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

Abstract : The determination of the spatial distribution of an insect is of paramount importance for decision-making to be efficient and effective for the control of their populations. In the present study, 30 samples were carried out in plots cultivated with corn, near the City of Durango, Mexico in order to know the population distribution of larvae of *Spodoptera frugiperda (*J. E. Smith 1797) (Lepidoptera: Noctuidae). In each plot, 5 sites were selected (type 5 sampling of golds), where 10 plants were selected in the phenological stages from V4 to V10, recording the presence of larvae. Statistical analyses were performed using the Scattering Indices 2/χ2 and the Chi-square test (χ2) (Supplementary Materials Table 2). The results show that the average infestation is slightly higher during stage V6 than in V4 and V8. According to the analyses carried out, the population of S. *frugiperda* has a negative, aggregate or binomial distribution only in stage V4 that corresponds to small larvae and in the other phenological stages the distribution is random.

Comment [A1]: What was the level of damage in the plants in Davis´s scale?

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). Both in India and in other countries, it will be necessary to resume the studies carried out to determine migratory routes, isolation, behavior, alternating hosts, spatial distribution, natural enemies, genetic structure and places to spend the cold season since they do not have diapause (López-Edwards et al., 1999; Pashley et al., 1985; Westbrook and Sparks, 1987; Murúa et al., 2006; Murúa et al., 2009; Afandi et al., 2022). Studies like this

Comment [A2]: Even in Asia, Africa and Oceania may support the analysis of insect behavior in new distribution areas, since in the coastal areas of the Pacific there are overlapping generations until reaching the peak of maximum infestation, while in that same region, with altitudes of 800 to 1200 meters above sea level there is clearly a generation that arrives when the plant is small and later there are overlapping generations that decrease when the plant reaches the reproductive stage (Hernandez-Mendoza, 1989; Hernandez-Mendoza et al., 2008).

The larvae of *S frugiperda* prefer grasses such as sorghum, rice and maize crops. The larvae are generally solitary, as they have cannibalistic habits (Bezerra *et al*., 2013; Andow *et al*., 2015; Nadoe *et al*. 2015) and this condition affects their spatial distribution in attacked 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).

Knowledge of the spatial distribution of this insect is a priority in decision-making for the efficient management of its populations (Giles *et al* et al. 2000; Yanqui-Díaz et al., 2022), since both insect-damaged plants and insect larvae release semiochemicals that can be used by parasitoids to locate their prey (Mohammed. 2020). In these studies on spatial distribution, the application of mathematical models has been analyzed, in order to know the behavior of the insect in crops, among them are: Poisson distribution, Positive Binomial, Negative binomial, dispersion indices, the relationship between variance and mean and are proposed as a way to study the behavior of the insect in a crop (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 analyses seek a mathematical representation of the behavior of insect larval populations within a plot and the measures to be used for the management of their populations may depend on this, as well as the use of information to estimate the sample size (Southwood 1966; Myers 1978; Crespo-Herrera *et al.* 2012).

For the noctuid, *S. frugiperda*, populations of negative binomial spatial distribution or aggregate, uniform or random distribution are reported (Clavijo 1978; Farías *et al*. 2001; Hernández-Mendoza *et al*. 2008). The aggregate distribution is detected in small maize plants, in vegetative phenological state (V2) or when the larvae hatch before starting their dispersal (Hernández-Mendoza, 1989; Hernández-Mendoza *et al*. 2008). In corn plants with greater phenological development, the larvae tend to separate and remain one per plant and thus reach their full growth until the pupal stage (Hernández-Mendoza 1989; Hernández-Mendoza *et al.* 2008; Murúa *et al.* 2009). Aspects related to the biology and ecology of this insect become recent relevance due to the infestations it is causing in the African continent, China Indonesia and other (Goergen *et al.* 2016; Baudron *et al.* 2019; Kuate et al., 2019; Dahi et al., 2020; Wang *et al.* 2020; Afandi et al., 2022; Chao *et al*., 2022; Jiang *et al*., 2022; Mohammed *et al*., 2022).

Another important aspect is that in some cases overlapping generations can be observed in maize plants, according to the phenological development of the plant, temperature, the variety of maize on which the larvae feed and their infestations can be estimated with a nonlinear regression model (Hernández-Mendoza *et al.* 2008). The work was carried out in order to determine the distribution of insect larvae within corn crops and derived from this measure can be taken for good management of infestations in corn cultivation.

Comment [A3]: A distribution whitout any damage crops consideration?

The records of the started of crops, infestation of the pest and productos used for the control.

Materials and methods

The present study was carried out in five maize cultivation sites near the City of Durango, Mexico (24°01´22´´N and 104°39´16´´W), where due to climatic conditions cultivation is recommended from May onwards (Castillo, 2015), and correspond to sites with altitudes between 1860 and 1892 meters above sea level. 30 plots of maize were sampled, recording the number of free leaves (from this the phenological state was estimated) and presence of larvae of *S. frugiperda.* In these samplings, the technique of five golds was used, reviewing 10 contiguous maize plants (50 plants per plot) by sampling date (Murúa *et al*., 2006; Hernández-Mendoza *et al.* 2008), noting the number of infested plants and larvae found.

Comment [A4]: What was the hybrid´s name? Or were native crops?

Comment [A5]: Did you record the instar of the pest and the damage level of the plant?

Two methodologies were used to determine the spatial distribution:

a) **Variance** obtained from the sum of each observation minus the mean squared on n-1 ($S2/\bar{x}$. $S2$ = Variance and $\bar{x}$ = Population mean. ($=((x_i - \bar{x})^2)/n-1$))

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

b) Dispersion index obtained with the Chi-square test (χ2). If the data obtained are within the values established in the distribution table χ2 with n-1 degrees of freedom and a α = 0.05, the distribution is completely random (Hernández-Mendoza *et al*. 2008). For the analysis of both indexes, the Excel 2016 program was used. For the calculation of the indices it is necessary to obtain the percentage of infested plants, which was done using the formula Murúa *et al*. (2006).

Results and discussion

When performing an analysis of the behavior of *S frugiperda* infestations detected in this work and its relationship with the phenology of the plant, it can be observed in Figures 1 and 2, that the behavior of this insect in corn plants is low at the beginning of crop growth as well as at the end of it, perhaps influenced by the release of the spike, disappearance of the bud and the insect's own population dynamics (Hernández-Mendoza *et al*. 2008). Thus, S. *frugiperda* infestations can be detected during all phenological stages of maize and their populations are influenced by the genetics of the maize itself and the environmental conditions of the site of establishment of the crop (Murúa *et al*. 2006; Farías *et al*. 2008; Hernández-Mendoza *et al*. 2008). In this case, the sampled sites 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, that is, when the plants are finishing the vegetative growth stage and until the flag leaf is free, just before the release of the spikes behavior previously observed in corn grown in sites with altitudes below 500 meters above sea level (Hernández-Mendoza, 1989; Hernández-Mendoza *et al.*, 2008). This behavior had also been observed in Argentina (Murúa *et al*. 2006; Murúa *et al.* 2009).

Comment [A6]: I don´t know what do you try to say.

Comment [A7]: If the populations are influenced by the genetics of the maize and the enviroment, what´s the best choise to aboid infestations?

Comment [A8]: The altitud and phenological stage are critical for the stablisment of the economic threshold?

Comment [A9]: What´s the critical stage in which the attack of S. frugipera cause a great lost in yield?

Comment [A10]: What conduct?

In a global analysis, taking into account only the phenological development and the population mean (S2) (Table 1 and Table 2 in supplementary materials) larvae *of S. frugiperda* in the sampled sites, it has that in V4 the value is higher and the lowest value is found in the populations detected in stage V10 that corresponds to the plants that are starting the reproductive stage, which is when the spike emerges (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 ($\overline{x}$)	Variance (S2)	S2/$\overline{x}$	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 graphical representation of the above data shows the similarity in the values of the index of variance at each phenological stage. This means that infestations were high during the development of the crop and decreased as the reproductive stage approached with the release of the spike. This behavior is similar to that reported by other authors (Murúa *et al*. 2006; Hernández-Mendoza *et al*. 2008).

Figure 1 shows that S2/χ2 and larvae (χ2) show very high values in terms of the number of S. *frugiperda* per sampled plant and it is coincidentally where the spatial distribution is of the aggregate or negative binomial type. As can be seen in this work, the determination of the population mean and variance are not indicative determinants of the spatial distribution (Crespo-Herrera *et al*. 2012), such is the case of the larvae of *S. frugiperda* in maize cultivation under the conditions where the work was carried out, since as can be seen in Table 1, a sample with V4 has a mean of 0.36, variance of 0.52, an S2/ χ2 of 1.45 and the distribution is aggregated, while another sample this time with V6, has 0.36, 0.4 and 0.92, respectively and the distribution is random.

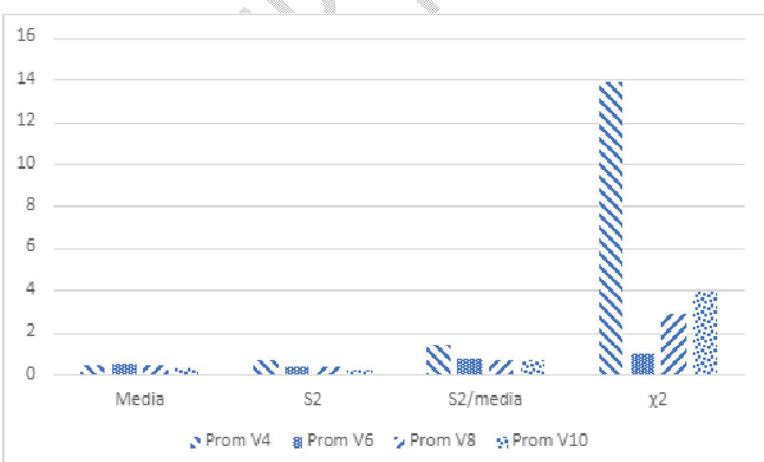

Figure 1. Result of the application of different methodologies for the estimation of the spatial distribution of larvae of *S. frugiperda* in maize cultivation.

The aggregate distribution has also been reported in other insects in egg stages and early developmental stages (Crespo-Herrera et al. 2012), as well as S. *frugiperda*, where females oviposite in aggregate masses with variable number of eggs and at birth the larvae begin dispersal (Hernández-Mendoza *et al*. 2008).

The highest infestations occurred in vegetative stage V6, with Colonia Hidalgo being the site with the highest infestation (Table 1). By contrast, for the state of Colima, Hernández-Mendoza *et al*. (2008) reported infestations of 69% on average, of *S. frugiperda* in corn plants in the vegetative stage of V9, almost when the plant has fully developed and is close to the emission of the spike**.** In this case, when the infestations occur, they cause damage to the corn, generating great losses since these cannot be marketed fresh.

Comment [A11]: It´s necesary to see in a map all the positions of the study.

In all cases shown in Figure 2, it is observed that infestations tend to decrease at the end of the vegetative development of the crop (Murúa *et al*., 2006; Hernández-Mendoza *et al.*, 2008) for maize grown in three agroecological regions of the Mexican Pacific coast (State of Colima), where altitudes are below 1000 meters above sea level. This shows that in this case the behavior of the insect is similar at high altitudes than at near-sea level (Hernandez-Mendoza *et al*. 2008).

On the other hand, 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.

When performing an analysis of the behavior of *S. frugiperda* infestations detected in this work and its relationship with the phenology of the plant, it can be seen that when graphing the population behavior of the larvae, they have a peak of maximum infestation when the plant is in full vegetative development giving the form of a parabola or a normal distribution (Figure 2). This behavior has been reported in several eco-geographic conditions and countries where this pest is present (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).

The general analysis of the sites sampled in this study show that the spatial distribution of *S. frugiperda* larvae in the area near the city of Durango is random, that is, they do not have a defined pattern to infest plants inside a plot. This would be important for applications of insecticides or biological control agents (release of parasitoids, predators or other agents). Otherwise, when the insect presents aggregate distribution, management measures must be adapted, from detection to the application of any form of control.

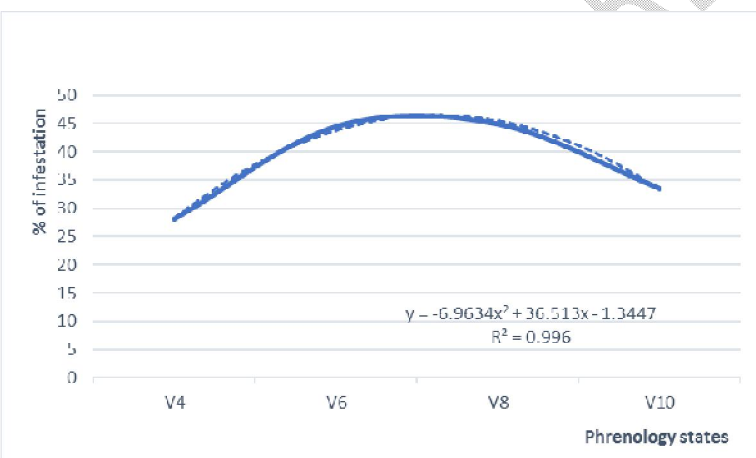

Figure 2. Estimation of the population behavior of S. *frugiperda* larvae according to the phenological development of corn cultivation at Durango.

On the other hand, the spatial distribution of insects can change due to altitudinal variants, climatic variants that in turn can be changing year by year, or other external factors (Redolfi *et al.* 2005; Alonso-Hernández *et al.* 2014; Amell-Caez *et al.* 2019), however, for this insect, the populations sampled at altitudes above 1800 meters above sea level remain random as well as those at altitudes below 500 meters above sea level (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 in this study it was 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 of V6 to V10, The distribution is random so the control measures with parasitoids or agrochemicals will depend on the age of the plant. The results of this study may be taken into account in the sampling for the determination of permissible levels of infestation.

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