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Incidence and Populations Fluctuation of *Leucinodes orbonalis* Guen. 1854 (Pyralidae) on African Eggplant (Solanaceae) and Their Relationship with Abiotic Factors

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Abstract: The study on the temporal fluctuation of populations and damage caused by *Leucinodes orbonalis* on African eggplant (*Solanum aethiopicum*) fruits was carried out in the forest region of South Cameroon from June 11 to September 22, 2018. It consisted of incubations of the attacked fruits in the laboratory for the study of *L. orbonalis* abundances and the evaluation of the damage caused by the same pest directly in the field and during each harvest; followed by the correlations with abiotic factors. The results showed that out of 331 incubated fruits for 06 harvests and 02 seasons of study, the average number of adults / fruit of *L. orbonalis* varied significantly from one harvest to another ($F (5, 325) = 27.038$, $p < 0.001$) with a peak of 4.37 ± 0.66 individuals / fruit (N= 2) at the 2nd harvest (in August), and season to season ($F (1, 329) = 15.002$, $p < 0.001$) with a peak of 3.22 ± 0.48 individuals / fruit (N=31) during the short dry season. Damage on *S. aethiopicum* fruits varied significantly from one harvest to another ($F (5, 325) = 27.038$, $p < 0.001$) with a peak of 13.05 ± 4.10% in the first week of harvest in August. This damage did not change from one season to another ($p < 0.659$). Means weight, length and diameter of an incubated fruit varied significantly from one harvest to another ($F (5, 325) = 5,893$; $F (5, 325) = 7.71$ and $F (5, 325) = 7.84$; $p < 0.001$ respectively). The highest means weight, length and diameter were obtained at the 2nd and 3rd harvest with average values of 36.15 ± 6.87g and 40.20 ± 4.40g for the mean weight; 4.03 ± 0.30cm and 3.86 ± 0.15cm for the mean length and 4.15 ± 0.34cm and 4.12 ± 0.20cm for the mean diameter. Study revealed that the mean number of *L. orbonalis* per fruit had a significant positive correlation with mean weight ($r=0.39$, $p < 0.01$), mean length ($r=0.40$, $p < 0.001$) and mean diameter ($r=0.41$, $p < 0.001$) of attacked fruits and multiple regression equations of $y=5.3302x+16.021$, $R^2=0.8172$; $y=0.3103x+2.6544$, $R^2=0.8194$ and $y=0.3684x+2.6037$, $R^2=0.8664$ of weight, length and diameter respectively. Field damage showed a positive and non-significant correlation with precipitation ($r = 0.80$, $p < 0.20$) and a negative and non-significant correlation with mean temperature ($r = -0.737$, $p < 0.262$) and mean relative humidity ($r = -0.632$, $p < 0.367$). These results are of practical significance in designing appropriate strategies for *L. orbonalis* control in eggplant intercropping systems.

Keywords: *Leucinodes orbonalis*, Seasonal Variation, Population, Damage, Correlation

1. Introduction

African eggplant (*Solanum aethiopicum* Linnaeus), member of the Solanaceous family, is one of the most important vegetable crops that is widely cultivated across the African continent especially in West, Central (Southern Cameroon) and East Africa [1-3]. It is an indigenous species that is consumed widely in Cameroon and is a source of cash for rural households in the southern and central regions on our country. The results showed that, African eggplant is a decent source of supplements, minerals, cancer prevention agents, vitamins, dietary fiber and weight training variables and proteins [4-6]. One hundred grams of fruit contains 0.7mg iron, 13.0mg sodium, 213.0mg potassium [7], 12.0mg calcium, 26.0mg phosphorus, 5.0mg ascorbic corrosive and 0.5 International Units of vitamin A and gives 25.0 calories [8, 4]. The nutritional content of African eggplant is comparable to that of tomato, but it has a lower content of vitamin C [9]. Some medicinal properties are attributed to the roots and fruits and they are described as carminative and sedative, and used to treat colic and blood pressure [2]. Production of this crop was estimated at 570.00 t for a cultivated area of 190.00 ha in Ghana in 2004 for a yield of 1.97 t / ha [9]. In 1997, approximately 750 tons of African eggplant fruits were exported from Ghana and this constituted about 5% of total production at that time [10]. However, it is currently estimated that the total national production of garden eggs fruits to be around 30,000 metric tons [9, 11]. Production constraints faced by farmers are multiple and low crop yields are compounded in the long-run by production shocks caused by environmental stresses such as drought, pests and diseases. A number of pests and diseases attack this vegetable crop in the field such as mites, stem borers, fruit borers and flower borers. The damage caused can reduce yields and affect the quality and quantity of the produce [9]. Among the many pest species, the eggplant fruit and shoot borer (ESFB), *Leucinodes orbonalis* Guenée (Lepidoptera: Pyralidae) is the most destructive and cause significant economic damage on *Solanum* spp. [12, 13]. This fruit and shoot borer is one of the most destructive pest on *S. aethiopicum* in Tropical Africa and Southern Cameroon [13]. It is generally depends on eggplant but sometimes turns towards other Solanaceous field crops like potato (*Solanum tuberosum*), tomato (*Lycopersicon esculentum*), pepper (*Capsicum annuum*) and may be on wild hosts [14, 4]. The young larvae of this pest attack both fruits and stems of several species / varieties of *Solanum* spp. [15]. Eggs are laid on various parts of the plant and after hatching, larvae develop in the fruit pulp from which they leave at the pre-nymph stage to pupate in the soil. Egg-laying occurs during night and incubation period ranges from 3-8 days depending of environmental conditions [4]. Larvae bore inside plant shoots and fruits adversely affecting plant growth, yield and fruit quality, and thus making it unfit for human consumption [16]. The yield reduction could be as high as 70% [17, 18, 13]. Yield losses reaching as high as 85-90% have been reported by [19, 20, 21]. Farmers largely follow the chemical method as it produces quick results. High-frequency application is the common scenario [21]. However, these chemicals, in many cases, invited the problems of pesticide resistance, resurgence, secondary pest outbreak, environmental contamination, residual toxicity and toxicity to beneficial organisms and disturbance in homeostasis of natural populations [21, 22]. Because larvae feed and live inside the fruit, they cannot be effectively controlled by contact insecticides, while systemic insecticides are not appropriates for vegetables [13]. Efficient control strategies may associates appropriates use of pesticides with other control technics [14, 15]. The integrated pest management (IPM) strategy for the control of eggplant fruit and shoot borer (EFSB) consists of resistant cultivars, mass trapping, sex pheromone, cultural practical, mechanical, biological control methods, physical and biotechnology control technics and population dynamics [16]. Implementation of these strategies needs a good knowledge of incidence and fluctuation population of *L. orbonalis* in the southern ecosystem. The general objective of this work was to study the incidence and monthly variation of *L. orbonalis* populations on *S. aethiopicum* fruits in relation to seasonality in the forest region of South Cameroon. Specifically, it consisted of: (i) stand out the seasonal fluctuation of emerged populations of *L. orbonalis* on incubated fruits, (ii) evaluate damage on fruits of *S. aethiopicum* due to *L. orbonalis* (iii) stand out the correlation between mean number of adults of *L. orbonalis* emerged from the incubated fruits and the weight and size (length and diameter) of the fruits, finally (iv) to stand out the correlation between the field attack rates due to *L. orbonalis* and abiotic factors.

2. Materials and Methods

2.1. Study Site and Period

Our study was carried out in the campus of the Higher Teacher Training College of the University of Yaoundé I, forest zone of South Cameroon, precisely in the urban area of Yaounde, Central Region. This study site has the following geographical coordinates: Lat. 03° 51'35.5"N; Long. 011° 30'37.1"E; asl. 729m (Figure 1). In the city of Yaounde, which has a population of around 2 million, there is a population density that varies from one locality to another from 14 to 88 inhabitants per square kilometer. The existing habitat is diverse and the degree of urbanization varies from one neighborhood to another [24]. The city of Yaounde is dominated by an equatorial climate of transition to four seasons. The long dry season extending from mid-November to mid-March, the short rainy season from mid-March to the end of June, the short dry season from July to August and the long rainy season from September to mid-November [25]. The study period extended from June to September 2018 (corresponding to the harvest period). The fruit harvest period (which was limited to the fruiting phase) covered two seasons: the short dry season and the long rainy season.

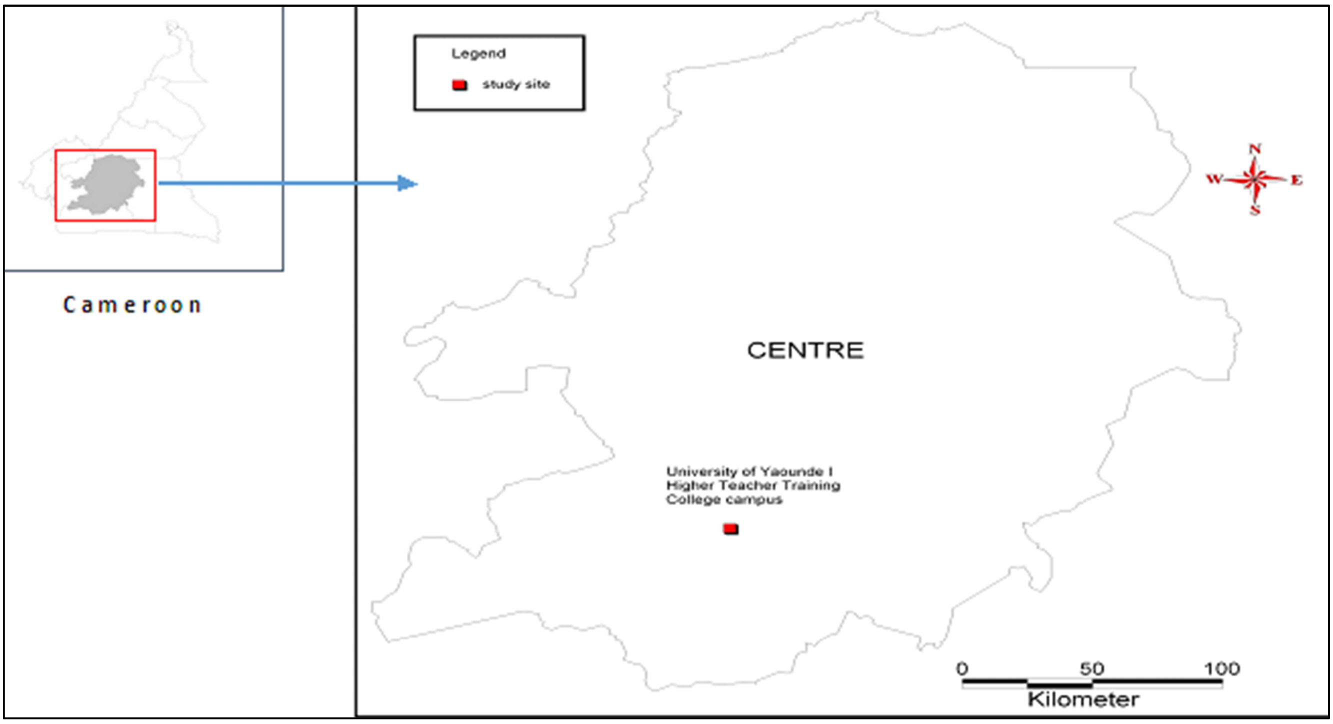


Figure 1. *Study site (Higher Teacher Training College Campus of the University of Yaoundé I, Centre Cameroon).*

2.2. Soil, Geology and Vegetation

Soils derived from the city of Yaoundé are ferralitic on interfluves [26]. The superficial levels of these soils are not only a support but also a reserve of nutrients and water for the plants. The region of Yaounde has a relief characterized by alternating hills and swampy lowlands [24]. The lithological substratum of this city consists of metamorphic rocks of gneissic nature. The vegetation of the city of Yaounde initially included in the so-called semi-deciduous forest estate is strongly degraded because of urbanization [27]. At the phytophysionomic level, the landscape of this city is dominated by deciduous forest [28]. This forest is degraded in places due to human activities. In the Higher Teacher Training College campus, the original vegetation was destroyed in favor of the construction of classrooms. The site that was exploited for our study is a plot that has never been used for a crop. The dominant vegetation in this setting was Sissongo (*Pennisetum purpureum*) and *Mimosa pudica*. Tree vegetation does not exist here.

2.3. Weather Data

Rainfall and temperature data for the year 2018 as part of our study were provided by Weatherbase.com. According to these data, the city of Yaoundé received 1546.9 mm of total rainfall and had an average annual temperature of 23.3°C. January was the hottest month with an average temperature of 24.4°C and August, the coolest month with an average temperature of 22.2°C. In the city of Yaoundé, most of the rain fell in October with 299.7mm of rainfall and the least rain fell in December with an average of 20.3mm of precipitations.

2.4. Biological Material

In this work, the biological material consisted of the plants of a single variety of *Solanum aethiopicum*: the local zong variety, whose seeds were extracted from fruits from the Mokolo market at Yaounde, Central Region of Cameroon. Eggplant before flowering and fruiting phase in the experimental field are shown in Figure 2.

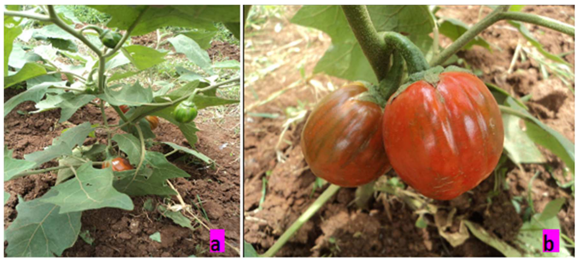


Figure 2. *(a): Plant of S. aethiopicum (eggplant var. Jakatu), (b): Mature young fruits during fruiting phase.*

2.5. Experimental Design

The experimental space, left fallow for two years, was weeded, cleaned and plowed two weeks before transplanting. On this parcel, four (04) ridges of local variety of eggplants were prepared. Les quatre billons servant à l'étude s'étendaient sur une superficie de 30 m^2. Each ridge was 4 m long by 1.5 m wide with 10 young plants transplanted on two lines, including five plants per line, with a spacing of 0.8 m between plants of the same line and 1 m between plants of two different lines. The spacing between two ridges was 0.5 m. We obtained a total of 40 plants to sample.

2.6. Data Collection

2.6.1. Seasonal Fluctuation of Emerged Populations of Leucinodes orbonalis

The harvested fruits and attacked in the field were incubated in transparent boxes of 15cm x 8cm x 4cm in the laboratory of Zoology of the Higher Teacher Training College of the University of Yaoundé I. These incubated fruits contained young larvae of Leucinodes orbonalis. Each box containing a single attacked fruit and was covered with a fine mesh fabric to prevent escape of emerging adults. Emerging adults of L. orbonalis were counted by incubated fruit, by harvest and by season in order to highlight the seasonal fluctuation of their populations.

2.6.2. Evaluation of Attack Rates Due to Leucinodes orbonalis from Fruits Harvests, Counts with Larval Exit Holes

To evaluate attack rates due to *L. orbonalis*, we have regularly harvested fruit during the period from fruit ripening to the end of the fruiting period (end of harvest). The harvested fruits were separated into healthy fruits and attacked fruits. The attacked fruits by *L. orbonalis* were recognizable in the field by the holes corresponding to the points of entry of the larvae of stage 1 or exit of the larvae of last stage. Healthy fruits were those with no lesions caused by *L. orbonalis*.

The attack rate (Txi) due to *L. orbonalis* was calculated from the ratio: number of fruits attacked by *L. orbonalis* (n) on the total number of fruits per plant during each harvest (N)*100, according to the formula:

$$\text{PDI or AR } (\%) = (ni/N)*100$$

Where: *PDI/AR* = Percent Index Damage or Attack rate (%);
ni = Total number of attacked fruits;
N = Total number of fruits on plant.

Fruit attack rates due to *L. orbonalis* were evaluated according to the harvests and seasons of the year throughout the study period. It should be noted that attack rates were evaluated during harvest and during field observations; the fruits with exit holes were evaluated directly in the field. Harvested fruits (mature and consumable), in addition to the presence of the holes, were dissected before being incubated to reassure themselves of the presence of *Leucinodes orbonalis* larvae.

2.6.3. Influence of Weight, Length and Diameter of the Attacked Fruit of Adults of Leucinodes orbonalis

During the incubations of the attacked fruits following the harvests, the weight and the size (length and diameter) of each fruit were taken before each incubation. Thus, the average weight and mean size (mean length and diameter) of the incubated fruits were correlated with the abundances of emerging *L. orbonalis* in order to note the influence of these parameters on their populations. The average number of *L. orbonalis* individuals per kg of fruit was also noted. The weight of the fruit was taken using a “Philips” brand gram scale and the size taken using a Vernier caliper.

2.6.4. Influence of Temperature and Precipitation on Average Field Damage Due to Leucinodes orbonalis

Average field damage (following observations and counts of fruits with holes in or out of *L. orbonalis* larvae) was correlated with total rainfall, mean temperature and mean relative humidity of the study site.

2.7. Data Analysis

The data were encoded using the Excel 2003 software as well as to calculate the average abundances of *L. orbonalis* adults obtained per incubated fruit. After a logarithmic transformation of the abundances, we compared the averages using the Analysis of Variances (ANOVA) test contained in the GLM procedure of the "*Statistica*" software version 8.0 (2007), followed by a multiple comparison of the averages 2 to 2 by a Tukey HSD test if there are significant differences. The Spearman correlation coefficient r between two variables was calculated for mean weight and size (length and diameter) of the incubated fruits and average abundance of *L. orbonalis*. All the results were assessed at the significance level $p < 0.05$.

3. Results

3.1. Temporal Fluctuation of Emerged Leucinodes orbonalis Populations on Eggplant Fruits

3.1.1. Fluctuation of Leucinodes orbonalis Populations According to the Harvests

The emerged populations of *Leucinodes orbonalis* during incubations showed significant differences from one harvest to another (F_{Harvest} (5, 325) = 27.038, $p < 0.001$). They were higher at the 2nd harvest (in August) with an average value of 4.37±0.66 individuals per fruit per harvest (Min=2.98, Max=5.75, N=12) corresponding to the short dry season (Table 1). This number decreases progressively with the arrival of the rains at the 6th harvest (September) with a lower mean abundance of 1.19 ± 0.08 individuals per fruit per harvest (Min=1.02, Max=1.36, N=67) (September) corresponding to the long rainy season. The average number of individuals (cumulative harvests) was 2.43±1.33 individuals per fruit (Min=1.88, Max=2.98) (Table 1).

Table 1. *Mean (±SE) number of Leucinodes orbonalis per fruit per harvest (H).*

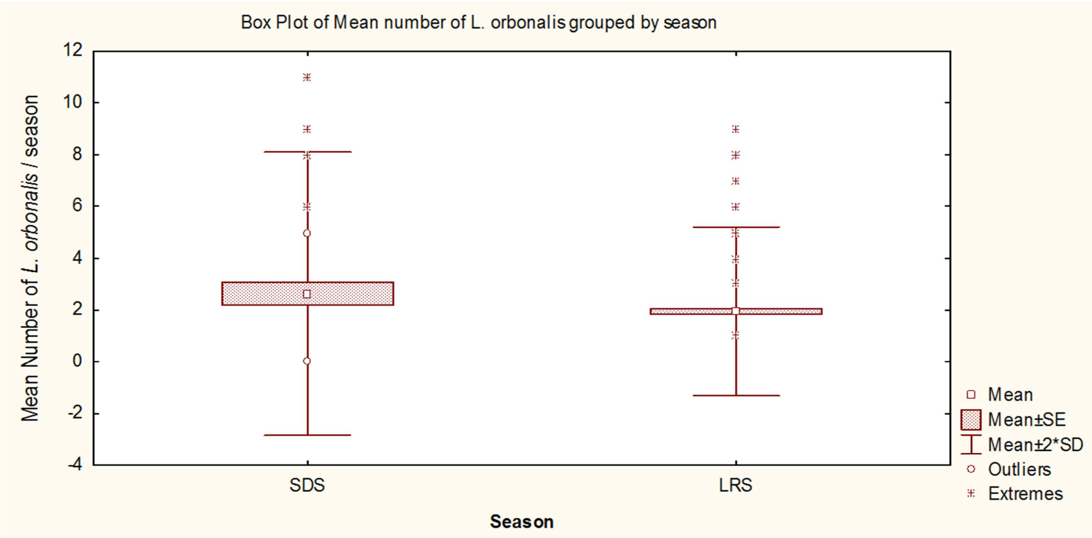
Harvests	M.N of *Leucinodes orbonalis*/fruit/harvest	M.N of *L. orbonalis* (-95.00%)	M.N of *L. orbonalis* (+95.00%)	N
H1	1.41±0.19 *a (*0.99-1.84)	0.99	1.84	12
H2	4.37±0.66 *b (*2.98-5.75)	2.98	5.75	19
H3	4.03±0.38 *b (*3.25-4.80)	3.25	4.80	35
H4	2.00±0.15 *a (*1.71-2.31)	1.71	2.31	113

Harvests	M.N of *Leucinodes orbonalis*/fruit/harvest	M.N of *L. orbonalis* (-95.00%)	M.N of *L. orbonalis* (+95.00%)	N
H5	1.59±0.12 *a* (1.35-1.83)	1.35	1.83	85
H6	1.19±0.08 *a* (1.02-1.36)	1.02	1.36	67
Mean±SD	2.43±1.33	1.88±0.94	2.98±1.74	55.16±38.02

Note: H=Harvest, M.N=Mean number, Std. Err=Standard Error, SD=Standard Deviation, Mean number of *Leucinodes orbonalis*/fruit followed by the different letter (s) differ significantly at (p<0.05, HSD Tukey *test*) and Mean Number of *Leucinodes orbonalis*/fruit followed by the common letter (s) do not differ significantly (p≥0.05, HSD Tukey *test*).

3.1.2. Fluctuation of Leucinodes orbonalis Populations According to the Seasons

The emerged populations of *Leucinodes orbonalis* showed significant differences from one season to the next (F_{Season} (1, 329) = 15.002, p <0.001). The average number of *L. orbonalis* individuals was higher during the short dry season with an average value of 3.22 ± 0.48 individuals per fruit per season (Min = 2.24, Max = 4.21, N = 31) and lower during the large rainy season with 1.94 ± 0.09 individuals per fruit per season (Min = 1.75, Max = 2.12, N = 300) (Figure 3). Rainfall significantly reduced the number of *Leucinodes orbonalis* individuals during this study.



Note: SDS=Short Dry Season; LRS=Long Rainy Season.

Figure 3. *Mean (±SE) number of Leucinodes orbonalis per fruit per season.*

3.2. Damage Index on Solanum aethiopicum Fruits Due to Leucinodes orbonalis

3.2.1. Damage Index (ID) Per Harvest

The average damage due to *L. orbonalis* did not vary significantly from one harvest to another ($F_{Harvest}$ (5, 332) = 0.550, p = 0.737) as well as the average total number of fruits per plant ($F_{Harvest}$ (5, 87) = 0.78, p = 0.57). On the other hand, the average total number of attacked fruits per plant varied significantly ($F_{Harvest}$ (5, 86) = 5.18, p <0.001). Indeed, for an average value of the total number of harvested fruit of 8.00 ± 1.96 / plant (Min = 2.94, Max = 13.05, N = 12), the highest average attack rate due to *L. orbonalis* was 13.05 ± 4.10% (Min = 4.01, Max = 22.09, N = 12) corresponding to the short dry season (August) (Table 2). The lowest average attack rate was 9.04 ± 2.49% (Min = 4.07, Max = 14.01, N = 85) for an average value of the total number of harvested fruit of 11.07 ± 1.73 (Min = 7.33, Max = 14.80, N = 85) (Table 2).

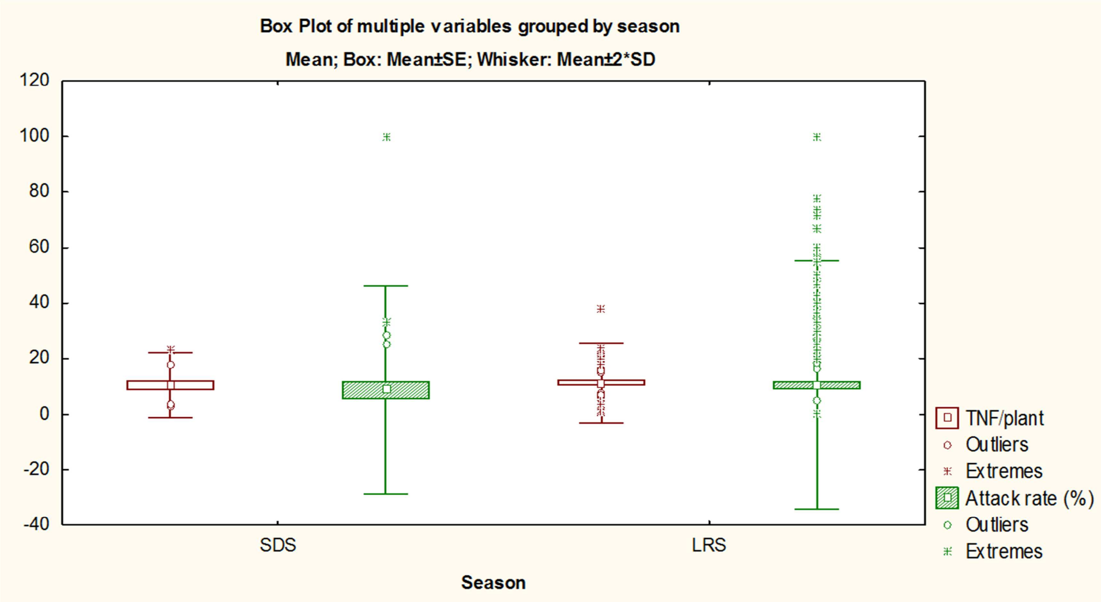
Table 2. *Mean attack rate (%) due to Leucinodes orbonalis on harvested fruits.*

Harvests	M.T.N.F/plant/ (-95%-+95%)	M.T.N.A.F/plant/ (-95%-+95%)	M.A.R (%) (-95%-+95%)	N
H1	8.00±1.96 (2.94-13.05)	2.00±0.44 (0.85-3.14)*a*	13.05±4.10% (4.01-22.09)	12
H2	12.11±2.03 (7.42-16.79)	2.37±0.56 (1.03-3.71)*a*	9.94±4.00% (1.30-15.20)	19
H3	13.64±1.84 (9.74-17.55)	2.05±0.22 (1.59-2.52)*ac*	9.43±2.34% (4.66-14.20)	35
H4	10.36±1.51 (7.23-13.48)	4.52±0.50 (3.48-5.55)*ad*	12.80±2.56% (7.73-17.88)	113
H5	11.07±1.73 (7.33-14.80)	6.07±1.24 (3.37-8.76)*bd*	9.04±2.49% (4.07-14.01)	85
H6	11.00±1.44 (7.99-14.00)	3.04±0.52 (1.94-4.14)*a*	9.19±1.76% (5.67-12.72)	67
Mean±SD	11.03±1.79	3.34±1.57	10.57±1.76%	55.16±36.02

Note. H=Harvest, Std. Err=Standard Error; SD=Standard Deviation; M.T.N.F/plant/harvest=Mean total number of fruits per plant per harvest; M.T.N.A.F/plant/harvest=Total number of attacked fruits/plant/harvest; MAR=Mean attack rate, Mean number of T.N.A.F/plant followed by the different letter (s) differ significantly (p<0.05, HSD Tukey *test*) and Mean number of T.N.A.F/plant followed by the common letter (s) do not differ significantly (p≥0.05, using HSD Tukey *test*).

3.2.2. Damage Index Per Season

The damage due to *Leucinodes orbonalis* did not vary significantly from one season to another (F_{Season} (1, 336) = 0.194, p <0.659). They were 8.87 ± 3.03% (Min = 2.72, Max = 15.03, N = 38) in the short dry season and 10.54 ± 1.28% (Min = 8.00, Max = 13.07, N = 300) in the long rainy season. The total number of fruit per plant per season also did not vary significantly from one season to another (F_{Season} (1, 336) = 0.219, p <0.64). This average number was 10.46 ± 1.50 fruits per season (Min = 7.24, Max = 13.68, N = 15) in the short dry season and 11.38 ± 0.80 fruits per season (Min = 9.77, Max = 12.99, N = 78) in the long rainy season (Figure 4).



Note: SDS=Short Dry Season; LRS=Long Rainy Season; TNF=Total Number of Fruits

Figure 4. *Mean (±SE) total number of fruit per plant and attack rate due to Leucinodes orbonalis on eggplant fruits per season.*

3.3. Correlation Matrix Between Mean of Leucinodes orbonalis Populations Per Fruit and Means Weight, Length and Diameter

3.3.1. Average Weight, Length and Diameter of an Incubated Fruit per Harvest

Mean weight, mean length, and mean diameter of an attacked and incubated fruit varied significantly from one harvest to another (F (5, 325) = 5.893, p <0.001; F (5, 325) = 7.71, p <0.001 and F (5, 325) = 7.84, p <0.001 respectively). The highest average weight, mean length and mean diameter were obtained at the second and third harvests with mean values of 36.15 ± 6.87 g (Min = 21.71, Max = 50.59, N = 19) and 40.20 ± 4.40 g (Min = 31.34, Max = 49.14, N = 35) for the average weight; 4.03 ± 0.30 cm (Min = 3.39, Max = 4.67, N = 19) and 3.86 ± 0.15 cm (Min = 3.54, Max = 4.19, N = 35) for the average length and 4.15 ± 0.34 cm (Min = 3.42, Max = 4.88, N = 19) and 4.12 ± 0.20 cm (Min = 3.71, Max = 4.53, N = 35) for the average diameter of the attacked fruits corresponding to the end of the short dry season (end of August) and at the beginning of the long rainy season (early September) (Table 3). The lowest values for the average weight, length and diameter of the attacked fruit were obtained during the last harvest, i.e 16.65 ± 2.27 g (Min = 12.11, Max = 21.19, N = 67); 2.68 ± 0.14 cm (Min = 2.39, Max = 2.96, N = 67) and 2.65 ± 0.14 cm (Min = 2.35, Max = 2.94, N = 67) respectively (Table 3).

Table 3. *Means weight (g), length (cm) and diameter (cm) variation of incubated fruits per harvest.*

Harvests	M.W (g) of attacked fruits	M.L (cm) of attacked fruits	M.D (cm) of attacked fruits	M.N of *L. orbonalis* per fruit	N
H1	23.83±3.70*ad* (15.68-31.97)	3.41±0.27*a* (2.81-4.01)	3.27±0.30*ab* (2.61-3.93)	1.41±0.19*a* (0.99-1.84)	12
H2	36.15±6.87*ab* (21.71-50.59)	4.03±0.30*ab* (3.39-4.67)	4.15±0.34*ad* (3.42-4.88)	4.37±0.66*b* (2.98-5.75)	19
H3	40.20±4.40*ab* (31.25-49.14)	3.86±0.15*ab* (3.54-4.19)	4.12±0.20*ad* (3.71-4.53)	4.03±0.38*b* (3.25-4.80)	35
H4	29.56±2.41*a* (24.77-34.35)	3.27±0.11*a* (3.05-3.49)	3.44±0.12*a* (3.19-3.68)	2.00±0.15*a* (1.71-2.31)	113
H5	25.37±2.31*ac* (20.79-29.99)	3.08±0.12*ac* (2.85-3.32)	3.22±0.15*acb* (2.91-3.52)	1.19±0.12*a* (1.35-1.83)	85
H6	16.65±2.27*adc* (12.11-21.19)	2.68±0.14*adc* (2.39-2.96)	2.65±0.14*ab* (2.35-2.94)	1.19±0.08*a* (1.02-1.36)	67
Mean±SD	28.62±8.18	3.38±0.47	3.47±0.54	2.43±1.33	55.16

Note. H=harvest, Std. Err=Standard Error; S.D=Standard Deviation, M.W=Mean weight, M.L=Mean length, M.D=Mean diameter, M.N=Mean number, Mean number of T.N.A.F/plant followed by the different letter (s) differ significantly (p<0.05, HSD Tukey *test*) and Mean number of T.N.A.F/plant followed by the common letter (s) do not differ significantly (p≥0.05, HSD Tukey *test*).

3.3.2. Correlation Matrix

The data in Table 4 indicated that the mean number of *L. orbonalis* per fruit had a significant positive correlation with mean weight (r=0.39, *p*<0.01), mean length (r=0.40, *p*<0.001) and mean diameter (r=0.41, *p*<0.001) of attacked fruits. Study reveal a significant positive correlation between mean weight (r=0.95, *p*<0.001) with mean length (r=0.95, *p*<0.001) and mean diameter (r=0.96, *p*<0.001); significant positive correlation between mean length and mean diameter (r=0.92, *p*<0.001) of attacked fruits during June to September 2018 (Table 4).

Table 4. *Correlation matrix between means weight (g), length (cm) and diameter (cm) of incubated fruits and mean number of Leucinodes orbonalis per fruit during the period running from June to September 2018.*

Pair of Variables		Agronomic characters of fruits		
		Mean weight (g) of attacked fruits	**Mean length (cm) of attacked fruits**	**Mean diameter (cm) of attacked fruits**
Mean Number of *L. orbonalis*	Valid N	331	331	331
	r-Value	0.39**	0.40***	0.41***
	T(N-2)	7.88	7.86	8.18
	p-Level	<0.01	<0.001	<0.001
Mean weight (g) of attacked fruits	Valid N		331	331
	r-Value		0.95***	0.96***
	T(N-2)		57.15	59.21
	p-Level		<0.001	<0.001
Mean length (cm) of attacked fruits	Valid N			331
	r-Value			0.92***
	T(N-2)			43.36
	p-Level			<0.001

Note. *=Significant at the p<0.05 level; **= Significant at the p<0.01 level; ***=Significant at the p<0.001 level; ns=non-significant at p≥0.05, r=Coefficient of correlation.

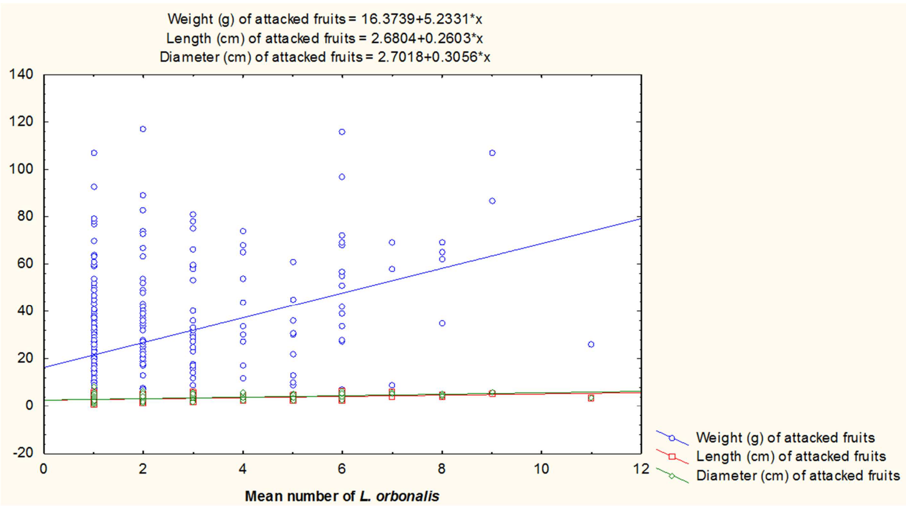
3.3.3. Multiple Regression Equations of Mean Number of Leucinodes orbonalis Per Fruit and Mean Weight, Mean Length and Mean Diameter of Eggplant Fruits

The multiple regression analysis indicated that the physical parameter of attacked fruit contributed for 81.72% (for mean weight), 81.94% (for mean length) and 86.64% (for mean diameter) of the mean number of *L. orbonalis* population / fruit during August to September 2018 (Table 5 and Figure 5).

Table 5. *Multiple regression equations of mean number of Leucinodes orbonalis population per fruit and mean weight, mean length and mean diameter.*

Pair of Variables		Agronomic characters of fruits			MN of *L. orbonalis*/fruit
		Mean weight (g) of attacked fruits	**Mean length (cm) of attacked fruits**	**Mean diameter (cm) of attacked fruits**	
MN of L. orbonalis/ fruit	Y	5.3302x+16.021	0.3103x+2.6544	0.3684x+2.6037	x
	R^2	0.8172	0.8194	0.8664	1.00
	p-Level	0.01**	0.001***	0.001***	

Note. ***=Significant at p<0.001 level, **=Significant at p<0.01 level ns=non-significant at p≥0.05, R^2=Co-efficient of determination, Y=ax+b (a and b constants) = regression equation, p=Significative level, MN=Mean number.



Note: Y=ax + b (a and b, constant)

Figure 5. *Multiple regression equations of mean number of Leucinodes orbonalis and mean weight, mean length and mean diameter.*

3.3.4. Mean Weather Parameters and Mean Attack Rate (%) on Field Due to Leucinodes orbonalis and Correlation Between Abiotic Factors and Attack Rate

Field damage due to *Leucinodes orbonalis* varied month to month (p<0.05) with the highest values of 9.50% and 10.54% attacks in June and September corresponding to the rains periods (small and long rainy seasons respectively). The lowest values were recorded in July and August with 8.87% and 7.79% of attacks corresponding to the short rainy season (Table 6).

Table 6. *Means numbers of abiotic factors and attack rate on field and correlation between abiotic factors and attack rate (%) due to Leucinodes orbonalis.*

Sampling Months	Sampling date	Abiotic factors			Attack rate (%) due to *L. orbonalis*
		Total Rainf. (mm)	Mean Temp. (°C)	Mean Relative Hum. (%)	
June	16 to 30/06/18	150.3	22.2	86.4	9.50bc
July	14 to 28/07/18	50.2	22.4	86.3	8.87ba
August	11 to 25/08/18	70.4	22.3	86.5	7.79a
September	01 to 22/09/18	200.3	22.2	86.3	10.54c
Mean±SD		117.5±64.75	22.3±0.08	86.4±0.09	9.17±1.07
Valid N		4	4	4	4
r-Value		0.80	-0.737	-0.632	1.00
T(N-2)		1.88	-1.54	-1.15	
p-Level		0.200	0.262	0.367	

Note. SD=Standard deviation, r=Co-efficient of correlation. The Mean number of attack rates affected of the different letters are significantly different according HSD Tukey *test* at the threshold of 5%, 18=2018.

3.3.5. Correlation and Multiple Regression Equations Between Abiotic Factors and Attack Rate Due to Leucinodes orbonalis on Field

The multiple regression analysis indicated that the weather parameter contributed for 75.08% (for total rainfall), 36.36% (for mean temperature) and 54.62% (for mean relative humidity) of the attack rate due to *L. orbonalis* on field during June to September 2018 at Yaoundé (Table 7 and Figure 6).

Table 7. *Multiple regression equations between abiotic factors and attack rate (%) due to Leucinodes orbonalis on field.*

Pair of Variables		Weather parameters			Attack rate (%) due to *L. orbonalis*
		Total Rainfall (mm)	Mean Temperature (°C)	Mean Relative Humidity (%)	
Attack rate (%) due to *L. orbonalis*	Y	0.0143x+7.4942	-7.2545x+170.77	-8.8909x+777.13	x
	R^2	0.7508	0.3636	0.5462	1.00
	p-Level	0.20ns	0.262ns	0.367ns	

Note. ns=non-significant at $p \geq 0.05$, R^2=Co-efficient of determination, Y=ax+b (with a and b constants) = regression equation, p=significant level

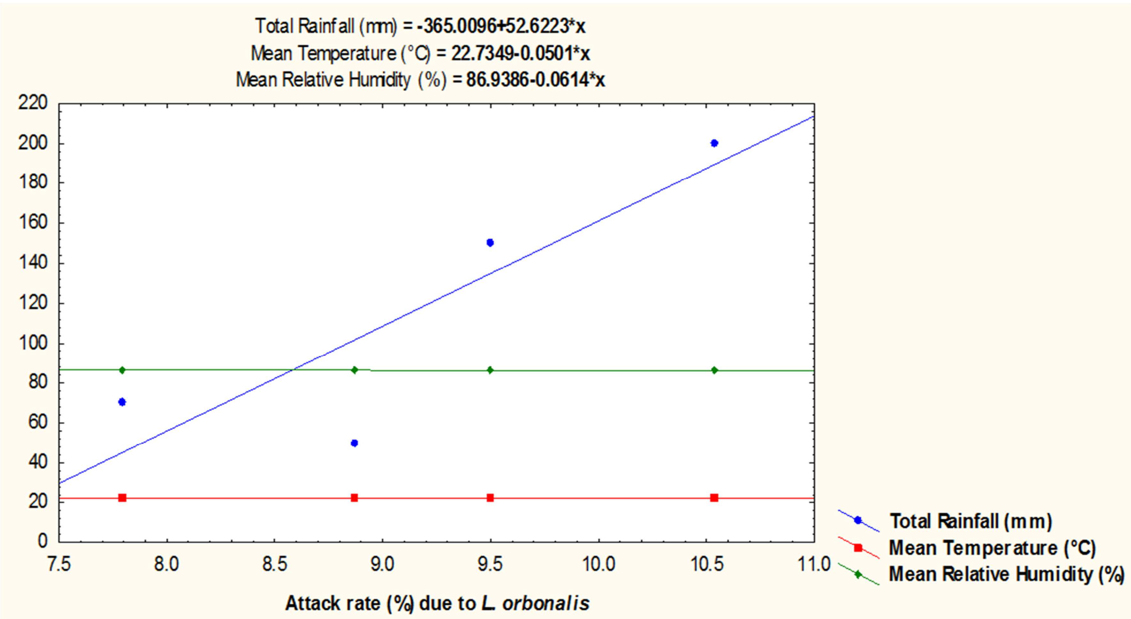


Figure 6. *Multiple regression equation with mean attack rate due to Leucinodes orbonalis and abiotic factors.*

4. Discussion

4.1. Temporal Fluctuation of Leucinodes orbonalis Population on Eggplant Fruit

The emerged populations of *Leucinodes orbonalis* per incubated fruit fluctuated significantly from one harvest to another ($p < 0.001$) with higher mean abundances at the 2nd harvest (August) with 4.37 individuals, corresponding to the wet period. They also fluctuated with study seasons ($p < 0.001$) with a higher mean value of 3.22 individuals in the short dry season and a lower value of 1.94 individuals in the long rainy season. These results showed that the rains of September considerably reduce *L. orbonalis* populations in the field. Others results showed that, the highest values of the average number of males of *L. orbonalis* caught on eggplant were obtained at the 3rd (4.5 individuals) and at the 7th (4.2 individuals) observation in one of the experimental fields in Bangladesh [29]. In Southeast Asia, *L. orbonalis* population are accounted for to increment with normal temperature and relative humidity [30]. The results on average number of *L. orbonalis* individuals (cumulative harvest dates) was 2.43 individuals per fruit. Similar results were obtained in Southern Cameroon at Koutaba (West Cameroon region) on *S. aethiopicum* var. zong (with 2.62 individuals per fruit), var. jakatu (with 2.16 individuals per fruit) and var. inerme (with 2.35 individuals per fruit) [13]. The results obtained in Bangladesh find an average value of 3.26 individuals in experimental field n°1 which is substantially equal to ours [29]. This would probably be due to the adaptive nature of this pest under several climatic conditions encountered in different study areas. Negative relationship between total rainfall and population of *L. orbonalis* was recorded during 2011 and 2012 in Pakistan [31].

4.2. Attack Rate Due to Leucinodes orbonalis on Eggplant Fruits

The damage caused by *Leucinodes orbonalis* on fruits of *S. aethiopicum* did not vary significantly from one harvest to another ($p > 0.05$), with slightly higher values of 13.05% at the 1st harvest and 12.80% at the 4th harvest during the wet period for a low temperature. The percentages of *L. orbonalis* infestation on *Solanum* gilo in Nigeria also did not vary significantly according to the three harvests in 2007 ($p > 0.05$) [32]. Nevertheless, according to the same authors, fruit infestation in the third planting in 2006 was significantly higher ($p<0.05$) (45.98%) than 40.57% and 42.60% recorded to the first and second planting respectively.

From one season to another, the damage calculated on the basis of harvests did not significantly vary ($p < 0.659$) with values of 8.87% in the short dry season and 10.54% in the long rainy season. *Leucinodes orbonalis* causes the most destruction on fruits and is most dynamic amid the late spring months (from May to August) [33]. Fruit damage in brinjal by BSFB was higher in May transplanted (spring) crops than that in July and September transplanted (fall) crops [4, 34].

4.3. Means Weight, Length and Diameter of Incubated Fruits and Correlation with Mean Number of Leucinodes orbonalis

The highest average weights, average lengths and average diameters of the incubated fruits were 36.15 g, 4.03 cm and 4.15 cm respectively at the 2nd harvest and 40.20 g, 3.86 cm and 4.12 cm respectively at the 3rd harvest corresponding to the end of the short dry season and the beginning of the long rainy season. The average weight of 17.7 g, the average diameter of 6.8 cm and the average length of 23.4 cm were reported in Ghana on the fruits of *Solanum* var. gilo Raddi on the basis of the Phenotypic Variance Coefficient (PVC) [11]. These results show that the average weight and average length were significantly higher compared to the agronomic traits recorded on our species / variety during the study. On the other hand, the value of the average diameter is close to that obtained in our study. The results obtained in Southern Cameroon show that, the average weight, mean length and average diameter of an incubated fruit were 35 g, 4.17 cm and 4.4 cm on *S. aethiopicum* var. zong, results that are similar to those obtained during our study; evidence that these different data were collected in the same agro-ecological zones [15].

Positive and significant correlations were found between the mean number of adults of *L. orbonalis* / incubated fruit and weight ($r = 0.39$, $p < 0.01$), length ($r = 0.40$, $p < 0.001$) and diameter ($r = 0.41$, $p < 0.001$) of the incubated fruits. Similar results were presented on the incubated fruits of *Solanum aethiopicum* var. zong at Okola ($r = 0.98$, $p < 0.001$) and at Koutaba ($r = 0.87$, $p < 0.004$) between the fruit weight and the average number of *L. orbonalis* [15]. Positive and significant correlations were also found between weight and length ($r = 0.95$, $p < 0.00$), weight and diameter ($r = 0.96$, $p < 0.001$), length and diameter ($r = 0.92$, $p < 0.001$) of an incubated fruit. These results corroborate those of Southern Cameroon with respective values of: $r = 0.81$, $p < 0.05$ between weight and length; $r = 0.89$, $p < 0.05$ between weight and diameter and $r = 0.63$, $p < 0.05$ between length and diameter [15]. Others results of Ghana also show the positive and significant correlations between weight and length ($r = 0.75$, $p < 0.01$), weight and diameter ($r = 0.81$, $p < 0.01$), but rather negative and non-significant correlations between the length and the diameter of the fruits ($r = -0.29$, $p > 0.05$) because of the very long length of the fruits [11].

4.4. Total Rainfall, Mean Temperature, Mean Relative Humidity and Correlation with Attack Rate (%) in Field Due to Leucinodes orbonalis

The damage from one month of study to another noted in the field ($p < 0.05$) gave values of the order of 10.54% of attack in September (rainy periods) and 7.79% in the month from August (relatively wet period so the small dry season) for 9.40 kg / 30m^2 on the yield. Others results show that, when no trap was operated in the eggplant fields, fruit damage and fruit yield were 31.15% and 13.70kg/100m^2 respectively in the non-IPM blocks and 10.66%, 27.54 kg/100m^2 in the IPM blocks respectively [29].

The results showed that *L. orbonalis* attacks on *S. aethiopicum* fruits in the field showed positive and non-significant correlations with precipitation and negative and non-significant correlations with mean temperature and mean relative humidity. In periods of rains, the larvae find the necessary resource for their optimal development. Rainfall contributed positively to 75% of attacks caused by *L. orbonalis*. Nevertheless, the incidence of *L. orbonalis* infestation had a non-significant relationship with temperature, relative humidity and rainfall on different brinjal varieties at Pakistan [35, 36]. Some authors also report that *L. orbonalis* is generally more active during rains periods on eggplant in India [33, 37].

5. Conclusion

Rainfall significantly reduced the number of *Leucinodes orbonalis* individuals during this study. The physical parameter of attacked fruit contributed for 81.72% (for mean weight), 81.94% (for mean length) and 86.64% (for mean diameter) of the mean number of *L. orbonalis* population / fruit and weather parameter contributed for 75.08% (for total rainfall), 36.36% (for mean temperature) and 54.62% (for mean relative humidity) of the attack rate due to *L. orbonalis* on field.

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