AP AGRO PRODUCTIVIDAD
Colegio de Postgraduados

Maize tolerance to *Spodoptera frugiperda* (J. E. Smith) leaf damage and insecticide application

Hernández-Trejo, Antonia[1]; López-Santillán, José A.[1*]; Estrada-Drouaillet, Benigno[1]; Reséndiz-Ramírez, Zoila[1], Varela-Fuentes, Sóstenes E.[1]; Coronado-Blanco, Juana M.[1]; Malvar, Rosa A.[2]

[1] Universidad Autónoma de Tamaulipas, Facultad de Ingeniería y Ciencias, División de Estudios de Posgrado e Investigación, Centro Universitario Adolfo López Mateos, Cd. Victoria, Tamaulipas, México, C. P. 87000.
[2] Misión Biológica de Galicia, Pazo de Salcedo, Carballeira 8 Salcedo, Pontevedra, España, C. P. 36143.
* Correspondence: jalopez@docentes.uat.edu.mx

ABSTRACT

Objective: To evaluate the tolerance of Tamaulipas native maize populations to the leaf damage caused by *Spodoptera frugiperda*.

Design/Methodology/Approach: During the two agricultural cycles of 2019, the leaf damage by *S. frugiperda* and the grain yield decrease in 10 populations of native maize were evaluated In Güémez, Tamaulipas.

Results: Leaf damage by *S. frugiperda* was minimal when synthetic insecticide (emamectin benzoate) was applied in the autumn-winter agricultural cycle; meanwhile, it was greater in the spring-summer cycle, but its levels remained lower than the rest of the *S. frugiperda* management strategies. Leaf damage was higher during the spring-summer cycle because the environmental temperature was higher than in the autumn-winter cycle.

Study limitations/Implications: *Spodoptera frugiperda* is an important pest of maize. It is mainly controlled using synthetic insecticides, which cause environmental and human health risks. The use of tolerant cultivars is a strategy that reduces these risks.

Findings/Conclusions: The TML_2S_3 and VHA maize populations were tolerant to *S. frugiperda* leaf damage in both agricultural cycles; it is considered as the base germplasm for a program aimed at enhancing this characteristic.

Keywords: fall armyworm control, yield decline, native populations, *Zea mays*.

Citation: Hernández-Trejo, A., López-Santillán, J. A., Estrada-Drouaillet, B., Reséndiz-Ramírez, Z., Varela-Fuentes, S. E., Coronado-Blanco, J. M., & Malvar, R. A. (2022). Maize tolerance to *Spodoptera frugiperda* (J. E. Smith) leaf damage and insecticide application. *Agro Productividad*. https://doi.org/10.32854/agrop.v15i4.2135

Academic Editors: Jorge Cadena Iñiguez and Libia Iris Trejo Téllez

Received: September 25, 2021.
Accepted: April 5, 2022.
Published on-line: May 25, 2022.

Agro Productividad, 15(5). May. 2022. pp: 23-31.

INTRODUCTION

The fall armyworm (*Spodoptera frugiperda* J. E. Smith) is one of the most important pest insects that attack maize (Real-Santillán *et al.*, 2019) crops, in the tropical and subtropical regions of the American continent (Sauceda-Acosta *et al.*, 2015). It has a high incidence in Mexico, mainly in the states of Guanajuato, Chiapas, Chihuahua, Sonora, Sinaloa, and Tamaulipas (Blanco *et al.*, 2014). It causes leaf damage, mainly in the vegetative stage, and


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consumes developing leaves in the whorl or shoot (García-Gutiérrez *et al.*, 2012), reducing the photosynthetic capacity of the plant and, consequently, decreasing grain yield (Lima *et al.*, 2010). In average, a larva can consume over 150 cm^2 of leaf tissue (Rezende *et al.*, 1994) and, in a single crop cycle, more than two generations can exist (Ramírez-Cabral *et al.*, 2020).

The foregoing shows the need to control this pest for which synthetic insecticides are commonly used (Sauceda-Acosta *et al.*, 2015). Blanco *et al.* (2014) have estimated that 2,600 tons of different active ingredients are applied per year in Mexico, which favors the development of resistance among *S. frugiperda* populations, causes the elimination of non-target species —some of which are beneficial insects (Ayil-Gutiérrez *et al.*, 2018) or pollinators—, and is a source of soil and water contamination (Botías and Sánchez-Bayo, 2018).

The dependence on synthetic insecticides in agriculture highlights the various effects they cause and their contribution to the environmental imbalance, showing the need to implement strategies that favor the agroecological management of this pest and consequently reduce the aforementioned effects (Harrison *et al.*, 2019). These alternatives include the use of botanical (Ayil-Gutiérrez *et al.*, 2018) and biological (Kuzhuppillymyal-Prabhakarankutty *et al.*, 2021) insecticides.

Meanwhile, the use of cultivars with tolerance to *S. frugiperda* reduces the effects of leaf damage and grain yield (Blanco *et al.*, 2014). This characteristic is highly important, since it is a response from the plant and does not involve reciprocity by the insect. Therefore, it does not cause selection pressure in its populations and does not induce the development of resistance in the pest (Peterson *et al.*, 2017). In addition, this strategy is compatible with any control method for this pest (Harrison *et al.*, 2019).

S. frugiperda tolerant cultivars are achieved through genetic improvement, for which identifying and having base germplasm with characteristics that provide tolerance is necessary (Kumar, 2002). These characteristics are found in populations developed under the incidence of this insect, such as native populations (Sauceda-Acosta *et al.*, 2015); these findings have been corroborated in studies carried out with Tamaulipas native maize. The objective of this study was to evaluate the tolerance of Tamaulipas native maize populations to leaf damage by *S. frugiperda*.

MATERIALS AND METHODS

Crop location and management

The experiments were established in the La Posta Zootécnica "Ingeniero Herminio García González" experimental field of the Facultad de Ingeniería y Ciencias of the Universidad Autónoma de Tamaulipas, in Güémez, Tamaulipas, Mexico, located at 193 masl, 23° 56' 26" N and 99° 05' 59" W. The experiments were carried out during the 2018-2019 autumn winter (OI) and 2019 spring summer (PV) agricultural cycles. Land preparation and crop management were carried out according to the maize production recommendations for the north-central zone of Tamaulipas (Reyes-Méndez, 2017a, 2017b), under irrigation conditions and with a population density of 50,000 plants ha^{-1}.

Vegetal material and management strategies

In both agricultural cycles, 10 populations developed from native maize germplasm from central-southern Tamaulipas were evaluated (Table 1) in four *S. frugiperda* management strategies: 1. synthetic insecticide (active ingredient: emamectin benzoate); 2. broad-spectrum biological-botanical insecticide (complex: *Beauveria bassiana*, *Nomuraea rileyi*, *Metarhizium anisopliae*, *Paecilomyces fumosoroseus*, and a multi-oleic active concentrate); 3. botanical insecticide (active ingredient: azadirachtin); and 4: control without application. The applications were made every 20 days with a previously-calibrated manual sprinkler, from the complete exposure of the fourth leaf until flowering. The application of the dose followed the recommendations of the manufacturer of each product.

Experimental design and evaluated variables

In each agricultural cycle, the experiments were established in a randomized complete block design with a split-plot arrangement and three replications. The experimental unit was 4 m^2. *S. frugiperda* management strategies were established in the large plot, while the maize populations were established in the small plot. Leaf damage was evaluated under natural *S. frugiperda* infestation, using the visual scale of Fernández and Expósito (2000) —in which 0 means no visible leaf damage and 5 means 81-100% leaf damage and destruction of the whorl—, by direct observation at the time of complete exposure of the sixth, twelfth, and flag leaves. The decrease in grain yield was also determined based on the difference between the management strategy with synthetic insecticide (less leaf damage) and the control without application (greater leaf damage). These two management strategies showed the greatest contrast in terms of leaf damage. The comparison of plants with and without damage enable the classification of the populations as tolerant or sensitive.

Statistical analysis

An analysis of variance and Tukey's comparison of means test were performed with a 0.05 significance leaf damage level; additionally, a regression analysis between leaf damage in the populations and the decrease in maize grain yield —as a result of the damage caused by *S. frugiperda*— was carried out. The Software Statistical Analysis System (SAS, 2002)

Table 1. Maize populations derived from Tamaulipas native germplasm evaluated in this study.

PWL_1S_3	3001	2003	Padilla
TGL_2S_3	3007	2003	Tula
TML_3S_3	3012	2003	Tula
$LlNL_4S_3$	3033	2003	Llera
$LlHL_5S_3$	3040	2003	Llera
PWL_6S_3	3001	2003	Padilla
VCII	-	2004	Centro-Sur
VHA	-	2004	Centro-Sur
Cam	2011	2011	Hidalgo
Morado	1016	2016	Antiguo Morelos

was used to estimate the trend-line and the 95% confidence intervals for the expected value of the mean. The quadrants formed by this regression line and the perpendicular to the X axis were established at the point of average leaf damage of all populations. The confidence interval was also established for the mean of leaf damage with the $\mu-\sigma$ and $\mu+\sigma$ values on the X axis. Regarding the damage caused by *S. frugiperda*, the populations located to the right of the $\mu+\sigma$ value on the X axis and below the lower limit of the confidence interval were considered tolerant and susceptible; those located above the upper limit were considered sensitive and susceptible. Populations located to the left of the $\mu-\sigma$ value on the X axis and above the upper limit of the confidence interval were considered resistant and sensitive, while those on the left and below would be tolerant and resistant. The foregoing is based on the classification methodologies for tolerant and/or resistant maize cultivars developed by Widstrom *et al.* (1972), Butrón-Gómez *et al.* (1998), and Reséndiz-Ramírez *et al.* (2018).

RESULTS AND DISCUSSION

Significant differences in the leaf damage caused by *S. frugiperda* were found between populations, agricultural cycles, and management strategies, as well as for the interactions of population × management strategy and of cycle × management strategy (Table 2). An independent analysis of the management strategies between populations only showed differences within the control and between agricultural cycles. Differences in leaf damage were observed in the control, as well as in the plants treated with either synthetic or botanical insecticides. In the same way, a significant population × agricultural cycle interaction within the control was observed (Table 2). Regarding the independent analysis of each cycle, there was significance between populations only in the OI cycle.

Likewise, the leaf damage caused by *S. frugiperda* was recorded when emamectin benzoate was applied in the OI agricultural cycle (0.0724, on a scale of 0 to 5) was lower than during the PV cycle (0.3812, on the same scale). However, its levels remained lower than the rest of the management strategies (Table 3).

At the beginning of the PV agricultural cycle, the environmental conditions present a higher average temperature (minimum 23 °C and maximum 35 °C) than at the beginning of the OI cycle (minimum 13 °C and maximum 28 °C). Consequently, the greater amount of damage observed during the PV cycle in the control, when emamectin benzoate and

Table 2. Statistical significance of the combined analysis and for each management strategy of *S. frugiperda* leaf damage in maize.

Source	Combined	Control	Synthetic	Botanical	Biological-Botanical
Population (P)	0.0224	0.0079	0.7065	0.0966	0.0684
Management strategy (MS)	<.0001	-	-	-	-
Cycle (C)	<.0001	<.0001	<.0001	0.0285	0.2186
P×MS	0.0465	-	-	-	-
P×C	0.1732	0.0420	0.2345	0.9822	0.4445
MS×C	<.0001	-	-	-	-

Table 3. *S. frugiperda* leaf damage[1] in maize under different management strategies during the autumn-winter (OI) and spring-summer (PV) agricultural cycles.

Management	autumn-winter 2018-2019		spring-summer 2019	
Control	1.0527	a	1.8462	a
	B		A	
Synthetic	0.0724	c	0.3812	d
	B		A	
Botanical	0.4748	b	0.6776	c
	B		A	
Biological-Botanical	1.1074	a	0.9405	b
	A		A	

[1] Scale 0-5 (Fernández and Expósito, 2000). Means with different lowercase letters per column are statistically different (Tukey, $p \leq 0.05$). Means with different capital letters per row are statistically different (Tukey, $p \leq 0.05$).

azadirachtin were applied, is likely the result of a greater incidence of *S. frugiperda* during this cycle, favored by a higher temperature (Cantú-Almaguer *et al.*, 2010).

In this sense, when a biological-botanical insecticide was applied during the OI cycle, the leaf damage caused by *S. frugiperda* was not different from that observed in the control, while it was 50% lower during the PV cycle (Table 3). Consequently, the higher temperature during the PV cycle seems to generate a better development of the populations of entomopathogenic microorganisms (Ghazanfar *et al.*, 2020).

On the one hand, no differences were observed between the different management strategies (application of synthetic, botanical, and biological-botanical insecticides) (Table 4) in the maize populations evaluated with regard to the damage caused by *S. frugiperda*. This showed that the application of these products prevented the expression of the variation of resistance against this insect among the populations (Kumar, 2002).

Table 4. Leaf damage[1] of *S. frugiperda* in maize populations with each management strategy and during each agricultural cycle.

Population	Control		Synthetic	Botanical	Biological-Botanical
	OI	PV			
Cam	0.894 ab	1.516 a	0.132 a	0.602 a	0.752 a
PWL$_1$S$_3$	2.139 a	1.878 a	0.312 a	0.740 a	1.216 a
TGL$_2$S$_3$	1.079 ab	2.217 a	0.130 a	0.166 a	1.327 a
TML$_3$S$_3$	0.338 b	1.941 a	0.328 a	0.743 a	1.065 a
LlNL$_4$S$_3$	1.656 ab	2.087 a	0.228 a	0.408 a	1.023 a
LlHL$_5$S$_3$	0.657 b	1.051 a	0.288 a	0.463 a	0.993 a
PWL$_6$S$_3$	0.776 ab	1.580 a	0.208 a	0.517 a	0.858 a
Morado	1.077 ab	2.210 a	0.252 a	0.732 A	0.953 a
VCII	0.785 ab	2.281 a	0.218 a	0.602 A	1.190 a
VHA	1.126 ab	1.700 a	0.179 a	0.731 A	0.860 a

[1] Scale 0-5 (Fernández and Expósito, 2000). OI: Autumn-winter; PV: Spring-summer. Means with different letters per column are statistically different (Tukey, $p \leq 0.05$).

On the other hand, differences were only observed between populations during the OI agricultural cycle, which corroborates the interaction of resistance to *S. frugiperda* in maize with environmental temperature (Ni *et al.*, 2011). During the OI cycle, the TML$_3$S$_3$ and LlHL$_5$S$_3$ populations showed greater resistance to *S. frugiperda* than the PWL$_1$S$_3$ —which showed a >2.0 leaf damage— (Table 4), confirming the existing variation within the populations evaluated (Reséndiz-Ramírez *et al.*, 2017).

According to the relationship between the leaf damage and the decrease in grain yield during the OI agricultural cycle, the LlNL$_4$S$_3$ and PWL$_1$S$_3$ populations can be classified as susceptible to *S. frugiperda* since they presented a higher leaf damage at 1.56 ($\mu+\sigma$). This caused a decrease in grain yield of 11.67 and 25.04%, respectively, which indicates that they have a similar tolerance than the average of the evaluated populations (Figure 1).

The PWL$_6$S$_3$ and TML$_3$S$_3$ populations with 0.76 and 0.33 leaf damage had a >15% decrease in grain yield, which puts them above the confidence interval of the regression line; therefore, they are classified as sensitive. Only the TML$_3$S$_3$ population showed resistance to this pest (Figure 1). According to the relationship between the leaf damage and the decrease in grain yield during the PV agricultural cycle (Figure 2), the PWL$_6$S$_3$, PWL$_1$S$_3$, and PWL$_3$S$_3$ populations were classified as sensitive to damage by *S. frugiperda*, since they presented a >23% decrease in grain yield and an average resistance; they suffered a leaf damage from 1.45 ($\mu-\sigma$) to 2.23 ($\mu+\sigma$).

Finally, the TML$_2$S$_3$ and VHA populations with average leaf damage showed a <5% decrease in grain yield (Figure 2) and are therefore considered tolerant. The VCII and

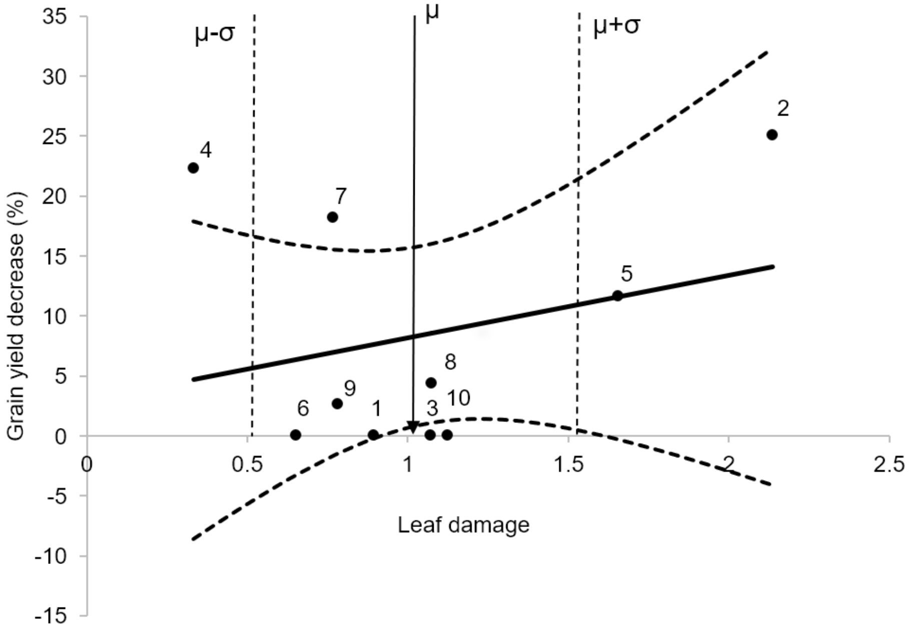

Figure 1. Relationship between the decrease in grain yield in maize populations and leaf damage caused by *Spodoptera frugiperda* in the 2018-2019 OI cycle. 1: Cam, 2: PWL$_1$S$_3$, 3: TGL$_2$S$_3$, 4: TML$_3$S$_3$, 5: LlNL$_4$S$_3$, 6: LlHL$_5$S$_3$, 7: PWL$_6$S$_3$, 8: Morado, 9: VCII, 10: VHA. μ: Mean, σ: Standard deviation. *Visual scale (Fernández and Expósito, 2000), 0: No visible damage and 5: 81-100% leaf area damaged, whorl destroyed.

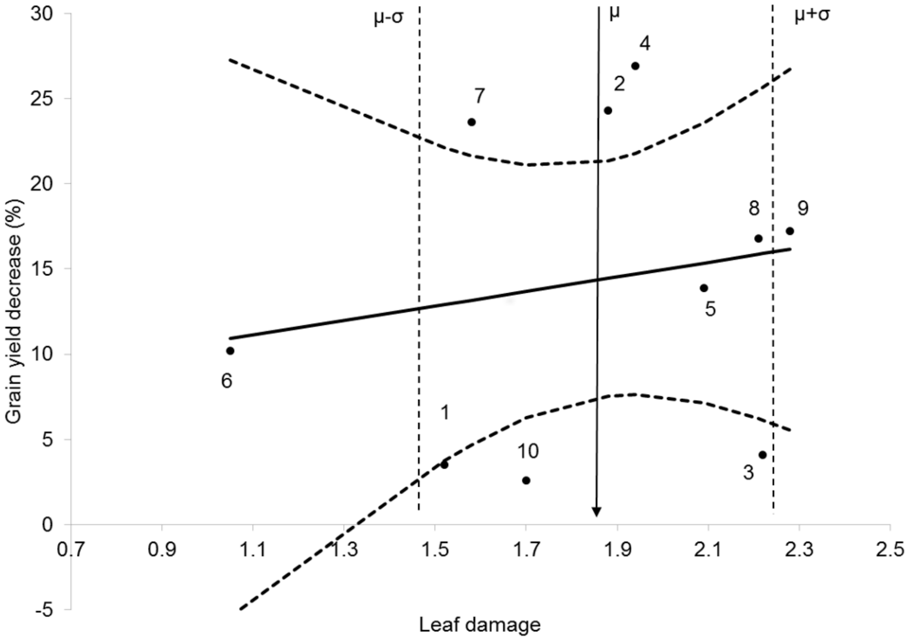

Figure 2. Relationship between the decrease in grain yield in maize populations and the leaf damage caused by *Spodoptera frugiperda* during the 2019 PV cycle. 1: Cam, 2: PWL_1S_3, 3: TGL_2S_3, 4: TML_3S_3, 5: $LlNL_4S_3$, 6: $LlHL_5S_3$, 7: PWL_6S_3, 8: Morado, 9: VCII, 10: VHA. μ: Mean, σ: Standard deviation. *Visual scale (Fernández and Expósito, 2000), 0: No visible damage, 5: 81-100% leaf area damaged, whorl destroyed.

$LlHL_5S_3$ populations with leaf damage outside the interval formed by $\mu-\sigma\sigma$and $\mu+\sigma$ are considered susceptible and resistant to *S. frugiperda* (Figure 2). Overall, *S. frugiperda* caused more damage during the PV cycle than during the OI cycle, because the higher environmental temperature during the former cycle, at the beginning of the vegetative cycle of the crop favors the development of this pest (Cantú-Almaguer *et al.*, 2010). The TML_2S_3 and VHA populations showed tolerance to leaf damage during both agricultural cycles and can, therefore, be used as a source of damage tolerance characteristics against this pest. It is important to consider that these two populations have hardiness characteristics and the populations evaluated for tolerance to *S. frugiperda* also showed genetic divergences. Therefore, they can be used as a source of variation for the genetic improvement of this characteristic.

CONCLUSIONS

Variation in leaf damage tolerance caused by *S. frugiperda* was observed among the Tamaulipas native maize evaluated populations. TGL_2S_3 and VHA were more tolerant than the average of the evaluated germplasm; therefore, these populations can be considered as a source of this characteristic.

ACKNOWLEDGEMENTS

The authors would like to thank the Consejo Nacional de Ciencia y Tecnología (CONACYT) and the Facultad de Ingeniería y Ciencias of the Universidad Autónoma de Tamaulipas for all the support they received.

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