Spatial distribution of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on corn crops in Durango, Mexico

Abstract: Accurately determining the spatial distribution of an insect is crucial for making effective decisions and efficiently controlling their populations. This study aimed to determine the population distribution of *Spodoptera frugiperda* (J. E. Smith 1797) (Lepidoptera: Noctuidae) larvae in corn plots near the City of Durango, Mexico. A total of 30 corn-cultivated plots were sampled. In each plot, 5 points were selected (5 of coins method), where 10 consecutive corn plants in these phenological stages V4 to V10 were checked for the presence of larvae and recorded. Statistical analysis was conducted using Scattering Indices 2/χ2 and the Chi-square test (χ2) (see Supplementary Materials Table 2). The results indicated that infestation was slightly higher during stage V6 than in V4 and V8. The population of *S. frugiperda* had a negative, aggregate, or binomial distributioonly in stage V4 (corresponding to small larvae), while in other phenological stages, the distribution was random.

Key words: Dispersal, crop phenology, maize, statistical analysis.

Introduction

Spodoptera frugiperda is an insect of wide distribution in the American continent and its populations can be detected from Canada to Argentina (Santos-Ríos *et al.* 2014). This species is reported feeding on more than 200 plant species in the Americas and its populations have been reported in Chikkaballapur, Karnataka in India (ICAR-NBAIR 2018), in Africa where it has spread in 37 countries of the sub-Saharan sector (Goergen *et al.* 2016; Baudron *et al.* 2019; Kuate *et al.*, 2019; Dahi *et al.*, 2020; Mohamed *et al.*, 2022) and recently in China (Wang *et al.* 2020; Chao *et al.*, 2022; Jiang *et al.*, 2022). To better understand *Spodoptera frugiperda* in India and other countries, it is essential to resume studies on migratory routes, isolation, behavior, alternate hosts, spatial distribution, natural enemies, genetic structure, and habitats for the cold season, as they do not undergo diapause (López-Edwards *et al.*, 1999; Pashley *et al.*, 1985; Westbrook *et al.*, 2016; Murúa *et al.*, 2006; Murúa *et al.*, 2009; Wu *et al.*, 2021; Afandi *et al.*, 2022).

Conducting studies like this can aid in analyzing insect behavior in new distribution areas. For example, in coastal areas of the Pacific, there are overlapping generations until reaching the peak of maximum infestation. However, in the same region with altitudes of 800 to 1200 meters above sea level, a clear generation arrives when the plant is small, followed by overlapping generations that decrease as the plant reaches the reproductive stage (Hernandez-Mendoza, 1989; Hernandez-Mendoza *et al.*, 2008).

The larvae of *S. frugiperda* tend to favor grasses like sorghum, rice, and maize crops. They are typically solitary due to their cannibalistic tendencies (Bezerra *et al.* 2013; Andow *et al.* 2015; Nadoe *et al.* 2015), which impacts their spatial distribution in affected crops (Barfield and Ashley 1987; Simmons and Marti 1992; Hernández-Mendoza *et al.* 2008; Murúa *et al.* 2009; Casmuz *et al.* 2010; Bohnenblust and Tooker 2012; Santos-Ríos *et al.* 2014).

Understanding the spatial distribution of this insect is crucial for effective population management decisions (Giles *et al.* 2000; Westbrook *et al.* 2016; Yanqui-Díaz *et al.* 2022). This is because insect-damaged plants and insect larvae release semiochemicals that parasitoids use to locate their prey (Mohammed. 2020). Mathematical models have been employed in studies of spatial distribution to understand the insect's behavior in crops (Terry *et al.* 1989; Álvarez and Martínez 1990; Farías *et al.* 2001; Murúa *et al.* 2006; Crespo-Herrera *et al.* 2012; Santos-Ríos *et al.* 2014). These models seek to represent the behavior of insect larval populations within a plot and can inform population management measures, as well as help estimate sample sizes. (Southwood 1966; Myers 1978; Hernández-Mendoza *et al.* 2008; Crespo-Herrera *et al.* 2012).

The spatial distribution of the noctuid *S. frugiperda* has been studied, and populations with negative binomial, aggregate, uniform, or random distribution have been reported (Clavijo 1978; Farías *et al.* 2001; Hernández-Mendoza *et al.* 2008). The aggregate distribution is observed in small maize plants in the vegetative phenological stage (V2) or when the larvae hatch before starting their dispersal (Hernández-Mendoza, 1989; Hernández-Mendoza *et al.* 2008). As the corn plants grow and develop, the larvae tend to separate and remain one per plant until reaching their full growth and pupal stage (Hernández-Mendoza 1989; Hernández-Mendoza *et al.* 2008; Murúa *et al.* 2009). Understanding the biology and ecology of this insect is of recent relevance due to the infestations it is causing in various locations such as the African continent, China, and

Indonesia. (Nagoshi *et al.*, 2009; Goergen *et al.* 2016; Westbrook *et al.*, 2016; Baudron *et al.* 2019; Kuate *et al.*, 2019; Dahi *et al.*, 2020; Wang *et al.* 2020; Wu *et al.*, 2021; Afandi *et al.*, 2022; Chao *et al.*, 2022; Jiang *et al.*, 2022; Mohammed *et al.*, 2022).

An important aspect to consider is the potential for overlapping generations of *S. frugiperda* in maize plants, which can vary based on factors such as plant phenology, temperature, and the specific maize variety being consumed. To estimate infestations in corn cultivation, a nonlinear regression model can be used based on the distribution of insect larvae within crops (Hernández-Mendoza *et al.* 2008). This research was conducted with the goal of improving the management of infestations in maize crops.

Materials and methods

The study was conducted in the vicinity of Durango city on 30 maize cultivation plots located at 24°01'22"N and 104°39'16"W (Figure 1). Maize cultivation is recommended from May onwards due to the prevailing climatic conditions (Castillo, 2015). The plots were situated at an altitude ranging from 1860 to 1892 meters above sea level. The research team recorded the number of free leaves in 10 continuous plants at 5 different points in each plot. The phenological state of the plants was estimated based on the number of free leaves. The team also checked for the presence of larvae of *S. frugiperda*, noting the number of infested plants and the number of larvae found, following the methods described by Murúa *et al.* (2006) and Hernández-Mendoza *et al.* (2008).

Figure 1. Map of the State of Durango and the city of the same name where the samples of *S frugiperda* were collected.

Two methodologies were used to determine the spatial distribution:

a) Variance is obtained by squaring the difference between each observation and the mean, summing up these values, and dividing by n-1.($S2/\bar{x}$. $S2$ = Variance and $\bar{x}$ = Population mean. $(=((xi - \bar{x})^2)/n\text{-}1))$

If the values of the dispersion index approach 1, the population's distribution is estimated to be random. If the values are close to zero, a uniform distribution is indicated. Values greater than 1 indicate an aggregate distribution. (Hernández-Mendoza *et al.* 2008; Vivas and Notz 2011).

b) Dispersion index obtained with the Chi-square test ($\chi 2$). If the data obtained are within the values established in the distribution table $\chi 2$ with n-1 degrees of freedom and a α = 0.05, the distribution is completely random (Hernández-Mendoza *et al.* 2008). Excel 2016 was used for the analysis of both indexes. To calculate the indices, the percentage of infested plants was obtained using the formula proposed by Murúa *et al.* (2006).

Results and discussion

Upon analyzing the behavior of *S. frugiperda* infestations detected in this study and their relationship with the phenology of the plant, it becomes evident from Figures 1 and 2 that the infestation rate of this insect in corn plants is relatively low at the beginning and end of crop growth. This low infestation rate may be influenced by the release of the spike, disappearance of the bud, and the insect's own population dynamics (Hernández-Mendoza *et al.*, 2008). Thus, infestations of *S. frugiperda* can be detected during all phenological stages of maize, and their populations are influenced by the genetics of the maize plant and the environmental conditions of the site of cultivation (Murúa *et al.*, 2006; Farías *et al.*, 2008; Hernández-Mendoza *et al.*, 2008).

The sampled sites in this study are located at altitudes greater than 1850 meters above sea level, and the observed infestations were higher in plants in the phenological stage of V6, when the plants are finishing the vegetative growth stage and until the flag leaf is free, just before the release of the spikes, which is consistent with previously observed behavior in corn grown in sites with altitudes below 500 meters above sea level (Hernández-Mendoza, 1989; Hernández-

Mendoza *et al.*, 2008). Similar behavior had also been observed in Argentina (Murúa *et al.*, 2006; Murúa *et al.*, 2009).

In a comprehensive analysis of the sampled sites, considering only the mean population (S2) and the phenological development of *S. frugiperda* larvae (as shown in Table 1 and Table 2 in the supplementary materials), it was found that the highest value was observed in V4, whereas the lowest value was recorded in V10, corresponding to the onset of the reproductive stage of maize, during which the spikes emerge (Hernández-Mendoza *et al.*, 2008).

Table 1. Relationship between the vegetative stages of maize, infested plants and analyses performed to estimate the distribution of *S. frugiperda* larvae.

Vegetative State	**% Infested plants**	**Media ($\underline{x}$)**	**Variance (S2)**	**S2/$\underline{x}$**	**x2 (Chi cuadrada)**	**Spatial Distribution**
V4	34	0,6	0,9	1,5	11,52	Added
V4	22	0,36	0,52	1,45	16,26	Added
Average	28	0,48	0,71	1,475	13,89	
V6	50	0,64	0,52	0,81	0,62	Random
V6	56	0,7	0,5	0,71	1,21	Random
V6	46	0,56	0,5	0,89	0,4	Random
V6	44	0,48	0,35	0,73	2,75	Random

V6	28	0,28	0,21	0,73	1,19	Random
V6	44	0,52	0,42	0,8	0,52	Random
V6	48	0,6	0,49	0,82	0,45	Random
V6	34	0,36	0,4	0,92	0,07	Random
V6	50	0,58	0,41	0,71	1,82	Random
Average	44.4444	0,52444	0,4222	0,7911	1,00333	
V6-V8	36	0,38	0,28	0,74	2,25	Random
V6-V8	36	0,36	0,24	0,65	2,6	Random
V6-V8	38	0,36	0,23	0,65	3,81	Random
Average	36,6667	0,36667	0,25	0,68	2,88667	
V8	42	0,46	0,34	0,73	2,13	Random
V8	48	0,54	0,38	0,70	2,47	Random
V8	52	0,6	0,47	0,78	2,47	Random
V8	40	0,4	0,25	0,62	5,54	Random
V8	44	0,52	0,42	0,80	0,52	Random
V8	50	0,6	0,46	0,76	0,98	Random
V8	36	0,38	0,3	0,79	2.25	Random

V8	52	0,6	0,41	0,68	2,47	Random
V8	38	0,38	0,24	0,63	5,54	Random
V8	50	0,54	0,34	0,62	5,13	Random
V8	42	0,46	0,34	0,73	2,13	Random
Average	44,9091	0,49818	0,3591	0,7127	2,87545	
V10	42	0,42	0,25	0,59	7,11	Random
V10	26	0,26	0,2	0,76	2,25	Random
V10	22	0,22	0,2	0,89	1,54	Random
V10	44	0,46	0,29	0,64	4,93	Random
Average	33,5	0,34	0,235	0,72	3,9575	

The data presented above shows a similarity in the variance index values across each phenological stage. This suggests that infestations were high during crop development and decreased as the reproductive stage approached, culminating in the release of the spike. This pattern is consistent with observations made by other authors. (Murúa *et al.* 2006; Hernández-Mendoza *et al.* 2008).

Figure 1 illustrates that both $S2/\chi 2$ and larvae ($\chi 2$) exhibit significantly high values in terms of the number of *S. frugiperda* per sampled plant, and this coincides with the spatial distribution being either of the aggregate or negative binomial type. The determination of population means, and variance alone are not conclusive indicators of the spatial distribution, as demonstrated by this and other studies (Crespo-Herrera *et al.*, 2012), which is the case for *S. frugiperda* larvae in maize cultivation under the conditions of this study. Table 1 shows that a sample with V4 has a mean of 0.36, variance of 0.52, an S2/ $\chi2$ of 1.45 and an aggregated distribution, whereas another sample with V6 has 0.36, 0.4, and 0.92, respectively, and a random distribution.

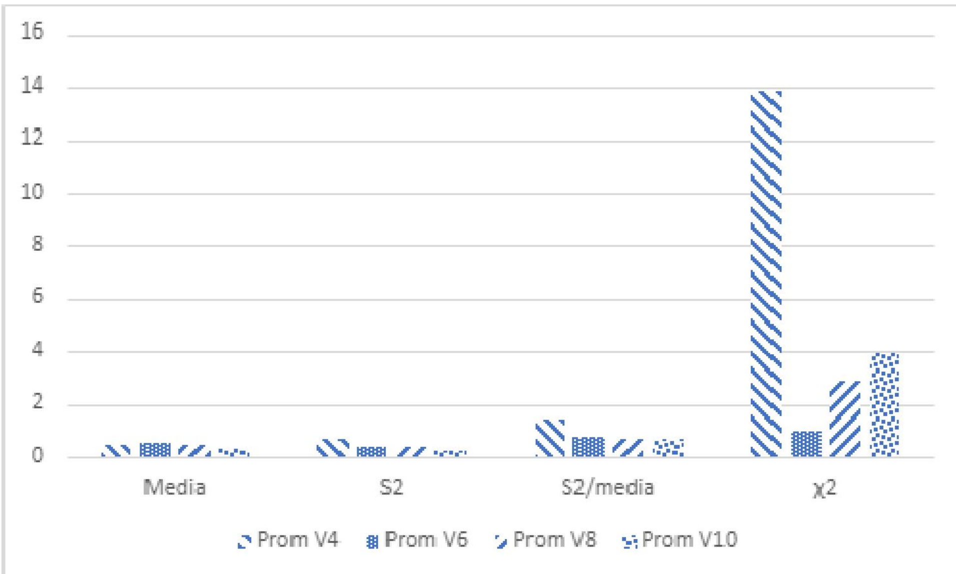

Figure 1. Result of the application of different methodologies for the estimation of the spatial distribution of larvae of *S. frugiperda* in maize cultivation.

An aggregate distribution has also been reported in other insect species during the egg and early developmental stages (Crespo-Herrera *et al.*, 2012). This type of distribution is also observed in *S. frugiperda*, where females lay their eggs in aggregate masses with a variable number of eggs. After hatching, the larvae begin to disperse (Hernández-Mendoza *et al.*, 2008).

The site with the highest infestation was Colonia Hidalgo, and it occurred during vegetative stage V6 (refer to Table 1). Conversely, Hernández-Mendoza *et al.* (2008) reported average infestations of 69% in corn plants during vegetative stage V9 in the state of Colima, which is almost when the plant is fully developed and close to the emergence of the spike. In this case, the infestations cause damage to the corn, resulting in significant losses as the affected crops cannot be sold fresh.

The data presented in Figure 2 indicates that *S. frugiperda* infestations tend to decrease towards the end of the vegetative development of the crop, consistent with previous findings in maize grown in three agroecological regions of the Mexican Pacific coast (State of Colima) where altitudes are below 1000 meters above sea level (Murúa *et al.*, 2006; Hernández-Mendoza *et al.*, 2008). This suggests that the insect's behavior is similar at high altitudes as it is at near-sea level. (Hernandez-Mendoza *et al.* 2008).

Infested plants suffer more damage from *S. frugiperra* larvae when the pest occurs in the initial phenological stages than in later vegetative stages. Similarly, Jaramillo *et al.* (1989) mentioned that adults of *S. frugiperda* prefer early developing maize plants for oviposition. Thus, infestations throughout the vegetative development of corn allow estimating the response or compensation to the loss of foliage caused by insect feeding (Hernández-Mendoza 1989). This estimation can be made by sampling in any part of the crop, thanks to the random spatial distribution that the insect presents inside it.

Upon analyzing the behavior of *S. frugiperda* infestations detected in this study and its correlation with plant phenology, it becomes apparent that the larvae population reaches its maximum infestation peak when the plant is in full vegetative development, resulting in a parabolic or normal distribution curve (Figure 2). This behavior has been observed in various eco-geographic conditions and countries where this pest is present, as reported in several studies (Hernández-Mendoza 1989; Jaramillo *et al.* 1989; Farías *et al.* 2001; Murúa *et al.* 2006; Hernández-Mendoza *et al.* 2008; Murúa *et al.* 2009; Crespo-Herrera *et al.* 2012; Santos-Ríos *et al.* 2014).

Based on the general analysis of the sampled sites in this study, it is evident that the spatial distribution of *S. frugiperda* larvae in the area near the city of Durango is random, implying that they do not exhibit a defined pattern for infesting plants within a plot. This is important for applications of insecticides or biological control agents, such as the release of parasitoids, predators, or other agents. Conversely, when the insect exhibits aggregate distribution, management measures must be adjusted, from detection to the application of any form of control.

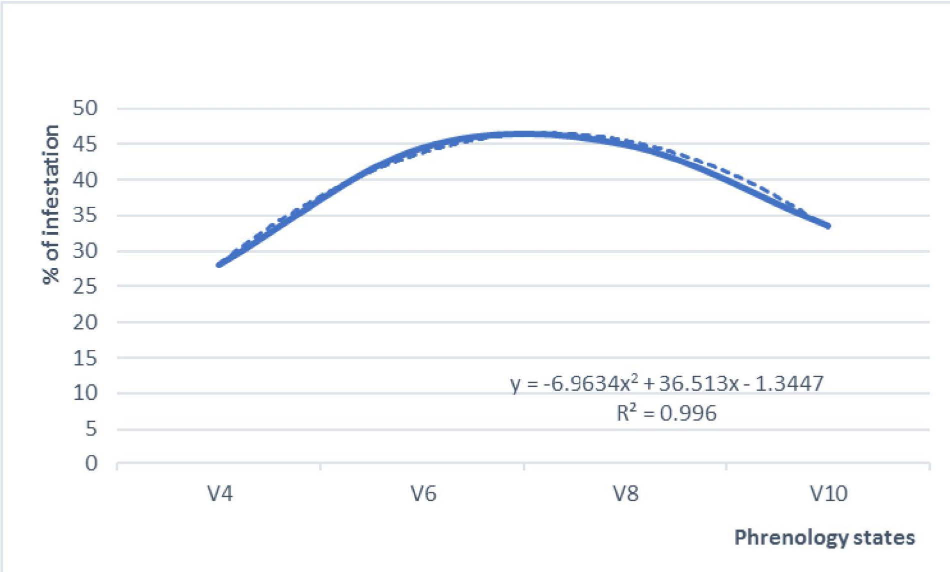

Figure 2. Estimation of the population behavior of *S. frugiperda* larvae according to the phenological development of corn cultivation in Durango.

The spatial distribution of insects can change due to various external factors such as altitudinal and climatic variants, which can vary from year to year (Redolfi *et al.* 2005; Alonso-Hernández *et al.* 2014; Amell-Caez *et al.* 2019). However, for the *S. frugiperda* insect, the populations sampled at altitudes above 1800 meters above sea level remain random, just as those at altitudes below 500 meters above sea level have been observed to be random (Hernández-Mendoza 1989; Hernández-Mendoza *et al.*, 2008).

Conclusions

The spatial distribution of *S. frugiperda* is estimated to be closely related to the phenology of the maize crop and the present study confirmed that in crops of vegetative development stage V4, that is, in small plants, the distribution is aggregated because they are newly-hatched larvae, while in stages of development V6 to V10 the distribution is random. Thus, control measures with parasitoids or agrochemicals will depend on the age of the plant. The results of the present study may be considered during sampling to determine acceptable levels of infestation.

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