

# Influence of fruit age of the Brazilian Green Dwarf coconut on the relationship between *Aceria guerreronis* population density and percentage of fruit damage

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**Abstract** The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae), is one of the main coconut pests in the American, African and parts of the Asian continents, reaching densities of several thousand mites per fruit. Diagrammatic scales have been developed to standardize the estimation of the population densities of *A. guerreronis* according to the estimated percentage of damage, but these have not taken into account the possible effect of fruit age, although previous studies have already reported the variation in mite numbers with fruit age. The objective of this study was to re-construct the relation between damage and mite density at different fruit ages collected in an urban coconut plantation containing the green dwarf variety ranging from the beginning to nearly the end of the infestation, as regularly seen under field conditions in northeast Brazil, in order to improve future estimates with diagrammatic scales. The percentage of damage was estimated with two diagrammatic scales on a total of 470 fruits from 1 to 5 months old, from a field at Ilhéus, Bahia, Brazil, determining the respective number of mites on each fruit. The results suggested that in estimates with diagrammatic scales: (1) fruit age has a major effect on the estimation of *A. guerreronis* densities, (2) fruits of different ages should be analyzed separately, and (3) regular evaluation of infestation levels should be done preferably on fruits of about 3–4 months old, which show the highest densities.

**Keywords** Coconut mite · Injury · Diagrammatic scales · Integrated pest management

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## Introduction

The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae), has been considered one of the main coconut pests in the American, African and parts of the Asian continents (Mariau 1977; Moore and Alexander 1987; Fernando et al. 2002; Lawson-Balagbo et al. 2008; Negloh et al. 2010, 2011; Navia et al. 2013). High *A. guerreronis* population densities have been found in coastal areas of northeastern Brazil (Lawson-Balagbo et al. 2008; Souza et al. 2012; Melo et al. 2014).

*Aceria guerreronis* reaches a maximum of about 255  $\mu\text{m}$  in length and lives in the meristematic region of the fruit, covered by bracts (perianth), where it commonly attains densities of several thousand individuals per fruit (Mariau 1977; Howard and Abreu-Rodriguez 1991; Lawson-Balagbo et al. 2007). Initial attack symptoms are small, yellowish-white triangular chlorotic areas in the fruit epidermis near the outer margin of the bracts. As the fruit develops and the mite population grows, the chlorotic area gradually increases, turning brownish, becoming necrotic and with longitudinal crevices on the fruit surface (Mariau 1977; Haq et al. 2002).

Populations of *A. guerreronis* have been found to be attacked naturally by predators and, less commonly, by pathogens, but some growers control this mite with the use of acaricides (Moore et al. 1989; Domingos et al. 2010; Lima et al. 2012, 2013; Melo et al. 2012). Regardless of the control strategy, the determination of the population level of *A. guerreronis* is fundamental in integrated pest management (IPM) programs, which require accurate and practical tools to estimate infestation levels (Sousa et al. 2017).

Several tools were developed to estimate fruit damage and to establish relations between the estimations and the population densities of *A. guerreronis* (Mariau 1977; Julia and Mariau 1979; Moore and Alexander 1987; Moore et al. 1989; Negloh et al. 2010, 2011). Some of these tools are the diagrammatic scales of Galvão et al. (2008) and Sousa et al. (2017), based on the total exposed damaged area on the fruit surface and the percentage of damaged extension along the distal margin of the inner bracts, respectively.

It seems reasonable to admit that initially the extent of the damaged area increases in parallel with the increasing density of *A. guerreronis* up to a certain point, beyond which the extent of damaged area would continue to increase, though more slowly, despite the decline of mite population (Galvão et al. 2008, 2011; Negloh et al. 2010, 2011; Souza et al. 2012; Sousa et al. 2017). Causes of reduction of the mite population have been discussed in the literature (Fernando et al. 2003; Negloh et al. 2010, 2011; Galvão et al. 2011; Souza et al. 2012). The difference in the pattern of variation of damaged area and population density causes a problem in trying to relate damage with mite densities, given that obviously a positive (but not necessarily linear) relationship is expected to occur only in the initial stage of the process, with the relationship becoming negative over time.

Considering fruits of the green dwarf variety of different ages together (1–6 months), Galvão et al. (2008) and Sousa et al. (2017) estimated maximum population levels to be around 3000 and 3500 mites per fruit, respectively, whereas Souza et al. (2012) estimated a maximum of about 7000 mites per 4-month-old fruit. Considering that the highest mite density is usually attained in 3- to 4-month-old fruits (Negloh et al. 2010, 2011; Galvão et al. 2011), our hypothesis is that a reduction of the estimated maximum occurs when fruits of different ages are considered together.

The objective of this study was to re-construct the relation between damage and mite density at fruit ages ranging from the beginning to nearly the end of the infestation, as regularly seen under field conditions in northeast Brazil, in order to improve future use of diagrammatic scales.

## Materials and methods

Four hundred and seventy fruits of about 1–5 months old were collected in an urban coconut plantation containing the Brazilian Green Dwarf variety, located in the municipality of Ilhéus, Bahia, northeastern Brazil (14°48'41''S, 39°02'20''W). The fruits had different intensities of damage by *A. guerreronis*. They were stored in polyethylene bags and transported to the laboratory within a period of 90 min, maintaining them at 15 °C for evaluation within a maximum of 10 days.

Fruit length was measured with a digital caliper (Digimess—Shiko Precision Gaging, China), from the top of the perianth to the distal portion of each fruit, and grouped into 11 length classes, from 4 to 14 cm. Given their low numbers, fruits shorter than 4 cm or longer than 14 cm were not in the study. Taking into account the damaged fruits ( $n = 263$ ), the percentage of symptomatic surface (in relation to the total surface of the fruit) and the percentage of the total exposed damaged area on the fruit surface and on the percentage of damaged perimeter close to the distal margin of the inner bracts were estimated using the diagrammatic scales of Galvão et al. (2008) and Sousa et al. (2017). The number of post-embryonic stages of *A. guerreronis* per fruit was estimated according to Sousa et al. (2017).

Linear and nonlinear regression analyzes were performed to select the best fitting models based on the coefficient of determination ( $R^2$ ) and the mean square of the residue (QMR) of the relation between the percentages of damaged area or of damaged distal margin of the inner bracts with mite densities within each fruit age. Significance of the regressions was verified by the *F* test. All regression analyzes were performed using the SigmaPlot® v.12.0 and Table Curve® 2D v.5.01 programs (Systat 2002).

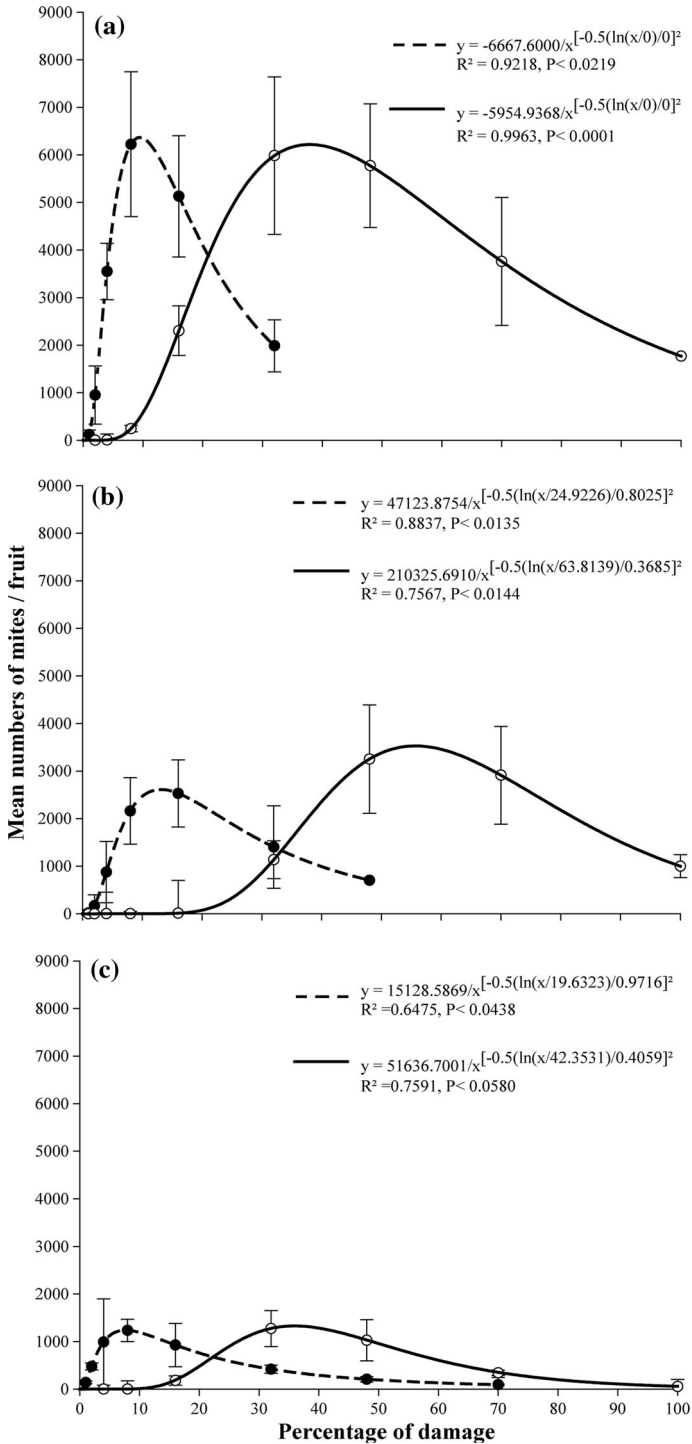
## Results

The number of symptomatic fruits of 1 (4 out of 84) and 2 (34 out of 103) months old was low (Table 1). The percentages of symptomatic areas on the surface of these fruits ranged from 1 to 8%, with mean numbers of mites per fruit ranging from 1043 to 4598 (1 month

**Table 1** Percentage of fruit surface (using the scale proposed by Galvão et al. 2008) and fruit perimeter close to the distal margin of the bracts (using the scale proposed by Sousa et al. 2017) with symptoms of attack by *Aceria guerreronis* and the corresponding mean ( $\pm$ SEM) number of mites per fruit of 1 and 2 months old

Fruit age (months)	Based on Galvão et al. (2008)			Based on Sousa et al. (2017)		
	% damaged surface	Nr. mites/fruit	$n^a$	% damaged margin	Nr. mites/fruit	$n^a$
1	1	1043	1	4	545 $\pm$ 498	2
	2	1541 $\pm$ 1493	2	16	3034	1
	8	4598	1	32	4598	1
2	1	720 $\pm$ 398	10	1	0	1
	2	1270 $\pm$ 800	5	4	542 $\pm$ 229	7
	4	3203 $\pm$ 776	14	8	589 $\pm$ 241	7
	8	2493 $\pm$ 868	5	16	2146 $\pm$ 573	11
	–	–	–	32	4082 $\pm$ 184	8

<sup>a</sup> Number of symptomatic fruits, out of a total of 84 (1 month old) and 103 (2 month old) fruits



◀ **Fig. 1** Relationship between the percentage of fruit surface (using the scale proposed by Galvão et al. 2008—*dashed line*) or distal margin of the perianth (using the scale proposed by Sousa et al. 2017—*solid line*) with symptoms of attack by *Aceria guerreronis* and the corresponding mean ( $\pm$ SEM) number of mites per fruit of **a** 3 months old, **b** 4 months old and **c** 5 months old

old) and from 720 to 3203 (2 months old). The percentages of symptomatic fruit perimeter of the perianth of 1- and 2-months-old fruits ranged from 4 to 32% and from 1 to 32%, respectively, with mean numbers of mites per fruit varying between 545 and 4598 and between 0 and 4082 (Table 1). Given the low numbers of symptomatic fruits, fruits of 1 and 2 months old were not considered in the subsequent analyses.

The numbers of symptomatic fruits of 3 (78 out of 109), 4 (69 out of 90) and 5 (78 out of 84) months old were high. The percentages of damaged areas on the surface of these fruits varied from 1 to 32, 1 to 48 and 1 to 70%, respectively, whereas the percentage of symptomatic margin varied from 1 to 100% in fruits of the three ages (Fig. 1).

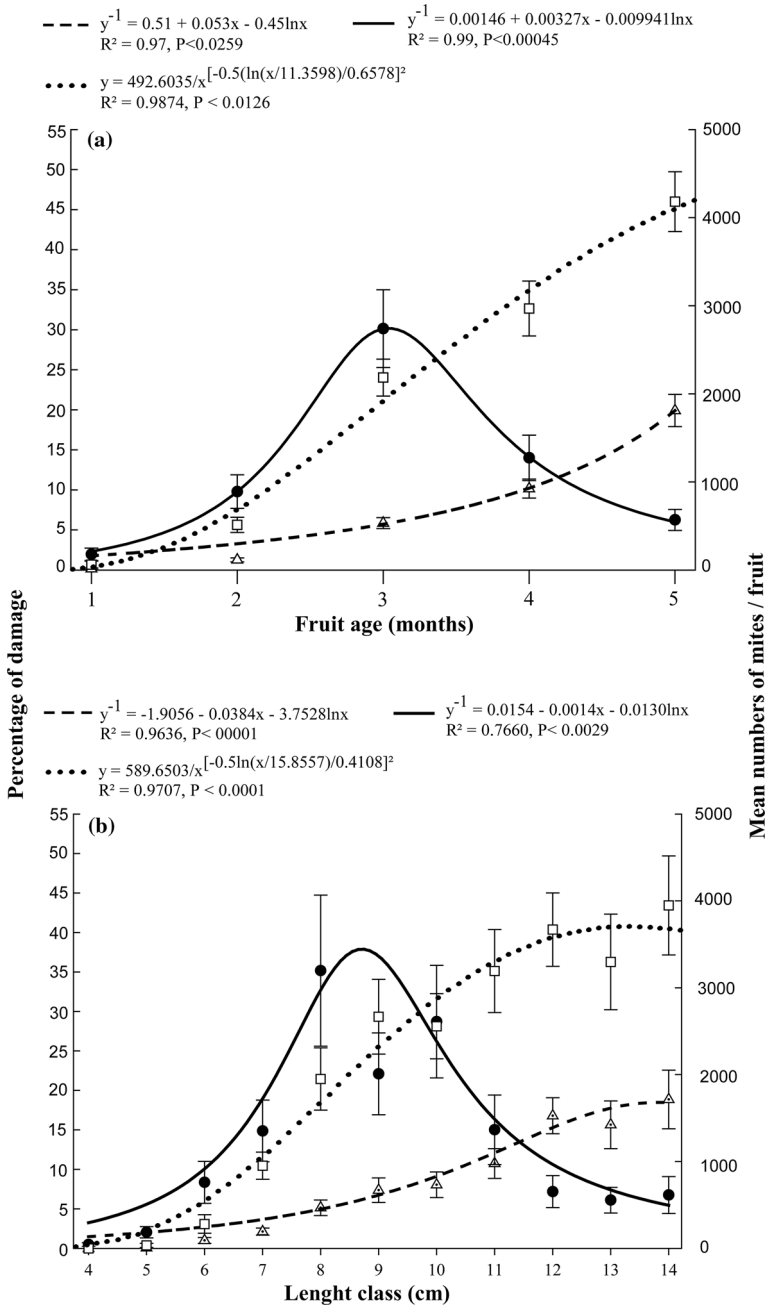
For fruits of 3–5 months old, the mean numbers of mites per fruit increased to a maximum and then decreased with the increase of the damage. In all cases the rate of increase was slightly faster than the decrease of the symptomatic area, regardless of the model used to estimate (based on the percentage of the symptomatic area or perimeter). For the fruits of the three ages, estimates of the maximum number of mites were similar by both models, with reductions of about 50% from fruits of 3–4 months old, as well as from fruits of 4–5 months old.

The maximum number of mites corresponded to the following percentages of symptomatic area of fruits of 3–5 months old: 8% (6200 mites/fruit), 12% (2500 mites/fruit) and 8% (1200 mites/fruit). Conversely, the maximum number of mites corresponded to the following percentages of symptomatic perimeter for those same fruits: 32% (6000 mites/fruit), 48% (3200 mites/fruit) and 32% (1300 mites/fruit), respectively.

The percentages of symptoms as well as the number of mites per fruit estimated by both scales (based on the percentage of the symptomatic area or perimeter) presented similar curves with increasing age and length classes of the fruits (Fig. 2). The mean lengths of fruits of 1, 2, 3, 4 and 5 months old were 4, 6, 9, 12 and 14 cm, respectively.

Considering the approximate age in months, the results suggest that in 1- to 5-month-old fruits the symptomatic area increased from 2 to 20% (Fig. 2a) and the symptomatic perimeter increased from 1 to 46%, whereas the highest number of mites occurred on 3-month-old fruits (2740 mites/fruit); at this level of infestation, the percentage of symptomatic surface was 7% and the percentage of symptomatic margin was 23%.

Considering the length of the fruits (Fig. 2b), the results suggest that in fruits between 4 and 14 cm long, the symptomatic surfaces area increased from 2 to 18% and symptomatic perimeter increased from 0 to 40%, whereas the highest number of mites occurred on fruits that were 9 cm long (3440 mites/fruit); at this level of infestation, the percentage of symptomatic surface was 7% and the percentage of symptomatic margin was 25%.



**Fig. 2** Relationship between the percentage of fruit surface (using the scale proposed by Galvão et al. 2008—dashed line) and distal margin of the bracts (using the scale proposed by Sousa et al. 2017—dotted line) with symptoms of attack by *Aceria guerreronis* and the corresponding mean ( $\pm$ SEM) number of mites per fruit (solid line) of **a** different fruit ages (1–5 months old) and by **b** different length classes (4–14 cm)

## Discussion

Our results suggest that because of the low number of infested fruits of 1 and 2 months old and, consequently, of the low precision of the data, it may not be recommended to apply diagrammatic scales to estimate the relationship between the percentage of damage and the number of *A. guerreronis* in such young fruits. Although the numbers of mites per fruit of these ages seemed high, on average, the total mite numbers were low, given that the most fruits were not infested. It would seem interesting to evaluate the reason for these high numbers, found in just a few fruits. Could that be due to the concurrent attack of other pest species that could eventually facilitate the entrance of *A. guerreronis* under the bracts of those fruits, as suggested by Lawson-Balagbo et al. (2007)?

The results suggested that the separate analysis of fruits of different ages increases the accuracy of the estimates in the relation between percentage of damaged areas or margin and the number of *A. guerreronis* with diagrammatic scales. It has been determined that the highest densities of *A. guerreronis* is usually found on fruits of about 3 and 4 months old (Negloh et al. 2010, 2011; Galvão et al. 2011). The results of the present study supported our hypothesis that by considering fruits of different ages separately, the estimated maximum density of *A. guerreronis* per fruit is about twice as high as the estimated value when fruits of different ages are considered together, as had been suggested by a comparison of the results of the numbers determined by Souza et al. (2012) for 4-month-old fruits and the results of Galvão et al. (2008) and Sousa et al. (2017) for fruits of different ages together.

Our results suggest that the dispersal of *A. guerreronis* can occur after it reaches high densities, as previously reported in the literature (Moore and Alexander 1987), probably due to intraspecific competition caused by scarcity of food and space, interspecific competition with other mites such as *Steneotarsonemus* spp. and/or the effect of predators such as *Neoseiulus* spp. (Negloh et al. 2011; Galvão et al. 2012). Furthermore, it is possible that the increasing lignin content in the fruit, and the injection of toxins with the mite saliva during plant feeding, may cause the decline of *A. guerreronis* populations leading them to migrate to new fruits (Galvão et al. 2008; Souza et al. 2012). Another possibility is that after reaching the population peak in 3- to 4-month-old fruits, the mites tend to disperse by wind or die with increasing necrosis under the perianth.

Our results agree with previous studies showing that, over time, although the extent of the damaged area increases continuously, the number of mites per fruit tends to increase up to 3–4 months old fruits (about 8–9 cm long), reducing afterward (Negloh et al. 2010, 2011; Galvão et al. 2011). Moore and Alexander (1987) also reported the highest density of *A. guerreronis* on 3-month-old Malayan Dwarf coconut fruits in a trial conducted in the Saint Lucia Island. A somewhat different pattern of increase in mite number with fruit age (unspecified variety) was reported by Fernando et al. (2003) in Sri Lanka. Although those authors showed continuous fruit damage along time, as also observed in this work, mite number increased until fruits were 5 months old, reducing only afterward.

Different factors can affect fruit sizes at different ages as well as mite numbers and symptoms. Thus, the results of this study may not apply, for example, to other varieties or other environmental conditions, in what concerns the rate of increasing damage and increasing unsuitability of fruits to *A. guerreronis* population growth, and fruit age of peak mite population. Important influence may also be exerted by the presence of predators, which in the present study was negligible. These factors might have contributed to the differences between the results of this and of previous studies.

In summary, as expected from previous studies showing *A. guerreronis* population dynamics dependence on fruit age (Negloh et al. 2010, 2011), our results suggest that: (1) fruit length can be used to estimate its age; (2) there is a great similarity in the relationship between the percentage of fruit surface (Galvão et al. 2008) and distal margin of the bracts (Sousa et al. 2017) with symptoms of attack by *A. guerreronis* and the corresponding number of mites per fruit; (3) fruit age has a major effect on the estimation of *A. guerreronis* densities on the Brazilian Green Dwarf using diagrammatic scales, and thus fruits of different ages should be analyzed separately; and (4) estimation of infestation levels should be preferably on fruits of 3–4 months old, which show the highest densities.

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