits harbor very few mites and do not show significant damage variations (Negloh et al. 2010). One fruit was sampled from each FBA plus one branch of inflorescence per palm when available. Samples were taken only from palms bearing at least one bunch of each FBA.

Sampled fruits were examined on-site with a 10× magnification head lens immediately after removal from the palm. Mites found on the fruit surface were collected with a brush and preserved in 75% ethanol. Each fruit was then labeled, placed in a paper bag and brought to the laboratory for further processing. In the laboratory, the bracts of each fruit were sequentially and carefully removed to uncover the meristematic zone. Mites other than *A. guerreronis* present beneath the bracts were counted and stored in 75% ethanol for further slide-mounting and species identification. Abundance of *A. guerreronis* was assessed using a methodology similar to that developed by Siriwardena et al. (2005). Bracts as well as the meristematic zone of the fruit and some distance away on the exocarp (2–5 cm depending on fruit size) were rinsed with 30 ml detergent solution into a small container. The solution was vigorously shaken to obtain a homogenous distribution immediately before 1.0 ml aliquot was drawn from the solution and placed in counting cells (Costar[®] Brand Cell Culture Clusters, 24 cells of 3.4 ml volume each). All individuals of *A. guerreronis* present in the 1.0 ml aliquot were counted using a stereomicroscope. Other mites in the solution were counted and added to those previously collected in alcohol. Abundance of *A. guerreronis* per fruit was then estimated by multiplying the obtained values by a factor of 30 (the total volume of the rinse solution). Inflorescences were dissected under a stereomicroscope and mites found were collected and preserved in 75% ethanol. For each sampled fruit, characteristics such as its age, FBA, damage grade, and weight were recorded.

Statistical analyses

All statistical analyses were performed using SAS 9.1 (SAS Institute 2005). Logistic regressions were used to assess variations in the incidence of damage among plantations, survey periods and growing areas. Based on grouping of fruits in damage grade classes, a Severity Index (SI) was calculated for each palm as $SI = \frac{\sum (X_i \cdot i)}{\sum X_i}$ where X_i is the number of damaged fruits of grade i (i varies from 2 to 5; undamaged fruits were not included). SI values were used in general linear models (GLM) to compare damage severity among survey periods and coconut growing areas for each country separately. The same analysis was performed on arcsine-transformed proportions of damaged fruits per palm. Furthermore, based on season similarities (occurrence of the dry season) the results of the Tanzania survey, conducted in August, were compared to those of the second survey in Benin, which was conducted from February to March.

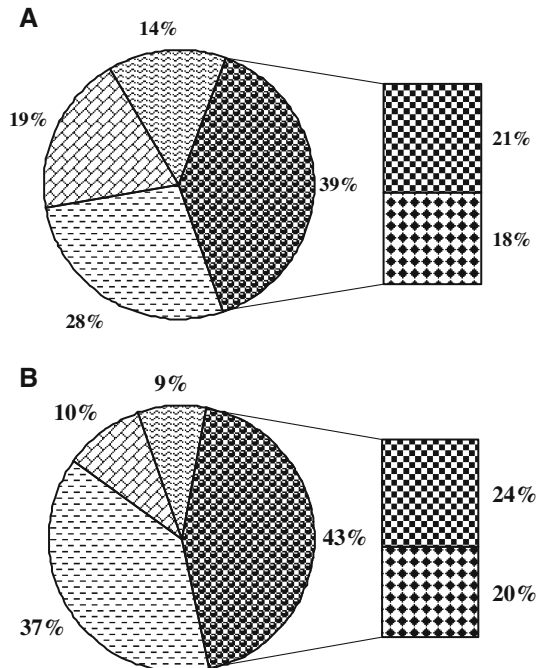
For each country, log-transformed densities of *A. guerreronis* (only mobile stages) were compared among fruit ages by analysis of variance (ANOVA). Mixed model analyses were used to assess the effect of survey period (random effects) and growing area (fixed effects) on *A. guerreronis* abundance and damage severity. The effect of damage severity on fruit weight within each FBA was assessed with general linear model (GLM) and subsequent Bonferroni multiple comparison tests on pooled data for both countries.

Results

Incidence and severity of damage caused by *Aceria guerreronis*

In Benin coconut fruit damage by *A. guerreronis* was observed on 90–100% of palms across plantations and throughout the three surveys. Overall mean percentage of damaged fruits per palm was $73 \pm 0.01\%$ (Fig. 2a), but fruit damage incidence differed among provinces (mean \pm SE: 67 ± 0.02 , 70 ± 0.01 and $85 \pm 0.01\%$ damaged fruits per palm in Atlantique, Mono and Oueme, respectively) (logistic regression: $\chi^2 = 3,923.72$, $P < 0.0001$). Of the coconut fruit showing visible mite damage, $39 \pm 0.01\%$ were severely damaged ($\geq 25\%$ of the fruit surface damaged) (Fig. 2a). Damage severity indices differed among survey periods (GLM: $F_{2,815} = 6.99$, $P < 0.0001$) and growing areas (GLM: $F_{2,815} = 4.36$, $P = 0.0131$). The interaction between survey period and growing area was also highly significant ($F_{4,815} = 18.90$, $P < 0.0001$), indicating that the difference in the severity indices among survey periods varied with the growing area. Mean separation using Bonferroni showed no difference between Mono and Oueme and between

Fig. 2 Overall mean percentage of sampled fruits per damage severity grade (1 [diagonal lines], 2 [horizontal lines], 3 [vertical lines], 4 [checkered], 5 [dots]) in Benin (a) and Tanzania (b). Grades correspond to % fruit surface damaged (Moore et al. 1989) as follows: 1 (0%), 2 (1–10%), 3 (11–25%), 4 (26–50%), 5 (>50%)



the first and second survey ($P > 0.05$). Overall mean severity indices were 3.70 ± 0.05 , 3.83 ± 0.04 and 3.82 ± 0.05 , respectively, in Atlantique, Mono and Oueme.

Incidence of *A. guerreronis* damage along the Tanzanian coast was 100%. All plantations surveyed and all palms in those plantations showed visible symptoms of *A. guerreronis* damage. All other plantations inspected informally midway between two surveyed sites were damaged also (K. Negloh, personal observations). Damage incidence assessed on-site varied among plantations from 43 ± 0.02 to $81 \pm 0.01\%$ of fruits damaged per palm. Overall, $63 \pm 0.01\%$ of coconut fruits per palm were damaged and $43 \pm 0.01\%$ of them were severely damaged, i.e. $\geq 25\%$ of the fruit surface was damaged (Fig. 2b). Logistic regression revealed highly significant differences among plantations (Maximum Likelihood $\chi^2 = 184.36$; $P < 0.0001$), with almost 40% difference between the maximum and minimum damage incidence. Damage severity indices ranged from 3.20 to 4.10 among plantations with an overall mean of 3.77 ± 0.05 (GLM: $F_{10,88} = 3.33$, $P = 0.001$). Comparisons between the Tanzanian survey and the second Beninese survey showed similarities in damage incidence (73 vs. 63%) (GLM: $F_{1,347} = 0.14$, $P = 0.701$) and severity indices (3.77 ± 0.05 vs. 3.88 ± 0.03) (GLM: $F_{1,347} = 3.22$, $P = 0.074$).

In both countries damage severity increased with fruit age (Fig. 3). Damage severity increased almost linearly from 1 to 5 months old, while it remained constant on older fruits (6–12 months old). Undamaged fruits were mostly younger fruits (1–3 months) with a rare occurrence of severe damage. The highest damage grades were observed on 4–12 months old fruits (Fig. 3).

Damage grade affected fruit weight in FBA₁, FBA₃ and FBA₄ (GLM: $F_{4,710} = 77.01$ $P < 0.0001$, $F_{4,84} = 4.95$, $P = 0.0012$ and $F_{4,75} = 5.45$, $P = 0.0007$ for FBA₁, FBA₃ and FBA₄, respectively) but not in FBA₂ (4–6 months old fruits) (GLM: $F_{4,87} = 0.35$, $P = 0.85$) (Fig. 4). Fruit weight differed between damage grades 2 and 5 in FBA_{3–4}, between grades 4 and 5 in FBA₃, and between grades 2 and 4 in FBA₄ (Bonferroni, $P < 0.05$ for each pairwise comparison).

Abundance of *Aceria guerreronis*

In Benin, the abundance of *A. guerreronis* varied from 0 to a maximum of 46,200 individuals per fruit, the latter observed on a 3 month-old fruit. Average density per fruit varied from 430 to 2,900 individuals among Benin plantations (Fig. 5). In general,

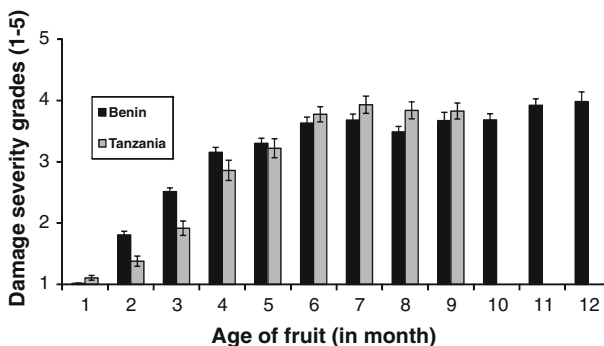


Fig. 3 Damage severity grade (1–5; mean \pm SE) in relation to coconut fruit age. Grades correspond to % fruit surface damaged (Moore et al. 1989) as follows: 1 (0%), 2 (1–10%), 3 (11–25%), 4 (26–50%), 5 (>50%)

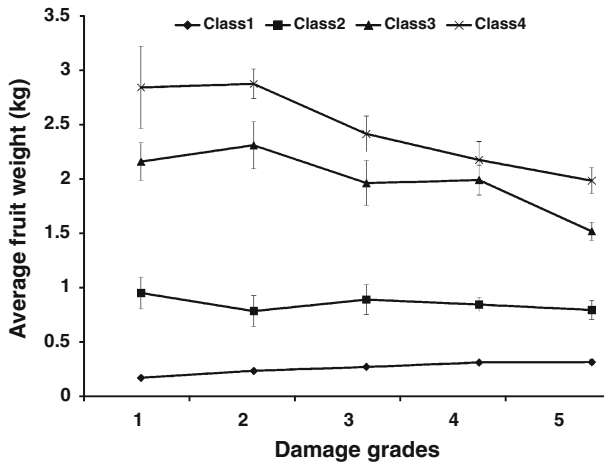
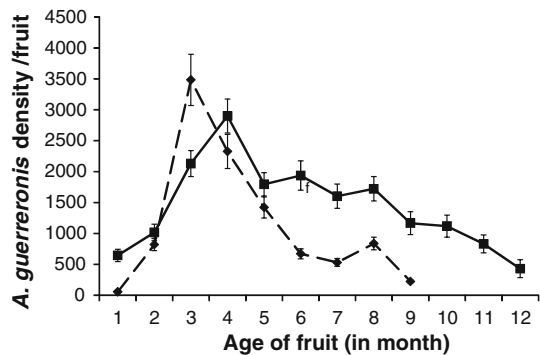


Fig. 4 Weight of coconut fruits (mean \pm SE) in relation to damage severity grade in four fruit bunch age classes (FBA₁₋₄). FBA₁ (bunches 1–3); FBA₂ (bunches 4–6); FBA₃ (bunches 7–9) and FBA₄ (bunches 10–12). Grades correspond to % fruit surface damaged (Moore et al. 1989) as follows: 1 (0%), 2 (1–10%), 3 (11–25%), 4 (26–50%), 5 (>50%)

Fig. 5 Population density of *Aceria guerreronis* (mean \pm SE per fruit) in relation to fruit age in Benin (solid line) and Tanzania (broken line)



A. guerreronis population densities were higher in Benin than in Tanzania where densities varied from 97 to 1,266 mites per fruit among plantations (Fig. 5). In Tanzania, the minimum and maximum counts were 0 and 22,680, with the latter, as in Benin, observed on a 3 months old fruit.

Abundance of *A. guerreronis* varied greatly among fruit ages (Fig. 5) in both countries (ANOVA: $F_{11,734} = 13.32$, $P < 0.001$ for Benin and $F_{8,615} = 13.95$, $P < 0.001$ for Tanzania). There was an almost exponential increase in *A. guerreronis* densities from 1 to 3 or 4 months old fruits followed by a gradual decrease in abundance on 5–12 months old fruits (Fig. 5). The lowest average densities were observed on 1 month old fruits followed by 9 or 12 months old fruits in Tanzania and Benin, respectively. Variability in *A. guerreronis* densities was the highest in FBA₁ (1–3 months old fruits) followed by FBA₄ (9–12 months old fruits). Their respective coefficients of variation (CV) were 0.61 and 0.42, while they were 0.27 for FBA₂ and 0.19 for FBA₃. Total densities were highest in FBA₂ and lowest in FBA₄ (10–12 months old fruits) (Fig. 5).

Other mites found on coconut fruits and inflorescences

Mites other than *A. guerreronis* found on coconut fruits in Benin and Tanzania belonged to the families Phytoseiidae, Ascidae, Acaridae, Tarsonemidae, Bdellidae, Eupodidae, Tydeidae, Cunaxidae and Tenuipalpidae. They were encountered on the exocarp or beneath the floral bracts of the fruits, where *A. guerreronis* resides. Specimens of the family Ameroseiidae were found in very large numbers on inflorescences but not on fruits (Table 1).

In Tanzania, four phytoseiid species were identified: *Neoseiulus baraki* Athias-Henriot, *N. neobaraki* Zannou, Moraes & Oliveira, *N. paspalivorus* De Leon, and *Amblyseius largoensis* (Muma) (Table 1). The first three species were found in the micro-habitat

Table 1 Numbers and percentages of mite specimens other than *A. guerreronis* collected on coconut fruits in Benin and Tanzania

Taxa	Benin		Tanzania	
	Number	Percentage	Number	Percentage
Ascidae				
<i>Asca</i> sp. Von Heyden	2	0.08	0	0.00
<i>Gamasellodes</i> sp. Athias-Henrot	3	0.11	0	0.00
<i>Hoploseius</i> sp. Berlese	1	0.04	0	0.00
<i>Lasioseius</i> sp. Berlese	38	1.43	1	0.16
<i>Proctolaelaps bickleyi</i> Bram	25	0.94	0	0.00
Acaridae				
<i>Tyrophagus putrescentiae</i> Schrank	764	28.7	63	9.84
Bdellidae				
<i>Bdella distincta</i> Baker & Balock	39	1.47	117	18.3
<i>Spinibdella</i> sp. Thor	0	0.00	5	0.78
Eupodidae				
<i>Eupodes</i> sp. Martin	1	0.04	7	1.09
Heatherellidae				
<i>Heatherella</i> sp. Walter	6	0.23	0	0.00
Phytoseiidae				
<i>Amblyseius largoensis</i> Muma	18	0.68	8	1.25
<i>Galendromus</i> sp. Muma	1	0.04	0	0.00
<i>Iphiseius degenerans</i> Berlese	3	0.11	0	0.00
<i>Neoseiulus baraki</i> Athias-Henriot	200	7.52	62	9.69
<i>Neoseiulus neobaraki</i> Zannou, Moraes & Oliveira	26	0.98	161	25.2
<i>Neoseiulus paspalivorus</i> De Leon	1,348	50.7	42	6.56
Tarsonemidae				
<i>Steneotarsonemus furcatus</i> De Leon	139	5.23	140	21.9
Tydeidae				
<i>Lorrya</i> sp. Oudemans	9	0.34	31	4.84
Ameroseiidae				
<i>Neocypholaelaps</i> spp. Vitzthum	>1,000 (only collected from inflorescences in both countries)			

beneath coconut bracts, closely associated with their prey *A. guerreronis*, while *A. largoensis* specimens were collected mostly from the fruit surface outside the bracts. *Neoseiulus neobaraki* was the most abundant and most frequent predator on coconut fruits in Tanzania (Table 1). It was present in 17 of the 18 plantations surveyed, while only 42 and 62 specimens of *N. paspalivorus* and *N. baraki*, respectively, were collected from only four and five plantations (Table 1). In one location, Ras Matuso, *N. neobaraki* and *N. paspalivorus* occurred together on two palms and one fruit. Other mites often collected from beneath the bracts were the tarsonemid *Steneotarsonemus furcatus* De Leon and the acarid *Tyrophagus putrescentiae* Schrank. Only one specimen of Ascidae, *Lasioseius* sp., was found on the fruit surface. Furthermore, the bdellids *Bdella distincta* Baker & Balock and *Spinibdella* sp. Thor and the eupodid *Eupodes* sp. Thor were found on the fruit surface. Ameroseiid specimens collected in extremely large numbers from the inflorescences belonged to the genus *Neocypholaelaps* Vitzthum. They were only scarcely found on the fruit exocarp. Larvae of the family Tenuipalpidae were collected from several fruits but no adult specimen were found.

In Benin, *N. paspalivorus* was by far the most abundant non-eriophyid mite collected from coconut fruits (Table 1). This predator was present in all surveyed plantations. *Neoseiulus baraki*, the second most abundant predatory mite on coconut fruits, was collected from five plantations in Mono province. In the same province only a few specimens of *N. neobaraki* were collected in two plantations. Like in Tanzania the two *Neoseiulus* species along with *T. putrescentiae* and *S. furcatus* were collected from beneath coconut bracts. *Steneotarsonemus furcatus* was far less abundant in Benin than in Tanzania. Other Phytoseiidae encountered in Benin on the fruit surface outside the bracts were *A. largoensis* and *Iphiseius degenerans* (Berlese) (Table 1). Four genera of Ascidae were collected from the fruit surface: *Asca* sp. von Heyden, *Gamasellodes* sp. Athias-Henriot, *Lasioseius* sp. Berlese and *Proctolaelaps bickleyi* (Bram). Like in Tanzania thousands *Neocypholaelaps* sp. were collected from inflorescences (Table 1).

Discussion

Our surveys revealed that, on the basis of frequency and severity of coconut fruit infestations, the coconut mite *A. guerreronis* continues to be a serious pest of coconut in Benin and Tanzania. All surveyed coconut plantations in both countries were damaged by *A. guerreronis* and almost all palms in every plantation had damage symptoms. Such high levels of damage incidence and severity are probably due to the inability of existing natural enemies to sufficiently suppress *A. guerreronis* which inhabits the protected areas beneath the bracts. (Lawson-Balagbo et al. 2007a; Reis et al. 2008; Negloh et al. 2010).

The three predatory mites *Neoseiulus baraki*, *N. neobaraki* and *N. paspalivorus* were the three main predators found beneath the bracts but how many individuals and how early they reach the area beneath the bracts is of key importance to their effect on the pest (Lawson-Balagbo et al. 2007a; Negloh et al. 2010). Coconut mite damage levels recorded in our study were similar to the highest damage level reported from the Kalpitiya area in Sri Lanka (Fernando et al. 2002). In our study, at least 61% of fruits were damaged and more than 44% were at least severely damaged (>25% of surface damaged). In contrast, Ramaraju et al. (2002) observed only 5–48% damaged fruits in Pollachi and Udumaplet in India. In our studies, damage severity increased with fruit age probably as a consequence of the persistence of infestation by *A. guerreronis*. Indeed, *A. guerreronis* often colonizes the newly fertilized fruits (Moore et al. 1989; Fernando et al. 2003; Negloh et al. 2010) but

visible injury to the fruits only appears a few weeks later. Population density of *A. guerreronis* increases progressively with fruit age, consequently increasing damage levels (Julia and Mariau 1979; Mariau 1986; Otterbein 1988).

Peak densities of *A. guerreronis* were observed on 3–4 months old fruits (see also Negloh et al. 2010). In Sri Lanka, Fernando et al. (2003) found that *A. guerreronis* densities increased within the first 5 months and declined thereafter. Declining densities on older fruits were likely caused by dispersal of *A. guerreronis* from these fruits to younger ones probably due to intensified intraspecific competition, reduced nutritional quality of feeding sites, and increased access beneath the bracts by natural enemies (Aratchige 2007; Lawson-Balagbo et al. 2007a).

Fruit weight loss increased with damage severity in maturing fruits of FBA_{3–4} (i.e. 7–12 months). Weight loss was not evident on fruits of FBA₁ (i.e. 1–3 months old fruits) probably because development outweighed the negative effects of *A. guerreronis* feeding. However, the increase in fruit tissue suitable for feeding on 1–3 month-old fruits fostered population growth of the pest, resulting in the highest densities on 3 and 4 month-old fruits, which can explain the high damage severity level and associated weight loss in FBA_{3–4}.

Various other mites, both herbivores and predators, were found on coconut fruits, some of which living in close association with *A. guerreronis* beneath the bracts. *Steneotarsonemus furcatus* was the second most frequently observed herbivorous mite, which was collected more frequently in Tanzania than in Benin (Table 1). *Steneotarsonemus furcatus* is, however, considerably less abundant in Benin and Tanzania than in Brazil (Navia et al. 2005; Lawson-Balagbo et al. 2008). Damage by *S. furcatus* was not observed in Benin and Tanzania, probably because of its very low density in these countries. Pollen feeding *Neocyphlaeplaps* sp. (Ameroseiidae) were abundant on coconut inflorescences in Benin and Tanzania as in India (Haq 2001) and Sri Lanka (Ramaraju et al. 2002) but was completely absent in Brazil (Lawson-Balagbo et al. 2008).

The most abundant predatory mite in Tanzania was *N. neobaraki*, consistently observed under the bracts in almost all plantations. Two closely related species, *N. paspalivorus* and *N. baraki*, were less abundant and found in only four plantations. In Benin, *N. paspalivorus* was the most frequent predator followed by *N. baraki*. The latter was found in only five plantations which were flooded during the rainy season or were bordering swamps, lakes or rivers. *Neoseiulus paspalivorus* and *N. baraki* also occur in Sri Lanka and Brazil (Fernando et al. 2003; Moraes et al. 2004; Lawson-Balagbo et al. 2008). Only a few specimens of *N. neobaraki* were found in two Beninese plantations together with *N. baraki*. The differing distribution of the three species in Tanzania and Benin seems to reflect species-specific humidity requirements. In Brazil, *N. baraki* was collected in regions characterized by elevated humidity whereas *N. paspalivorus* was more abundant in drier regions (Lawson-Balagbo et al. 2008). Similarly, climatic differences between Tanzania and Benin could explain the observed differences in the occurrence of the three *Neoseiulus* species. Rainfall in coastal Tanzania is almost everywhere above 1,000 mm and can exceed 1,500 mm per year in some locations, while in Benin most places on the coast experience rainfall below 1,000 mm (BBC 2010).

The three *Neoseiulus* species found on coconut fruits during this study are considered promising candidates for biological control of *A. guerreronis* (De Moraes and Zacarias 2002; Fernando et al. 2003; Lawson-Balagbo et al. 2007b; Negloh et al. 2008, 2010). All three species have elongated, flattened idiosomas and short legs, probably morphological adaptations to live in the tight areas similar to the areas beneath coconut bracts, and all three readily prey and reproduce on *A. guerreronis* (Lawson-Balagbo et al. 2007b; Negloh

et al. 2008; Domingos et al. 2010; K. Negloh personal observations). *Amyseius largoensis* was also frequently found on coconut palms, but unlike the three *Neoseiulus* species, it was mostly collected from the fruit surface outside the bracts. It has a larger idiosoma than the *Neoseiulus* spp., which hampers its ability to creep under the bracts. Other predatory mites encountered were *P. bickleyi* (uniquely from fallen fruits) and *Lasioseius* sp. of the family Ascidae, reported from Brazil (Lawson-Balagbo et al. 2008), and *Lasioseius phytoseiodes* Chan, reported from Columbia (Cardona and Potes 1971), and *B. distincta* reported from Brazil (Lawson-Balagbo et al. 2007a) and Benin (Mariau and Tchiboza 1973). The latter species preys on *A. guerreronis* but because of its large body size it rarely enters the area beneath the bracts as reported in this study and by Lawson-Balagbo et al. (2007a, 2008).

The present study focused on determining the diversity and distribution of the acarine fauna only on coconut fruits and inflorescences. Several additional studies are needed in order to obtain a comprehensive assessment of the diversity and distribution of the acarine fauna in the two targeted countries. First, similar future efforts should include other parts of the coconut palm and associated vegetation in order to get greater insight into the diversity and distribution of the acarine fauna. Of particular interest are the other host plants for the three *Neoseiulus* species found under coconut bracts, and if these phytoseiids move between the coconut fruits and the ground vegetation. Such findings can have significant implications for promoting phytoseiid abundance to enhance biological control of *A. guerreronis*. Second, for Tanzania, where only one survey was conducted, additional surveys should provide further insights into the diversity and abundance of the acarine fauna at different climatic conditions (e.g. rainy season, end of dry season, etc.) than those occurring during the survey of the present study. Third, we found that coconut mite damage is widespread in both countries despite the presence of adapted predators under the coconut bracts where the pest resides and thrive. This indicates the need to conduct further studies on biology, ecology and interactions among all mites found beneath the bracts in order to determine the efficiency of associated predators as natural and biological control agents. Studies conducted in Benin (Negloh et al. 2010) showed that *A. guerreronis* colonizes the young fruits almost 1 month earlier than the predators. This gives *A. guerreronis* a head-start in population build-up and results in a delayed impact of the predators on the pest. In addition the rate of colonization by the predators is relatively slow. Recent studies demonstrated that *N. paspalivorus* and *N. baraki* performed the best on *A. guerreronis* as prey compared to other food sources (Lawson-Balagbo et al. 2007b; Negloh et al. 2008). Moreover, a single female of both predator species could kill over 50 individuals of *A. guerreronis* per day (Negloh et al. unpublished). These results suggest that the predators would be effective against the pest when it is reachable for them. Lastly, the presence of numerous other predators outside the coconut fruit bracts suggests that they may also play an important role in suppressing dispersing individuals of *A. guerreronis*. Their presence on other parts of the coconut palm and their role in the suppression of *A. guerreronis* merits consideration.

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References

- APCC (2010) Webpage of Asian and Pacific coconut community. <http://www.apccsec.org>. Accessed on 30 Sept 2010
- Aratchige AS (2007) Predators and the accessibility of herbivore refuges in plants. Ph.D. thesis, University of Amsterdam, The Netherlands
- BBC (2010) Webpage of British Broadcasting Corporation. <http://www.news.bbc.co.uk/weather/>. Accessed 21 Oct 2010
- Cabrera RIC (2002) Biological control of the coconut mite *Aceria guerreronis* (Acari: Eriophyidae) with the fungus *Hirsutella thompsonii* and its possible integration with other control methods. In: Fernando LCP, de Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on the coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 89–103
- Cardona IZ, Potes SA (1971) Coconut scab or excoriation (*Cocos nucifera* L.) in Columbia. *A. guerreronis*. Acta Agronomica 21:133–139
- De Moraes GJ, Zacarias MS (2002) Use of predatory mites for the control of eriophyid mites. In: Fernando LCP, de Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on the coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 78–88
- Domingos CA, da S Melo JW, Gondim MGC Jr, de Moraes GJ, Hanna R, Lawson-Balagbo LM, Schausberger P (2010) Diet-dependent life history, feeding preference and thermal requirements of the predatory mite *Neoseiulus baraki* (Acari: Phytoseiidae). Exp Appl Acarol 50:201–215
- Edgington S, Fernando LCP, Jones K (2008) Natural incidence and environmental profiling of the mite-pathogenic fungus *Hirsutella thompsonii* Fisher for control of the coconut mite in Sri Lanka. Int J Pest Manag 54:123–127
- FAO (2010) Webpage FAOSTAT. <http://faostat.fao.org>. Accessed 10 Aug 2010
- Fernando LCP, Wickramananda IR, Aratchige NS (2002) Status of coconut mite, *Aceria guerreronis* in Sri Lanka. In: Fernando LCP, de Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on the coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 1–8
- Fernando LCP, Aratchige NS, Peiris TSG (2003) Distribution patterns of the coconut mite *Aceria guerreronis* K. and its predator *Neoseiulus paspalivorus* in coconut palms. Exp Appl Acarol 31:71–78
- Fernando LCP, Manoj P, Hapuarachchi DCL, Edgington S (2007) Evaluation of four isolates of *Hirsutella thompsonii* against coconut mite (*Aceria guerreronis*) in Sri Lanka. Crop Prot 26:1062–1066
- Foale M (2003) The coconut odyssey: the bounteous possibilities of the tree of life. Australian Centre for International Agricultural Research, vol 101
- Gopal M, Gupta A (2001) Has *Hirsutella thompsonii* the wherewithal to counter coconut eriophyid mite scourge? Curr Sci 80:831–836
- Gopal M, Saleena A, McCoy C (2002) Study of the microflora associated with coconut eriophyid mite as a preliminary step towards pathogen isolation. Curr Sci 82:22–24
- Hall RA (1981) The coconut mite *Eriophyes guerreronis*, with a special reference to the problem in Mexico. In Proceedings of the Brazilian crop protection society, pp 113–119
- Hall RA, Hussey NW, Mariau D (1980) Results of a survey of biological control agents of the coconut mite *Eriophyes guerreronis* Keifer. Oléagineux 35:395–400
- Haq MA (2001) Life cycle and behavior of the coconut mite *Neocypholaelaps stridulans* (Evans) (Acari: Ameroseiidae) in India. In: Halliday RB, Walter DE, Proctor HC, Norton RA, Colloff MJ (eds) Proceedings of the 10th international congress of acarology. CSIRO Publishing, Collingwood, pp 361–365
- Hernandez RF (1977) Combate químico del eriofido del cocotero, *Aceria guerreronis* K. en la costa de Guerrero. Agric en Mexico 4:23–38
- Howard FW, Abreu-Rodriguez E (1991) Tightness of the perianth of coconuts in relation to infestation by coconut mites. Fla Entomol 74:358–362
- Howard FW, Abreu-Rodriguez E, Denmark HA (1990) Geographical and seasonal distribution of the coconut mite, *Aceria guerreronis* (Acari: Eriophyidae), in Puerto Rico and Florida, USA. J Agric Univ PR 74:237–251
- Howard FW, Moore D, Giblin-Davis RM, Abad RG (2001) Insects on palms. CABI Publishing, Wallingford, pp 251–257
- Julia JF, Mariau D (1979) Nouvelles recherches en Côte d'Ivoire sur *Eriophyes guerreronis* Keifer, acarien ravageur des noix du cocotier. Oléagineux 34:181–189
- Lawson-Balagbo LM, Gondim MGC Jr, de Moraes GJ, Hanna R, Schausberger P (2007a) Refuge use by the coconut mite *Aceria guerreronis*: fine scale distribution and association with other mites under the perianth. Biol Control 43:102–110

- Lawson-Balagbo LM, Gondim MGC Jr, de Moraes GJ, Hanna R, Schausberger P (2007b) Life history of the predatory mites *Neoseiulus paspalivorus* and *Proctolaelaps bickleyi*, candidates for biological control of *Aceria guerreronis*. *Exp Appl Acarol* 43:49–61
- Lawson-Balagbo LM, Gondim MGC Jr, de Moraes GJ, Hanna R, Schausberger P (2008) Exploration of the acarine fauna on coconut palm in Brazil with emphasis on *Aceria guerreronis* (Acari: Eriophyidae) and its natural enemies. *Bull Entomol Res* 98:83–96
- Mariau D (1977) *Aceria (Eriophyes) guerreronis* Keifer: an important pest of African and American coconut groves. *Oléagineux* 32:109–111
- Mariau D (1986) Comportement de *Eriophyes guerreronis* Keifer à l'égard de différentes variétés de cocotiers. *Oléagineux* 41:499–503
- Mariau D, Julia JF (1970) L'acariose à *Aceria guerreronis* Keifer, ravageur du cocotier. *Oléagineux* 25:459–464
- Mariau D, Tchibozo HM (1973) Trials of chemical control of *A. guerreronis* (Keifer). (Coconuts). *Oléagineux* 28:133–135
- Moore D (2000) Non-chemical control of *Aceria guerreronis* on coconuts. *Biocontrol News Info* 21:83–88
- Moore D, Alexander L (1987) Aspects of migration and colonization of the coconut palm by the coconut mite, *Eriophyes guerreronis* (Keifer) (Acari: Eriophyidae). *Bull Entomol Res* 77:641–650
- Moore D, Alexander L, Hall RA (1989) The coconut mite *Eriophyes guerreronis* Keifer in St Lucia: yield losses and attempts to control it with polybutene and *Hirsutella* fungus. *Trop Pest Manage* 35:83–89
- Moraes GJ, Zacarias MS (2002) Use of predatory mites for the control of eriophyid mites. In: Fernando LCP, Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 78–88
- Moraes GJ, Lopes PC, Fernando LCP (2004) Phytoseiid mites (Acari: Phytoseiidae) of coconut growing areas in Sri Lanka, with description of three new species. *J Acarol Soc Jpn* 13(2):141–160
- Navia D, de Moraes GJ, Roderick G, Navajas M (2005) The invasive coconut mite *Aceria guerreronis* (Acari: Eriophyidae): origin and invasion sources inferred from mitochondrial (16S) and nuclear (ITS) sequences. *Bull Entomol Res* 95:505–516
- Negloh K, Hanna R, Schausberger P (2008) Comparative demography and diet breadth of Brazilian and African populations of the predatory mite *Neoseiulus baraki*, a candidate for biological control of coconut mite. *Biol Control* 46:523–531
- Negloh K, Hanna R, Schausberger P (2010) Season- and fruit age-dependent population dynamics of *Aceria guerreronis* and its associated predatory mite *Neoseiulus paspalivorus* on coconut in Benin. *Biol Control* 54:349–358
- Otterbein HD (1988) Studies on the biology, importance and control of *E. guerreronis* on *Cocos nucifera* in Costa Rica. Dissertation, University of Kiel, Germany
- Perring TM (2002) Eriophyid mites: special considerations in applied ecological research. In: Fernando LCP, de Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on the coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 71–77
- Ramaraju K, Natarajan K, Sundara Babu PC, Palanisamy S, Rabindra RJ (2002) Studies on coconut eriophyid mite, *Aceria guerreronis* Keifer in Tamil Nadu, India. In: Fernando LCP, de Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on the coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 13–31
- Reis AC, Gondim MGC Jr, de Moraes GJ, Hanna R, Schausberger P, Lawson-Balagbo LM, Barros R (2008) Population dynamics of *Aceria guerreronis* Keifer (Acari: Eriophyidae) and associated predators on coconut fruit in Northeastern Brazil. *Neotrop Entomol* 37:452–467
- SAS Institute (2005) SAS/SAT user's guide, release v9.1. SAS Institute, Cary
- Seguni Z (2002) Incidence, distribution and economic importance of the coconut eriophyid mite, *Aceria guerreronis* K. in Tanzanian coconut based cropping systems. In: Fernando LCP, de Moraes GJ, Wickramananda IR (eds) Proceedings of the international workshop on the coconut mite (*Aceria guerreronis*). Coconut Research Institute, Sri Lanka, pp 54–57
- Siriwardena PHAP, Fernando LCP, Peiris TSG (2005) A new method to estimate the population size of coconut mite, *Aceria guerreronis*, on a coconut. *Exp Appl Acarol* 37:123–129