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Groundnut field infestation in different pedoclimatic sites by the peanut beetle, *Caryedon serratus* (Olivier) and conducted losses

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ABSTRACT

Groundnut (*Arachis hypogea* L.), used for direct consumption and cooking oil in several African countries, suffers tremendous losses during storage due to pests. The main pest of groundnut under prolonged storage in tropical countries is the peanut beetle, *Caryedon serratus* (Olivier) (Coleoptera; Bruchidae). The present study aimed at (1) assessing the variability of field pods infestation by *C. serratus* on sites of different pedoclimatic conditions and at (2) evaluating the losses in laboratory storage. Groundnut pod samples were collected in six sites of Senegalese groundnut main farming areas (Bambey, Sandiara, Kaffrine, Coki, Keur Baka and Keur Ayib), and placed in glass jars (5 L) aerate with lid mesh (2 mm) and brought to laboratory. Number of eggs, insect progeny, emerged insects' weight, survival rate, percentage of attacked kernels and weight loss were assessed and confronted among different sampling sites (field soil pH and moisture content, and photoperiodicity). The results showed a presence of groundnut bruchid in all sites, with significant variations of eggs on pods during the drying period across the sites. These variations in field infestation can be explained by several factors such as cultural practices and field environmental factors which varied greatly between the sites. Considering these factors and our preliminary results, this study suggests to dry the groundnuts furthest possible from the beetle hosts trees (wild hosts Cesalpinaceae) and shorten the pod exposure time in field as much as possible, in order to control this preharvest infestation and reduce groundnut storage losses.

Keywords: Groundnut, *Caryedon serratus*, field environmental factors, Storage.

INTRODUCTION

Groundnut, *Arachis hypogaea* L., is used for direct consumption and also for extraction of cooking oil in several African countries. It is one of major oilseed crop of many sub-tropical and tropical countries. Groundnut is an important source of edible oil (consisting of 48 to 50% oil) and vegetable protein (containing 26 to 28% protein). Oleic and linoleic acids content contribute about 75 – 80% of the total fatty acid content and carbohydrates content in groundnut oil ranges

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from 10 to 20% (Sakhare et al., 2018). Adequate storage of groundnut is therefore critical to ensure food security, nutrition and livelihood in developing countries where the population keeps growing. However, stored groundnut often suffers huge losses (Massala, 1997), forcing farmers to sell their groundnut off cheaply soon after harvest and later to buy seed at higher prices. Several factors including previous crop, insects and rodents' attacks, fungal development and synthesis of mycotoxins, contribute to the decrease of groundnut quantity and quality (Manizan et al., 2018; Yoboue et al., 2020). Among these biotic factors, insects cause the most storage losses. The main insect pest of groundnut under tropical climate conditions is the peanut beetle, *Caryedon serratus* (Olivier) (Coleoptera; Bruchidae) (Roubaud, 1916; Davey, 1958; Green, 1959; Delobel, 1995). Its infestation starts in field, but the most serious damages take place during storage (Matokot et al., 1987; Ndiaye and Jarry, 1990; Sembène, 2000). However, other studies suggested that the pods contaminations are due to adults already inhabiting the stores (Green, 1959). This beetle attack both shelled (kernels) and unshelled (pods) groundnut causing huge losses (Oaya et al., 2012), but kernels are more susceptible than pods during storage (Rekha, 2015). The peanut beetle can cause tremendous losses reaching 83% in 4 months in Senegal (Ndiaye, 1991). Females' groundnut bruchid lay their eggs on the surface of ripe pods, then newly hatched larvae bore into kernels and feeds on the embryo and endosperm and damage are usually poorly visible. Its infestation leads to reduction in weight, nutritive value and also affects the quality of oil and seed germination. The heat and moisture generated by the insects facilitate secondary contaminations by fungi and bacteria (Delobel and Tran, 1993). These fungi, particularly *Aspergillus flavus* Link, produce carcinogenic substances such as aflatoxin (Gillier and Bockelée-Morvan, 1979), causing serious problems for consumer health (consumed part) and for export of African groundnut. Pest management actions taken for these pests were the use of chemical insecticides (powdering and fumigation) (Guèye, 2000), bio-insecticides (Thiaw and Sembène, 2010; Thiaw et al., 2015) and hermetical storage in appropriate rooms or containers. However, the problems associated with synthetic insecticides and fumigants (detrimental impact on human health, environmental safety and pest resistance) (Subramanyam and Hagstrum, 1995) necessitated alternate measures for protection of stored products. In addition, most farmers in developing countries cannot afford hermetic storage structures and have not access to selective and more environment-friendly pesticides due to availability and cost.

Caryedon serratus has wide range of wild hosts Cesalpinaceae including *Bauhinia rufescens* Lam., *Cassia sieberiana* DC., *Piliostigma reticulatum* (DC) Hochst, *Tamarindus indica* L., *etc*, which favor the field pods infestation (Sembène, 2006). The field environment strongly influences the initial pods infestation (Ouedraogo et al., 2010) and can be used for an efficient management strategy of the pest to reduce groundnut losses in storage. In this context, the present study aimed at (1) assessing the variability of field pods infestation by *C. serratus* on sites of different pedoclimatic characteristics and at (2) evaluating the losses in laboratory storage.

MATERIALS AND METHODS

Study sites

Groundnut samples were collected in Bambey, Sandiara, Kaffrine, Coki, Keur Baka and Keur Ayib sites. These sites are within the Senegalese groundnut basin, which located in West zone of Senegal between latitudes 13º and 14º North and longitudes 14º and 17º West.

Evaluation of sites pedoclimatic characteristics

To measure the field soil pH and moisture content (humidity) and the photoperiodicity, a device with three measures "THREE WAY SOIL METER" was used. In each site, the probes were inserted in soil of five fields at least 5 km apart. The recorded data by the three-way soil meter were collected every 24 hours.

Pod infestation assessment

Two groundnut pod samples were collected in several fields of each site in November 2017. The collected pods were placed in glass jars (5 L) aerate with lid mesh (2 mm) and brought to the Entomology and Acarology laboratory of Cheikh Anta Diop University (Dakar, Senegal). Once at the laboratory, three subsamples of 100 pods were used per glass jar for the egg counting. Each of groundnut pods was observed under an illuminant lamp (220 volts) and the number of eggs laid by groundnut bruchids was counted. Three other subsamples of 100 pods were placed separately in aerate glass jars with lid mesh (2 mm) and incubated in insectarium at room temperature (25-35°C) and 70 - 80% relative humidity. After four months of insectarium storage, emerged adults were counted and kernels were sorted into 'damaged' and 'undamaged'. Then, the following parameters were determined.

1. Number of eggs laid (oviposition)
2. Insect progeny emerged (live and dead insects)
3. Weight of emerged insects
4. Survival rate (reproductive success):

$$\% S = \frac{Number\_eggs\ laid}{Number\_emerged\ insects} x\ 100$$

5. Percentage of attacked kernels:

$$\% Attack = \frac{Number\_attacked\ kernels}{Number\_total\ kernels}\ x\ 100$$

6. Percentage of kernel weight loss:

$$\% Weight\ loss = \frac{Initial\ weight - Final\ weight}{Initial\ weight}\ x\ 100$$

Statistical analyses

Data were analyzed using R software (R-3.0.0 and R-3.4.1, packages ade 4, rgl, ggplot 2, grid, FactoMineR, devtools, factoextra, mclust, Hmisc, readxl and stats) following recommendations of Bloomfield (2014). Normality assumption and homogeneity of variances were tested using Shapiro-Wilk's test and Bartlett's test, respectively. Given that all series followed normal distribution and had homogeneous variance, the effect of site on groundnut field infestation (oviposition), progeny, emerged insects weight, survival rate, damage and kernel losses were performed by one-way analysis of variance (ANOVA) followed by Tukey's HSD (honestly significant difference) test for multiple comparison of means. A $p < 0.05$ was considered statistically significant.

Correlation matrix (Spearman's correlation) and multivariate analyses such as Principal Component Analysis (PCA) and Factorial Discriminant Analysis (FDA) were performed to assess the effect of sites pedoclimatic characteristics on pods initial infestation. A variable was considered as Principal Component (PC) when its contribution on one of PCA axes construction was greater than 11.11% (average contribution, according to Elbow criterion). The FDA was performed with the PC obtained. The number of factorial axes for PCA was chosen according to Elbow criterion which enabled to obtain the maximum of inertia with a minimum of factorial axes.

RESULTS

Pedoclimatic characteristics of the sites

The data presented in the Table 1 revealed that the sites in which groundnut pods were collected had a significant difference ($P < 0.01$) on pedoclimatic characteristics. The field soil pH of Bambey (7.56±0.05), Kaffrine (7.56±0.05) and Sandiara (7.58±0.04) are higher than that of Coki (7.44±0.05). The field soils of Kaffrine (2.14±0.05%) are more humid, while those of Coki, Keur Ayib and Sandiara are the least humid (1.12±0.08, 1.2±0.07 and 1.24±0.05%, respectively). The photoperiodicity was higher in Coki (2060±41.83 photons), and Keur Ayib (2060±7.07 photons) and lower in Bambey and Keur_Baka (1938±8.37 photons).

Reproductive dynamics of *C. serratus*

Reproductive parameters of groundnut bruchid are summarized in Table 2. There were significant differences (P < 0.001) among the sites for all evaluated parameters. Groundnut pods were infested in the field with *C. serratus* at all sites. However, the infestation is higher on Kaffrine pods (43.33±2.31 eggs / 100 pods), followed by those of Coki (35.67±1.53 eggs / 100 pods). The emergence of first progeny (F_1) records more insects for Kaffrine pods (29.00±1.00 adults / 100 pods) followed by those of Keur Baka (23.33±1.53 adults / 100 pods). The survival rate of insect is higher with the pods of Keur Baka (88.58±0.61% of the eggs), then those of Kaffrine (66.98±1.93% of the eggs). The weight of adults emerged from Sandiara pods (6.55±0.02 g / 20 adults) is higher than that of adults from Bambey (6.51±0.02 g / 20 adults) and Keur_Ayib (6.45±0.01 g / 20 adults).

Shelled groundnut damage and losses

The damage and losses inflicted to groundnut kernels by *C. serratus* (Figure 1) varied significantly (P < 0.001) across the sites. The percentage of attacked kernels ranged between 56.44±2.25 to 79.56±2.55%. Sandiara, Keur Baka and Coki recorded highest kernel attacks (79.56±2.55, 79.17±3.73 and 75.47±2.06%, respectively). Conversely, lowest kernel attack was recorded on Bambey groundnut (56.44±2.25%). For groundnut kernel losses, the percentage of weight loss ranged between 14.07±1.40 to 22.42±1.80%. The groundnut kernels of Kaffrine, Coki and Keur Baka showed the severest losses (22.42±1.80, 19.98±0.06 and 18.26±1.60% kernel weight loss, respectively).

Relation between assessed variables

Binary correlations between variables

The matrix showed significant binary correlations between pedoclimatic characteristics, beetle reproductive parameters and kernels damage and losses (Table 3). The field soil humidity was positively and significantly correlated to emerged progeny (rho = 0.499*) and survival rate (rho = 0.576*), and no-signicantly correlated to kernel weight loss (rho = 0.406). Kernel weight loss was positively correlated to number of eggs laid (rho = 0.801***) and emerged progeny (rho = 0.591**). Emerged progeny was positively correlated to survival rate (rho = 0.742***) and kernel attack (rho = 0.469*). The emerged adults' weight was correlated to kernel attack (rho = 0.505*).

Multivariate analyses of variables

The PCA revealed that the first axis (37% of information) and the second axis (20.8% of information) with 57.8% total inertia best explained variability (Figure 1). A positive relationship was observed between field soil pH, field soil humidity and survival rate. These variables were negatively correlated to photoperiodicity and kernel attack.

Field soil pH, emerged adults' weight and percentage of attacked kernels had contribution of less than 11.11% on PCA axes construction. Therefore, they were not considered as PC and were excluded from the FDA analysis. The FDA conducted with six PC showed 74.7% total inertia (Dim1 = 49.5% and Dim2 = 29.2%). It classified the sites into five groups (Figure 3).

- The Keur Baka site, was characterized by high field soil humidity and high survival rate of eggs laid.
- The Bambey site, was characterized by low egg laying, progeny and kernel weight loss, and low photoperiodicity.
- The group including Sandiara and Keur Ayib sites, was characterized by low field soil humidity and low insect progeny that emerged in groundnut.
- The Coki site, was characterized by high photoperiodicity, low field soil humidity and low survival rate of eggs laid.
- The Kaffrine site, characterized by high egg laying, progeny and kernel weight loss, contained the most susceptible groundnut to beetle.

Table 1: Sites pedoclimatic characteristics.

Site	pH	Humidity (%)	Photoperiodicity (photon)
Bambey	7.56±0.05[a]	1.94±0.05[b]	1920±27.39[c]
Coki	7.44±0.05[b]	1.12±0.08[c]	2060±41.83[a]
Kaffrine	7.56±0.05[a]	2.14±0.05[a]	2020±27.39[ab]
Keur_Ayib	7.52±0.04[ab]	1.2±0.07[c]	2060±7.07[a]
Keur_Baka	7.54±0.05[ab]	1.92±0.08[b]	1938±8.37[c]
Sandiara	7.58±0.04[a]	1.24±0.05[c]	2000±0.71[b]
P-value	*	***	***
ANOVA	$F_{5,24} = 3.58$	$F_{5,24} = 220.6$	$F_{5,24} = 31.76$

ANOVA test: " . " not significant : P ≥ 0.05; " * " Significant : 0.05 > P ≥ 0.01; " ** " very significant : 0.01 > P ≥ 0.001; " *** " highly significant : P < 0.001. Means followed by the same letter are not significantly different (Tukey test, P < 0.05). **pH**: Field soil pH; **Humidity**: Percentage of field soil humidity; **Photoperiodicity**: site photoperiodicity.

Table 2: Reproductive parameters of the peanut beetle in the different site pods.

Site	Oviposition (eggs / 100 pods)	Progeny (adults / 100 pods)	Survival (%)	Insect weight (g / 20 adults)
Bambey	29.67±2.08[c]	13.00±1.00[d]	43.81±0.99[e]	6.51±0.02[b]
Coki	35.67±1.53[b]	15.00±1.00[c]	42.03±1.08[e]	6.52±0.03[ab]
Kaffrine	43.33±2.31[a]	29.00±1.00[a]	66.98±1.93[b]	6.53±0.03[ab]
Keur_Ayib	25.33±0.58[d]	14.67±1.15[cd]	57.85±2.77[c]	6.45±0.01[c]
Keur_Baka	26.33±1.53[d]	23.33±1.53[b]	88.58±0.61[a]	6.54±0.02[ab]
Sandiara	31.33±1.53[c]	16.33±1.53[c]	52.05±0.86[d]	6.55±0.02[a]
P-value	***	***	***	***
ANOVA	$F_{5,12} = 47.5$	$F_{5,12} = 78.19$	$F_{5,12} = 370$	$F_{5,12} = 8.95$

ANOVA test: " . " not significant : P ≥ 0.05; " * " Significant : 0.05 > P ≥ 0.01; " ** " very significant : 0.01 > P ≥ 0.001; " *** " highly significant : P < 0.001. Means followed by the same letter are not significantly different (Tukey test, P < 0.05).
Oviposition: number of eggs laid on 100 groundnut pods; **Progeny**: number of adults emerged on 100 groundnut pods; **Survival**: number of eggs successfully giving adults (reproductive success); **Insect weight**: weight of 20 emerged adults

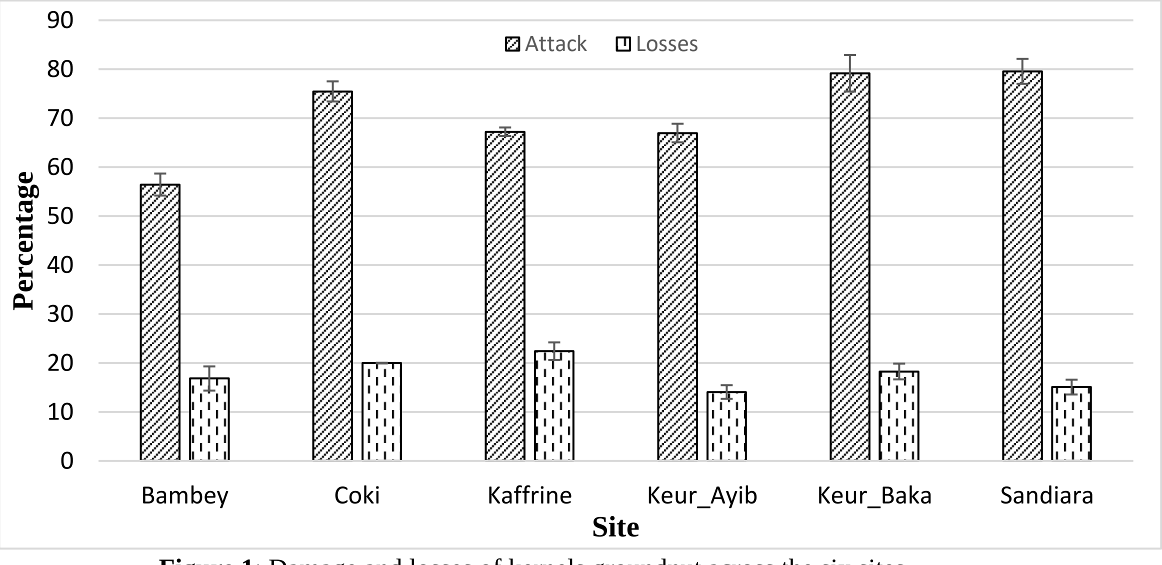

Figure 1: Damage and losses of kernels groundnut across the six sites.

Table 3: Matrix of correlations between pedoclimatic characteristics, beetle reproductive parameters and kernels damage and losses.

Site	pH	Humidity	Photoperiodicity	Eggs	Progeny	Survival	Insect_weight	Attack	Losses
pH	1								
Humidity	0.512*	1							
Photoperiodicity	-0.198.	-0.363.	1						
Eggs	0.068.	0.186.	0.155.	1					
Progeny	0.236.	0.499*	-0.006.	0.398.	1				
Survival	0.353.	0.576*	-0.135.	-0.240.	0.742***	1			
Insect_weight	0.288.	0.142.	-0.210.	0.406.	0.420.	0.129.	1		
Attack	-0.160.	-0.281.	-0.043.	0.042.	0.469*	0.226.	0.505*	1	
Losses	0.030.	0.406.	0.009.	0.801***	0.591**	0.108.	0.292.	0.074.	1

ANOVA test: " . " not significant: P ≥ 0.05; " * " Significant : 0.05 > P ≥ 0.01; " ** " very significant : 0.01 > P ≥ 0.001; " *** " highly significant : P < 0.001.
pH: Field soil pH; **Humidity**: Percentage of field soil humidity; **Photoperiodicity**: site photoperiodicity; **Eggs**: number of eggs laid on 100 groundnut pods (oviposition); **Progeny**: number of adults emerged on 100 groundnut pods; **Survival**: number of eggs successfully giving adults (reproductive success); **Insect weight**: weight of 20 emerged adults; **Attack**: Percentage of kernels attacked (kernels damage percent); **Losses**: Percentage of kernels weight loss

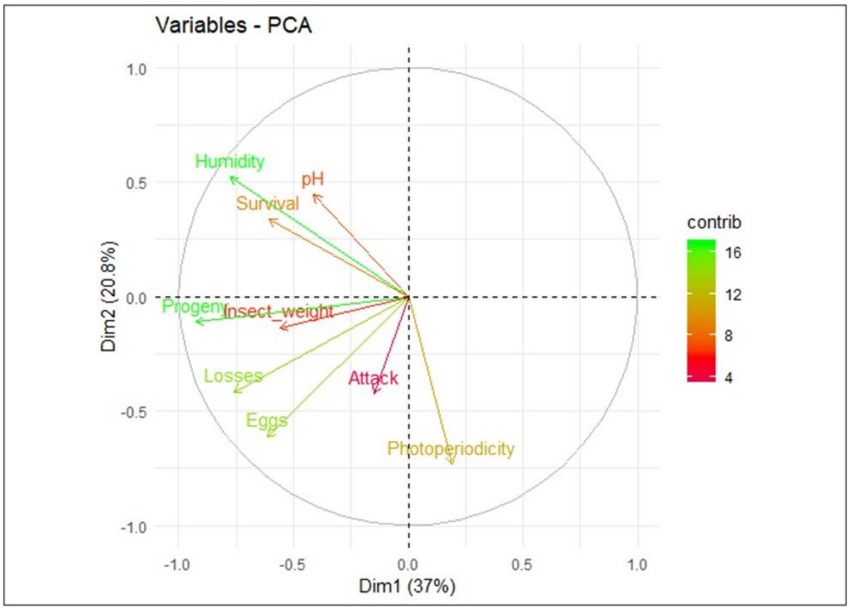

Figure 2: Eigenvalue diagram on PCA of pedoclimatic characteristics, beetle reproductive parameters and kernels damage and losses.

Principal components are colored from red to green on PCA graphic according to their contribution level in the two axes.

pH: Field soil pH; **Humidity**: Percentage of field soil humidity; **Photoperiodicity**: site photoperiodicity; **Eggs**: number of eggs laid on 100 groundnut pods (oviposition); **Progeny**: number of adults emerged on 100 groundnut pods; **Survival**: number of eggs successfully giving adults (reproductive success); **Insect_weight**: weight of 20 emerged adults; **Attack**: Percentage of kernels attacked (kernels damage percent); **Losses**: Percentage of kernels weight loss.

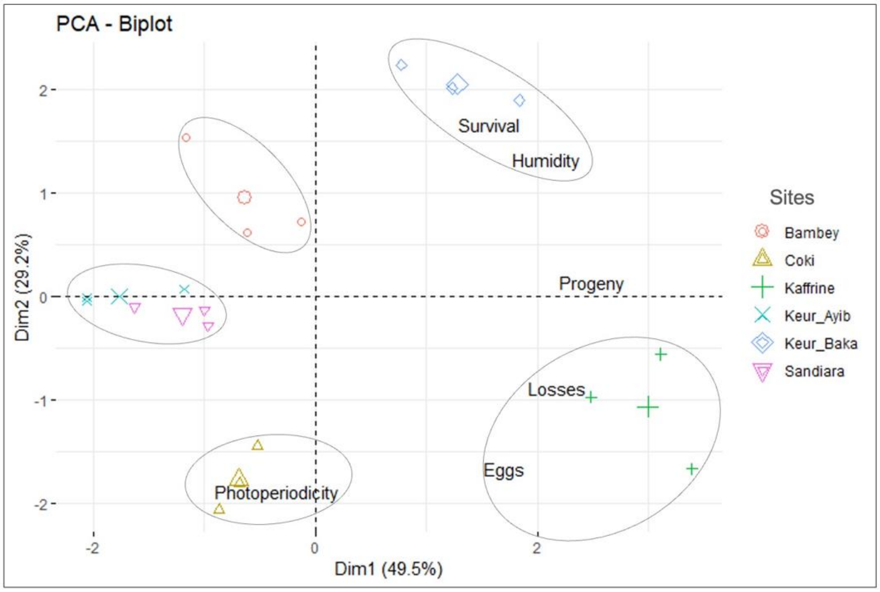

Figure 3: Groundnut field infestation by *C. serratus* based on pedoclimatic characteristics of sites (FDA).

pH: Field soil pH; **Humidity**: Percentage of field soil humidity; **Photoperiodicity**: site photoperiodicity; **Eggs**: number of eggs laid on 100 groundnut pods (oviposition); **Progeny**: number of adults emerged on 100 groundnut pods; **Survival**: number of eggs successfully giving adults (reproductive success); **Insect_weight**: weight of 20 emerged adults; **Attack**: Percentage of kernels attacked (kernels damage percent); **Losses**: Percentage of kernels weight loss.

DISCUSSION

This study showed strong evidence of presence of groundnut bruchid, *C. serratus,* in the Senegalese groundnut basin, particularly at Bambey, Kaffrine, Sandiara, Keur Baka, Keur Ayib and Coki. The infestation of groundnut pods started in field when they were being air-dried and it varied significantly across the different locations. These results corroborate those of Sembène (2000) and Ngom (2014). The current study indicates also that the number of emerged adults is positively related to attacks and weight loss percent of kernels, which is consistent with previous work (Rekha, 2015). At Keur Baka, the beetle had high survival rate (reproductive success) and therefore high progeny. Thus, although egg laying was low on these pods, high weight losses were recorded. This result would be explained by varietal effect which suggested that varieties from this site were more favorable to the insect development. It was reported that varietal factor strongly influences the groundnut susceptibility and *C. serratus* development (Shivalingaswamy and Balasubramanian, 1992; Harish et al., 2012; Sakhare et al., 2018). Pod morphological characters by which *C. serratus* is faced are an important perceptual attribute providing information on nature and composition of food resources (Rekha et al., 2017). The data revealed an influence of environmental factors (pedoclimatic characteristics) on the biology of *C. serratus*. The high field soil humidity (Keur Baka site) allows a good maturation of groundnut kernels. Thus, the well-developed kernels fill the pods and is suitable for an optimal development of *C. serratus* larvae. This would explain the high survival rate of the insect's eggs at this site. On the other hand, in sites with low field soil humidity (Sandiara and Keur Ayib), we recorded low insect progeny that emerged in groundnut. At Coki, the high photoperiodicity led to a decrease in soil humidity and consequently that of larval survival. In Bambey where we had low photoperiodicity, there was low egg laying and insect progeny, and therefore low kernel weight loss. Mishra et al. (2012) and Sujatha et al. (2015) reported significant variations in oviposition and developmental stages duration of *C. serratus* due to environmental factors such as temperature and relative humidity. In fact, these two factors are related to photoperiodicity and soil humidity. In Kaffrine, where we had the most susceptible groundnut pods to the beetle, oviposition and progeny of *C. serratus* were very high, leading to high kernel weight loss. This could be explained by several factors such as high presence of wild host Caesalpinaceae of insect on the site, long duration of pods exposure in field or proximity of fields to previous groundnut storage. The effect of these factors on initial infestation of groundnut pods has been highlighted in several studies (Sembène et al., 2012; Ngom, 2014; Sujatha et al., 2015). Indeed, it was indicated that the preinfestation level of groundnut pods depends on the distance between the heaps groundnut in field and the Caesalpinaceae host trees, and also on the time of exposure during field drying (Ndiaye and Jarry, 1990; Sembène, 2000; Ngom, 2014). Conway (1975) observed an increase of groundnut pods infestation with the exposure time for groundnut drying in fields which were on proximity of insect wild host Caesalpinaceae (*Piliostigma retieularum, Piliostigma thonningii*, *Cassia sieberiana* and *Tamarindus indica*).

Conclusion

In conclusion, we can say the groundnut bruchid, *C. serratus,* is strongly presents in Bambey, Kaffrine, Sandiara, Keur Baka, Keur Ayib and Coki sites of Senegalese groundnut basin. Its infestation starts in field when the pods were drying and varied significantly across the sites. These variations in pod field infestation can be explained by several factors such as cultural practices and field environmental factors which varied greatly between the sites. Taking all these factors into consideration and preliminary results of present study, we can give some recommendations, in order to control this preharvest infestation and reduce groundnut storage losses. Groundnuts should be dried furthest possible from the beetle hosts trees during drying period and shorten the pod exposure time in field as much as possible. Further studies on groundnuts preharvest infestation in relation to locality temperature and wild host Caesalpinaceae abundance are also being performed.

AUTHORS' CONTRIBUTIONS

Conceptualization: DN, BD, MS, CT; Data curation: BD; Formal analysis: BD, DN; Methodology: DN, BD, MS; Resources: BD, DN, SN, AG, CT. Software: DN; Writing – original draft: DN; Writing – review & editing: DN, BD.

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