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# Seasonal Fluctuation of The Populations of The Stem Borer, *Apate terebrans* (Coleoptera: Bostrichidae) in Cashew Orchards in North-Eastern Côte d'Ivoire (West Africa)

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## ABSTRACT

In Côte d'Ivoire, the stem borer, *Apate terebrans*, is one of the three main insect pests of cashew (*Anacardium occidentale*), an important cash crop. But, the lack of scientific knowledge about its ecology is a real obstacle to the development of efficient control methods. This study aimed to know the seasonal fluctuation of *A. terebrans*, in relation to the phenological stage of cashew and some climatic factors. The cryptic life of the pest led to the evaluation of its abundance by counting monthly the openings of fresh galleries that it digs in the cashew tree. Systematic sampling was carried out on 1924 cashew trees distributed in 10 orchards in the departments of Bondoukou and Bouna in the North-East of Côte d'Ivoire, from July 2018 to June 2020. Climatic data were recorded over this period. The first individuals of *A. terebrans* were observed in July in the rainy season; peak numbers were reached in November-December in the dry season, before decreasing considerably in January and becoming nil in March-April. Individuals were significantly more abundant at cashew flowering. Significant differences were observed between the abundances within and between departments and from year to year. Simple regression analyses showed that temperature favours the growth of pest populations, while rainfall and hygrometry are unfavourable. This study contributes to the effective control of *A. terebrans*, and provides insights into the determinants of the variability of *A. terebrans* infestations from one orchard to another.

## INTRODUCTION

Cashew tree (*Anacardium occidentale* Linnaeus) cultivation is undergoing an extensive dynamic in West Africa, particularly in Côte d'Ivoire. This is due both to incentive prices for the purchase of cashew nuts (Cashew Handbook, 2014; Fitzpatrick, 2019) and to an ecological transition of adaptation to climate change (Ruf *et al*., 2019). Cultivation thus contributes strongly to solving problems of food insecurity, unemployment, access to financial resources and gender, through its strong capacity to create jobs. It also contributes to the fight against soil degradation (Ruf *et al*., 2019). Since

2016, Côte d'Ivoire has been the world's leading producer and exporter of raw cashew nuts, with a production of 702,000 tonnes, i.e., 21% of world production (CCA, 2017).

However, the Ivorian cashew orchard, in general, suffers from real agronomic and phytosanitary constraints (Soro *et al*., 2020), resulting in low yields, around 450 kg/ha compared to 1200 kg/ha in experimental stations in West Africa (Djaha *et al*., 2010). These include unimproved planting material (Kouakou *et al*., 2018), high cashew tree density (Kambou *et al*., 2019) and the proliferation of phytopathologies (Soro *et al*., 2020) and insect pests (N'Dépo *et al*., 2017; Ouali-N'Goran *et al*., 2020)

*Apate terebrans* Pallas, an insect of tropical and arid zones (Ivie, 2002) and a forest pest in Africa (Schabel *et al*., 1999), is one of the main insect pests of cashew trees in West Africa (FAO, 2007; Agboton *et al*., 2017). Indeed, the adult digs galleries inside the woody tissues of the cashew tree, in which it feeds and lives, rejecting at the foot of the attacked tree a large quantity of sawdust. This leads to tree dieback and even death (Topper *et al*., 2001; Agboton *et al*., 2017; Yéo *et al*., 2019). Vasconcelos *et al*. (2014) reported a 30% mortality of cashew trees in Guinea-Bissau due to *A. terebrans* attacks.

In Côte d'Ivoire, *A. terebrans* is classified as one of the three main insect pests of cashew. It is present in almost all cashew-producing regions, with variability in the level of infestation (CCA, 2017). However, despite the increasing damage of this pest, no science-based control methods exist against it. Indeed, much knowledge such as the biology and ecology of the pest, which is essential for the establishment of sustainable control methods (Gurr *et al*., 2013), remains non-existent in Côte d'Ivoire, to date. Furthermore, the use of synthetic chemical insecticides is increasing (PACCVA, 2017; Soro *et al*., 2020), despite the risks to the environment and human health (Gibbs *et al*., 2009; Rumschlag *et al*., 2020).

In order to provide knowledge on the ecology of *A. terebrans*, this study is the first one in Côte d'Ivoire which aims at knowing the seasonal fluctuation of the populations of this pest, and in relation to the phenological stage of cashew trees and climatic factors (temperature, rainfall, and relative air humidity).

## MATERIALS AND METHODS

**Study Area:**

The study was conducted in the departments of Bondoukou and Bouna, approximately 180 km apart, in the northeast of Côte d'Ivoire. In 2014, these two departments were areas of high and medium cashew nut production respectively (Ricau, 2013). Also, in 2015, the level of *A. terebrans* infestation in Bouna was higher than in Bondoukou (CCA, 2017; Yéo *et al*., 2019). In Bondoukou, the climate is transitional equatorial, with four seasons: a long and short rainy season, and a long and short dry season. The average annual temperature is 26 - 27 °C, with an average annual rainfall of 942 – 1625 mm. The climate in Bouna is wet and dry Sudanese, with two seasons: a rainy season and a dry season. The average annual temperature is 26 - 27 °C, with an average annual rainfall of 992 – 1383 mm (Kouakou *et al*., 2017). The natural vegetation consists of forest and wooded savannah in Bondoukou, and shrub and tree savannahs in Bouna (Guillaumet *et al*., 1971).

**Selection and Description of Study Sites:**

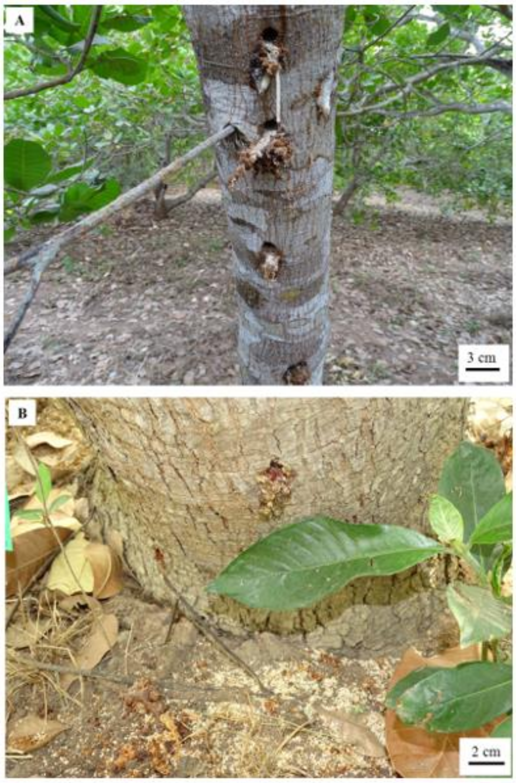
In each department, five cashew orchards of at least 2 ha in size, 15 to 20 years old, infested by *A. terebrans*, and free of insecticides were selected. The distance between these orchards varied from 2 to 30 km. For each orchard, an elementary plot of 100 m x 100 m (1 ha) was delimited from an edge. This was then subdivided into 13 quadrats of 20 m x 20 m (400 $m^2$) at 20 m intervals. All cashew trees in the 13 quadrats were then numbered separately using indelible ink. Each study site was geo-referenced using a Garmin 64 GPS (Global Positioning system) (Table 1).

**Table 1**. Geographical coordinates of the study sites.

| Departments | Study sites | Geographical coordinates | | |
|---|---|---|---|---|
| | | Latitude | Longitude | Altitude (m) |
| Bondoukou | BDK1 | 7°53.344'N | 2°57.560′W | 299 |
| | BDK2 | 7°54.623′N | 2°59.064′W | 275 |
| | BDK3 | 7°58.111′N | 2°56.537′W | 304 |
| | BDK4 | 8°05.546′N | 2°48.778′W | 394 |
| | BDK5 | 8°02.396′N | 2°46.112′W | 376 |
| Bouna | BNA1 | 9°15.655′N | 2°58.037′W | 286 |
| | BNA2 | 9°18.845′N | 2°56.686′W | 370 |
| | BNA3 | 9°20.535′N | 3°10.209′W | 329 |
| | BNA4 | 9°14.337′N | 3°02.023′W | 267 |
| | BNA5 | 9°18.480′N | 2°59.085′W | 345 |

**Monitoring the Seasonal Variation of *A. terebrans* Populations:**

Systematic sampling using the quadrat method was carried out. Given the cryptic life of *A. terebrans,* the monitoring of its population was done through the galleries it digs inside the cashew tree (Agboton *et al*., 2017). The presence of the insect inside the cashew tree is characterised by the presence of fresh sawdust from the cashew wood at the gallery opening, known as the 'fresh gallery', and under the infested cashew tree (Fig. 1). Thus, in this study, a 'fresh gallery' is equivalent to one individual of *A. terebrans*, although sometimes two individuals can be found in it (personal observation). For two consecutive years, from July 2018 to June 2020 (i.e., two cashew production campaigns), all marked cashew trees were inspected at the end of each month, in order to count all 'fresh galleries' present on each infested cashew tree. This count was done at sight, without considering the previous count (cumulative number). In total, 1339 and 585 cashew trees were monitored monthly in Bondoukou and Bouna respectively, by cashew tree density.




**Figs. 1**. A – B. *Apate terebrans* and his recognition signs ('fresh gallery' and sawdust under an infested cashew tree).

**Phenological Stage of Cashew:**

Four phenological stages were defined according to the phenological state of cashew observed in the field: i) vegetative or post-harvest (June to August); ii) leafing (September to October); iii) flowering (November to December) and iv) fruiting (January to May). However, these periods are subject to slight variations related to climate and region (Ricau, 2013).

For each phenological stage, the total number of 'fresh galleries' present on the sampled cashew trees represented the population size of *A. terebrans* in that phenological stage.

**Measurement of Climatic Factors:**

Temperature, rainfall, and relative air humidity are the three climatic factors considered in this study. Indeed, in the tropics, the abundance of Bostrichids varies according to the seasons with more or less the influence of temperature and relative air humidity (Hodges *et al*., 2003).

In each department, two memory thermo-hygrometers (Data Logger EL-USB-2) were used to simultaneously record temperature and humidity during the study; and two direct-reading rain gauges were used to measure rainfall. All these measuring instruments were installed within a 5 km radius of the study sites.

**Statistical Analysis:**

The collected data were processed and analysed using Microsoft Excel 2013 and RStudio v 1.2.5033 (Rstudio Team, 2019). Population trend curves of *A. terebrans* were plotted over the whole monitoring period. Following the Shapiro-Wilk and Bartlett tests, the Kruskal-Wallis's test was used to compare the average population sizes of the study sites, and the Friedman test for the different phenological stages of cashew. The Wilcoxon post hoc test was followed for pairwise comparisons. Simple linear regression was used to assess the influence of climatic factors on *A. terebrans* populations. The Student's t-test was used, after Levene's, to compare the population densities during the two years of monitoring of the departments. The Wilcoxon test was the alternative for comparisons between years, in case of heterogeneity of variances.

## RESULTS

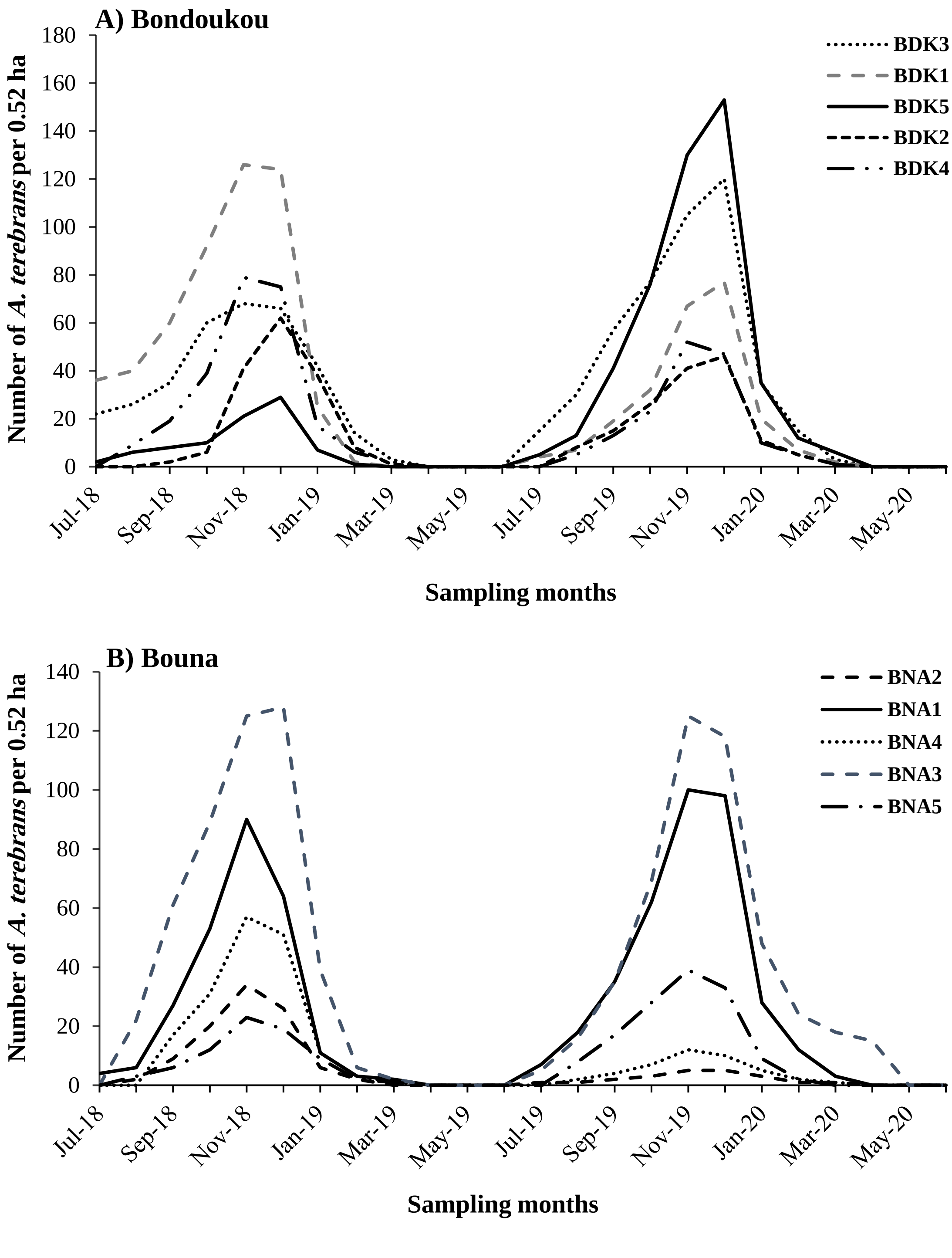
**Seasonal Variation of *A. terebrans* Populations in Cashew Orchards:**

Individuals of *A. terebrans* were present in cashew orchards from July to April (i.e., 10 months), with a variation in population numbers. Thus, from July onwards, the numbers increased progressively to reach a peak between November and December. From January onwards, they fell by more than half until they became nil from March onwards. This cycle was repeated the following year (Fig. 2).

In Bondoukou, a mean density (± SD) of 99.2 ± 37.4 individuals of *A. terebrans* were counted per 0.52 ha study site in the first year (July 2018 to June 2019), with a significant difference between the numbers at the 5 sites (Kruskal-Wallis's test: $\chi^2 = 11.08$; df = 4; p = 0.02). In the second year of monitoring (July 2019 to June 2020), the population increased by 1.8%, or 101 ± 47.88 individuals/0.52 ha. No significant difference was observed between the numbers at the 5 sites (Kruskal-Wallis's test: $\chi^2 = 7.55$; df = 4; p = 0.11) as well as between the mean numbers in the two years of monitoring (Paired t-test: t = - 0.07; df = 64; p = 0.95). However, a significant difference was observed between the numbers at site BDK5 (Wilcoxon test: p = 0.009).

In Bouna, 73.8 ± 45.85 individuals/0.52 ha were counted during the first year of monitoring, with no significant difference between the numbers at the 5 sites (Kruskal-Wallis's test: $\chi^2 = 3.35$; df = 4; p = 0.5). In the second year of monitoring, the population decreased by 17.07%, or 61.2 ± 57.76 individuals/0.52 ha. A significant difference was observed between the numbers at the 5 sites (Kruskal-Wallis's test: $\chi^2$ = 28.58; df = 4; p = 0.001); however, no significant difference was observed between the average numbers in the two years of monitoring (Paired t-test: t = 0.71; df = 64; p = 0.48).

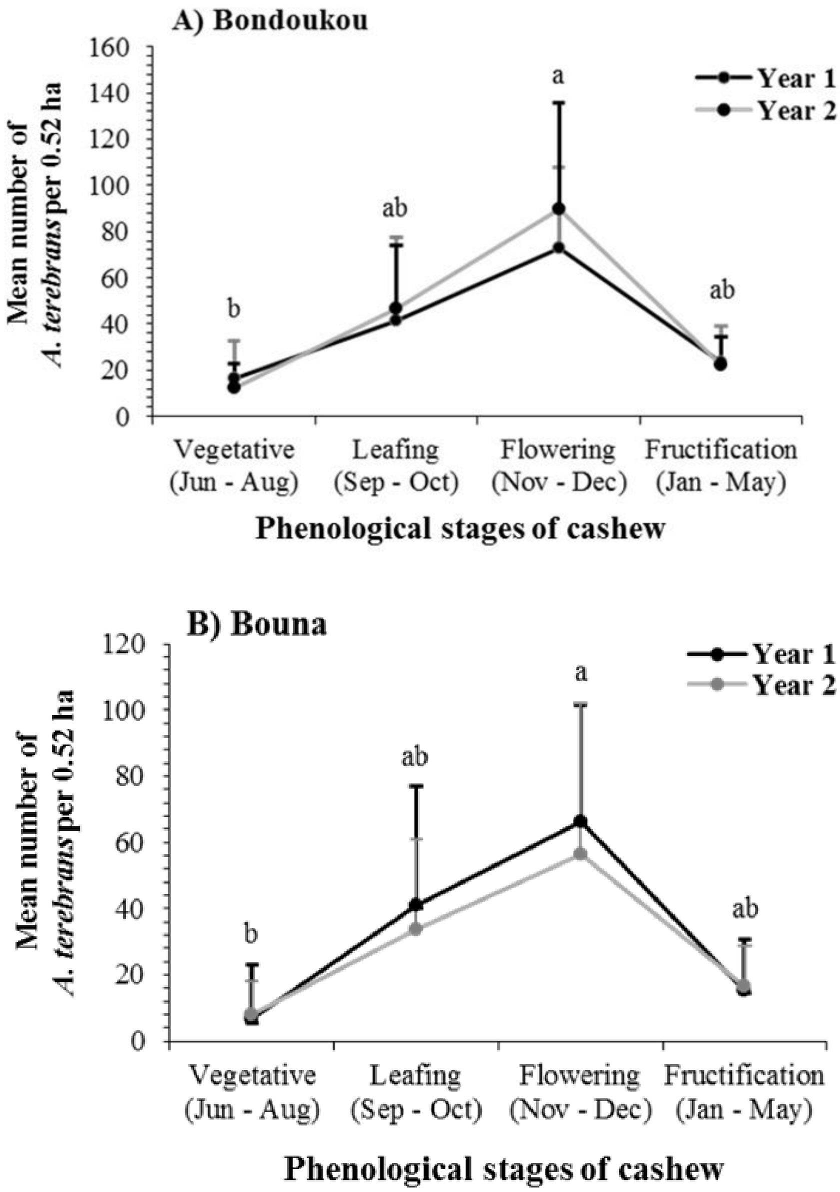
Comparisons of the mean numbers of *A. terebrans* populations in the two departments showed no significant difference in the two years of monitoring (t-test: Year 1: t = 0.96; dl = 8; p = 0.36 / Year 2: t = 1.19; dl = 8; p = 0.27). However, these numbers were higher in Bondoukou.




**Figs. 2.** A – B. Seasonal fluctuation of *Apate terebrans* populations (based on fresh entry holes) in cashew orchards in Bondoukou and Bouna, from July 2018 to June 2020.

**The Abundance of *A. terebrans* According to The Cashew Phenological Stage:**

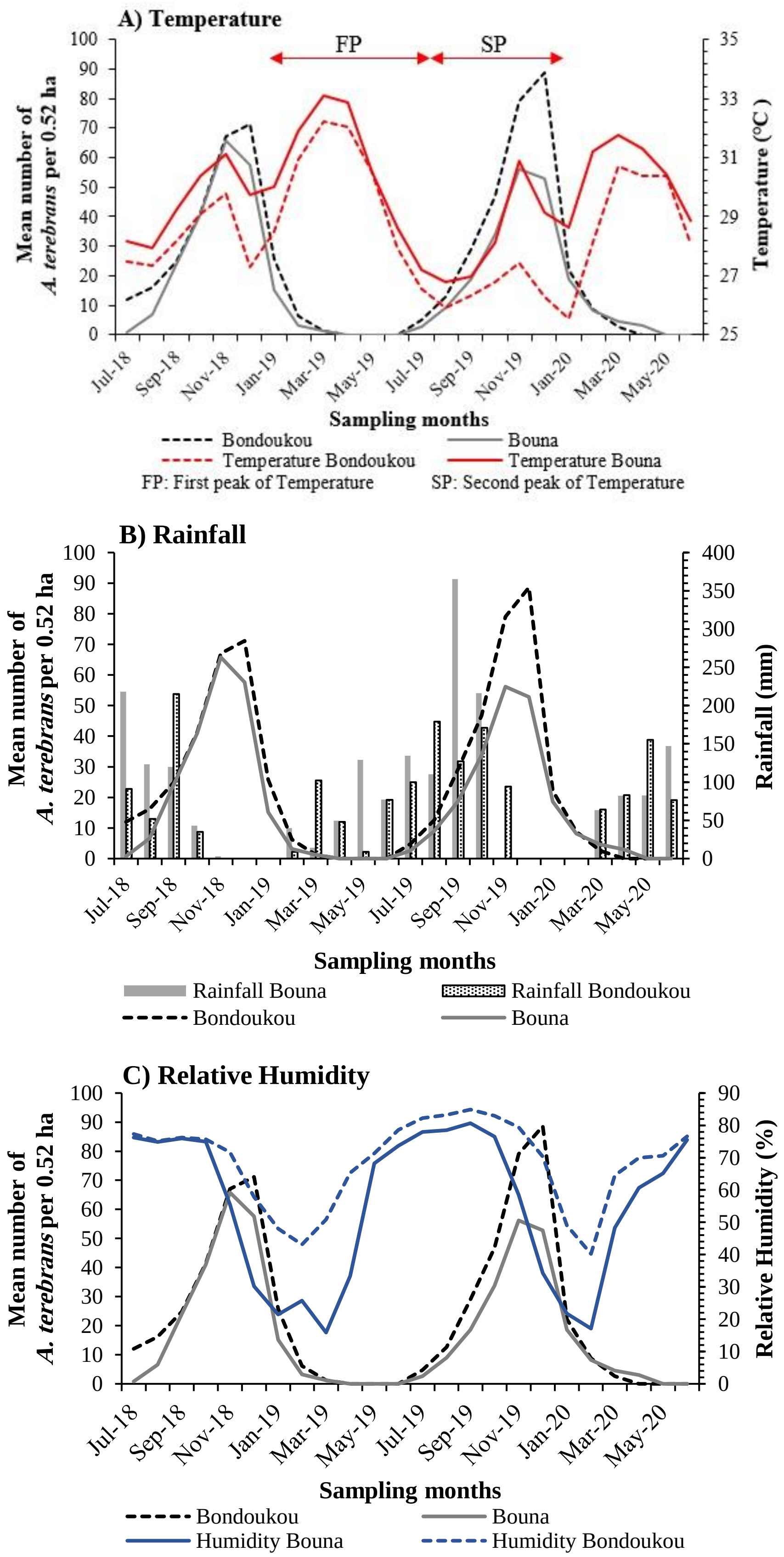
The numbers of *A. terebrans* varied significantly according to the phenological stage of the cashew (Friedman's test: dl = 3; $p < 0.01$) (Fig. 3). In both departments, individuals were more abundant at the cashew flowering stage (November - December) and less abundant at the vegetative or post-harvest stage (June - August).




**Figs. 3**. A – B. Average population abundances of *Apate terebrans* according to the phenological stage of cashew trees, in Bondoukou and Bouna, from July 2018 to June 2020. For one year, histograms with the same letters are not significantly different ($P > 0.05$).

**Evolution of *A. terebrans* Populations in Relation to Climatic Factors:**

Figure 4 shows the fluctuation of *A. terebrans* populations in relation to climatic factors.




**Figs. 4**. A, B and C. Fluctuation of *Apate terebrans* populations in relation to climatic factors, in Bondoukou and Bouna, from July 2018 to June 2020.

**Temperature:**

The analysis of temperature evolution reveals two annual peaks in each department. The first peak (FP) extends globally from January to July, and the second peak (SP) extends from August to December. In both departments, the FP is greater than the SP. FP temperatures ranged from 25.5 to 32.2 °C in Bondoukou, compared to 28.6 to 33.1 °C in Bouna. SP temperatures ranged from 26.5 to 29.8 °C in Bondoukou, compared to 26.8 to 31.1 °C in Bouna.

The first individuals of *A. terebrans* were observed at the minimum temperatures of the SPs and the peaks were reached during the maximum temperatures of the SPs. The decline of the population occurred during the FP. Thus, simple linear regression analyses showed that temperature had a positive effect on the populations before this effect became negative at much higher temperatures (Table 2).

**Table 2**. The relationship between climatic factors and population density of *Apate terebrans* in Bondoukou and Bouna, from July 2018 to June 2020. Regression equations are given as y = ax + b, where y is the population density, x is the climate factor, a is slope and b is intercept.

| Departments | Climatic factors | Years | Evolutionary phases of populations | Regression parameters | | |
|---|---|---|---|---|---|---|
| | | | | Linear regression | $R^2$ | P |
| Bondoukou | Temperature | 1 | Growth | y = 10.62x - 260.56 | 0.18 | 0.4 |
| | | | Decline | y = - 2.59x + 84.04 | 0.21 | 0.36 |
| | | 2 | Growth | y = 31.40x - 790.38 | 0.22 | 0.34 |
| | | | Decline | **y = - 3.75x + 113.92** | **0.73** | **0.03** |
| Bouna | Temperature | 1 | Growth | **y = 20x - 555.63** | **0.85** | **0.009** |
| | | | Decline | y = - 0.85x + 29.72 | 0.06 | 0.63 |
| | | 2 | Growth | **y = 12x - 337.53** | **0.83** | **0.01** |
| | | | Decline | y = - 0.83x + 31.25 | 0.05 | 0.68 |
| Bondoukou | Rainfall | 1 | Growth | y = - 0.2x + 51.83 | 0.4 | 0.18 |
| | | | Decline | y = - 0.13x + 10.86 | 0.3 | 0.26 |
| | | 2 | Growth | y = - 0.34x + 82.06 | 0.42 | 0.16 |
| | | | Decline | y = - 0.11x + 12.85 | 0.58 | 0.08 |
| Bouna | Rainfall | 1 | Growth | **y = - 0.3x + 57.74** | **0.89** | **0.004** |
| | | | Decline | y = - 0.08x + 7.4 | 0.39 | 0.19 |
| | | 2 | Growth | y = - 0.09x + 40.76 | 0.29 | 0.27 |
| | | | Decline | **y = - 0.1x + 12.21** | **0.68** | **0.04** |
| Bondoukou | Relative humidity | 1 | Growth | y = - 2.71x + 235.11 | 0.6 | 0.07 |
| | | | Decline | y = - 0.4x + 29.19 | 0.32 | 0.24 |
| | | 2 | Growth | y = - 5x + 446.42 | 0.59 | 0.07 |
| | | | Decline | y = - 0.47x + 34.51 | 0.56 | 0.09 |
| Bouna | Relative humidity | 1 | Growth | y = - 1.04x + 99.77 | 0.53 | 0.1 |
| | | | Decline | y = - 0.11x + 7.76 | 0.22 | 0.34 |
| | | 2 | Growth | y = - 97x + 94.73 | 0.62 | 0.06 |
| | | | Decline | **y = - 0.24x + 17.48** | **0.71** | **0.03** |

*Significant P values are indicated in bold (α = 0.05).*

**Rainfall:**

Annual rainfall was 638 mm and 1049.5 mm for years 1 and 2 respectively in Bondoukou, compared to 817 mm and 1201.3 mm in Bouna over the same period. The second year thus recorded nearly 400 mm more rain than the first year in each department. The first individuals of *A. terebrans* emerged at the beginning of the rainy season; then, numbers peaked during the dry season, before becoming nil at the beginning of the new rainy season. Thus, the simple linear regression analyses performed show that in both departments, rainfall had a negative effect on the number of *A. terebrans* populations (Table 2).

**Relative Humidity:**

The annual mean values of relative air humidity were 65.93 ± 12.69% and 71.16 ± 14.09% respectively during years 1 and 2 of monitoring in Bondoukou, compared to 52.18 ± 24.68% and 58.26 ± 22.82% in Bouna, respectively over the same period.
Simple linear regression analysis showed a negative effect of relative air humidity on *A. terebrans* populations (Table 2).

## DISCUSSION

**Seasonal Fluctuation of *A. terebrans* Populations:**

The seasonal fluctuation of *A. terebrans* populations shows the same pattern in cashew orchards in Bondoukou and Bouna, in the north-east of Côte d'Ivoire. *A. terebrans* is present in cashew orchards from July to April, i.e., 10 months. Its numbers reached a peak 5-6 months after its appearance in July, before dropping considerably in January until it became zero from March onwards. These results corroborate those of Agboton *et al*. (2017) obtained in Benin. According to this study, the first emergences of *A. terebrans* were observed in September, but the peak of the population size was also reached 5 to 6 months later. It clearly appears that the evolution of the *A. terebrans* population follows the production cycle of its host, the cashew tree. Indeed, the first individuals emerge when the cashew tree begins a new phase of fruit production. Numbers gradually increase until they reach their peak when the host is in the flowering stage, between November and December. This synchronisation between the pest and its host is thought to be the result of a long adaptation of the pest's phenology with that of the host (Sauvion *et al*., 2013). It would allow the survival of the pest and its offspring (Hunter, 1992; Hunter and Elkinton, 2000), especially since *A. terebrans* lives and feeds in the sapwood of cashew trees, which is the storage area for the nutrient reserves of woody plants (Wilson, 1932, in Peters *et al*., 2002). It is therefore crucial for insects to synchronise their feeding phase with the availability of their nutrient resource (Neau, 2014), otherwise, they may starve to death (Régnière and Fletcher, 1983). Thus, the more synchronous the insect is with its host, the better the insect performs (Hunter, 1992; Hunter and Elkinton, 2000).

The significant variation in *A. terebrans* population numbers according to the phenological stage of the cashew tree would therefore be closely linked to a probable physical-biochemical variation within the cashew tree, modulated by a set of bioclimatic factors including the phenology of the cashew tree, the ambient temperature and rainfall. At flowering, the physical and biochemical state of the cashew tree would therefore be ideal for optimal performance of *A. terebrans* and its offspring, which will feed on the 'dead' cashew wood. The temperature and rainfall range observed during this period would therefore be more favourable to the insect. Indeed, according to Creffield (1991) and Peters *et al*. (2002), Bostrichids prefer wood with a high starch content and relatively low moisture content (Ivie, 2002). The drop in the numbers of *A. terebrans* in January (7 months after emergence) would be more related to the natural death of the insect, in addition to the unfavourable physical and biochemical state of the cashew tree. During this period, corpses of *A. terebrans* were found under dead leaves at the foot of infested cashew trees. In Benin, Agboton *et al*. (2017) also noted the drop in the numbers of *A. terebrans* populations, 7 months after the first emergences, and also put forward the hypothesis of the insect's natural death. The death of individuals, as early as January, would also be an indicator of the reproduction period of *A. terebrans*, which is still unknown in Côte d'Ivoire. Indeed, before dying, the females of *A. terebrans* would have already laid their eggs, in order to ensure the survival of the species.

**Evolution of the Populations of *A. terebrans* During the Two Years of Monitoring:**

The number of *A. terebrans* increased by 1.8% during the second year in Bondoukou, in contrast to Bouna where they decreased by 17.07%. However, in 60% of the sites in each department, the numbers decreased. These results are believed to be the result of a combination of several biotic and abiotic factors. According to Agboton *et al*. (2017), *A. terebrans* preferentially attack healthy cashew trees. This behaviour is partly related to the secondary defence metabolites that the infested cashew tree may synthesise following *A. terebrans* attacks (Wittstock and Gershenzon, 2002). These metabolites, such as tannins, are insect toxins (Boone *et al*., 2011; Bohlmann, 2012). The availability of healthy cashew trees within the orchard would therefore be a determining factor. However, in order for them to be attacked, these healthy cashew trees would have to be in a microclimate favourable to *A. terebrans*; indeed, according to Yéo *et al*. (2019), the insect avoids areas with high relative humidity. This behaviour, therefore, highlights the role of the landscape in insect dispersal (Farhig *et al*., 2011; Rush *et al*., 2013). Furthermore, the variations in numbers observed between orchards in a given department during the same year suggest that farmers' cultivation practices should also be taken into account. Indeed, these practices partly govern the microclimate. In addition, given that the development cycle of *A. terebrans* takes place entirely in "dead" cashew wood (Agboton *et al*., 2017; personal observation), the availability and quality of this oviposition support within and/or around the study sites could also be a determining biotic factor. In addition, the type of cashew variety (yellow or red) within the orchards, also deserves to be taken into account. In sum, cashew tree characteristics, agricultural practices, microclimate and climate are key factors that could account for variations in *A. terebrans* population density.

## CONCLUSION:

This study reports, for the first time in Côte d'Ivoire, the seasonal fluctuation of populations of *A. terebrans*, a major pest of cashew. A single 10-month period of occurrence is observed from July to April in cashew orchards in the northeast of Côte d'Ivoire. The phenology of the host plant as well as the climate (temperature, hygrometry and rainfall) influence the abundance of the populations. A single seasonal peak in numbers is recorded, at cashew flowering (November to December), during the drought. These results should contribute to the efficiency of all control methods against *A. terebrans* in Côte d'Ivoire, and constitute a step towards integrated management of this pest.

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