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Exploitation of the genetic variance in maize (*Zea mays* L.) populations for the mexican tropic

Aprovechamiento de la varianza genética en poblaciones de maíz (*Zea mays* L.) para el trópico mexicano

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Abstract

VS-536, The most used maize variety in the southeast of México, present favorable plant and ear traits and adaptation to the tropical conditions. The objectives of this research were to exploit the genetic variance present in maize populations, particulary in the improved version of VS-536. In mass selection is exploited the additive portion of the genetic variance. In varietal crosses of maize formed and evaluated during 2016 to 2023, there was found int the best hybrids, the presence of the VS-536 variety as parent. It suggest that an important portion of the genetic variance correspond to dominance and overdominance gene action and they can be exploited through varietal crosses as SINT4BxVS-536 and V-537CxVS-536; These crosses registered the highest grain yield across the 10 environments in Veracruz and Tabasco states of 6.84 and 6.34 t ha^{-1} statistically similar to H-520, used as check, that registered 6.73 t ha^{-1}; Heterosis values with respect to the best parent were 15.80 and 11.21% for each cross respectively. The varietal cross SINT4BxVS-536 present short plant and ear height, tolerant to lodging, good plant and ear aspect and sanity, the leaves above the ear are in semierect position, excellent husk cover, the grain is white and present semident texture.

Gene action, *Zea mays* L., *Aditivity, overdominance*

Resumen

VS-536, variedad de maíz de mayor uso en el sureste mexicano, presenta características favorables de planta y de mazorca y adaptación a las condiciones del trópico. Los objetivos de este trabajo fueron aprovechar la varianza genética presente en poblaciones de maíz, particularmente en la versión mejorada de VS-536. La selección masal aprovecha la porción aditiva de la varianza genética. De cruzamientos varietales de maíz formados y evaluados durante 2016 al 2023, se encontró un grupo sobresaliente en el que se observó la presencia de VS-536 como progenitor. Lo anterior sugiere una porción importante de genes con tipo de acción génica dominancia o sobredominancia que pueden ser aprovechados en cruzas varietales como SINT4BxVS-536 y V-537CxVS-536; Estas cruzas registraron rendimientos a través de 10 ambientes en Veracruz y Tabasco de 6.84 y 6.34 t ha^{-1} estadísticamente similar al testigo H-520, mismo que registró 6.73 t ha^{-1}; La heterosis con respecto al mejor progenitor fue de 15.80 y 11.21% para cada cruza respectivamente. La cruza varietal SINT4BxVS-536 presenta altura de planta y mazorca baja, tolerante al acame, buen aspecto y sanidad de planta y de mazorca y las hojas arriba de la mazorca en posición semierecta, excelente cobertura de la mazorca, grano de color blanco y textura semidentada.

Acción génica, *Zea mays* L., Aditividad, sobredominancia

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Introduction

In México Maize is the most important crop because of it is part of the diet for human consumption, the sown area and generate 36% of the agriculture production value. During 2022, there were sown in México, 7.47 million of hectares with maize, which of them, 6.904, were for grain production, with an average in yield of 3.90 t ha^{-1}, and a total production of 26.55 million tons, which of them 19.35 million tons are utilized in different ways through the direct consume for human consumption; Besides, during 2022, there were imported 17.40 million tons of yellow grain for animal feed industry and an apparent *per cápita* consume of 338.10 kg; (SIAP, 2022). Improved seeds are the most important input in corn production, they represent the genetic yield potential and quality production (Sierra *et al.,* 2016).

In the humid tropic in México, at the same year there were sown 2.8 million of de hectares with maize, which of them, one million are included in agronomic provinces of good and very good productivity, and 91 thousand hectares under irrigation conditions, where is recommended the improved seed of synthetic maize varieties and hybrids (SIAP, 2022; Sierra *et al*., 2019). In the maize breeding program of Cotaxtla experimental station, INIFAP, there have been generated hybrids and synthetic maize varieties, which expressed good yield and favorable agronomic characteristics through the tropical region in the southeast of México, but above all, they have been adopted by maize farmers (Sierra *et al.,* 2019).

The synthetic maize varieties is the best way of joining the good *per se* grain yield of inbred lines and their general combining ability in generating varieties adapted to the humid tropic in México. This kind of germplasm can be used by farmers for several seasons of sown without affecting the grain yield and is easier and profitable the commercial seed production, (Márquez *et al.,* 1983; Reyes 1985; Andrés *et al.,* 2017).

Márquez *et al.,* (1983) define a synthetic maize variety those that can be maintaining by open pollination, after joining by hybridization in all combinations among one number of selected genotypes The synthetic maize varieties have been proposed as an alternative in using of hybrid (Coutiño *et al.,* 2017).

The synthetic maize varieties present an additive portion of the genetic variance, that can be exploited trough recurrent selection. However, an important portion of the genetic variance correspond to dominance and overdominance gene action that can be exploited through the heterosis in varietal crosses (Sierra *et al.,* 2019; Márquez 2014). High heterosis values suggest that exist genetic divergence between the parental varieties (Reyes, 1985; Márquez 2014; Córdova *et al.,* 2007; Sierra *et al.,* 2004; Ramírez *et al.,* 2019; Palemón *et al.,* 2012; Velasco *et al.,* 2019; Trachsel *et al.,* 2016; Gómez *et al.,* 2017).

Márquez (1974), in his contribution, the problem of the Genetic Environment Interaction in plant breeding, he wrote, F= G+E+GE,

Where:

F= Phenotype

G= Genotype

GE= Genetic Environment Interaction

According with this, if we eliminate or reduce the environment effect, automatically is eliminated the interaction and the formula is expressed as follow: F=G

In this way, is more efficient plant or family selection for each one recurrent selection method. The ways more efficient for eliminating the environmental effect are the stratification of selection plots and consider plants with complete competence or using experimental designs with replications than permit to reduce the experimental error or environmental variance.
Besides, a condition for getting genetic response to selection is that exist genetic variability in maize populations (Sierra *et al.,* 2019).

Varietal hybrids in maize represent an alternative in maize commercial production due to heterosis that result of crossing two open pollinating maize varieties as parents; Besides another advantage in this kind of hybrids are that only two parents for maintaining and is easier and profitable the commercial seed production (Sierra *et al.,* 2018; Sierra *et al.,* 2016; Reyes, 1985; Tadeo *et al.,* 2021; López *et al.,* 2021; Palemón *et al.,* 2012).

The objectives of this research were: a) To practice mass selection in the synthetic maize varieties VS-536, V-537C and SINT4B for breeding in yield and agronomic traits, b) To know the yield and the heterosis for yield with respect to the best parent in varietal crosses and c) To know the agronomic traits for the best maize varietal crosses, using the synthetic variety VS-536 as a male parent.

Materials and Methods

Localization. The mass selection plots of the maize varieties VS-536, V-537C and Sint 4B and the plot for getting the varietal crosses, were carried out in Cotaxtla experimental station in Veracruz, which belongs to INIFAP, México and is located at the km 34 through the public road from Veracruz-Córdoba in the municipality of Medellín de Bravo, Ver., in the 18º 56’ North Latitude and 96º 11’ West longitude and altitude of 15 masl. The evaluation of the maize hybrids was carried out in Cotaxtla Experimental Station and CBTA 84 in Carlos A. Carrillo municipality in Veracruz, and Huimanguillo in Tabasco, The clime condition is Aw1(w), Aw2 y Am, for each location, respectively; According with the clime classification described by Köppen and modified by García (2004), correspond to humid and subhumid warm conditions with average annual temperature of 25 ºC and annual precipitation of 1400 mm, distributed from june to november with a dry season from December to May. The soil is Vertisol, from alluvial origin, deep, with medium texture troughout the profile, slope less than 1% and good drainage and slightly acid pH (6.6) (INEGI, 2020).

Germplasm used. The germplasm used in the present research, belongs to the Tuxpeño race and they were the synthetic maize varieties VS-536, V-537C and SINT 4B on wich there were practiced four seasons of mass selection for breeding in yield and agronomic traits, and varietal maize crosses formed with experimental synthetic varieties wich of them belongs to tuxpeño race. There were evaluated 28 genotypes, wich of them 20 were varietal crosses, five experimental synthetics, the commercial varieties VS-536 and V-537C and the commercial hybrid H-520, used as check. The varietal cross SINT4B with VS-536, both open pollinating synthetic maize varieties; Particulary, SINT 4B present short plant, semierect leaves, Good yield, White grain con and semident texture.

In reference to improved version of VS-536 it was focused in selecting short plant and ear, good plant and ear aspect, dent grain, good husk cover and tolerance to lodging; present nixtamal and flour quality and good acceptance by the industry (Sierra *et al.,* 2019).

Description of the experiment. During the spring summer season from 2016 to 2023, under rainy conditions, there was carried out an experiment, for evaluating 20 varietal crosses 5 experimental maize synthetics and three commercial genotypes, which of them, were distributed in complete blocks at random, with 28 treatments and three replications in plots of two rows 5 m long and 80 cm wide in a density of 62,500 plants ha^{-1} (Reyes, 1990). The fertilization was made according to the recommendations of INIFAP, Thus, in this Cotaxtla was utilized the formula 161-46-00, applying all the Phosphorus and a third part of Nitrogen at sowing moment, the rest of Nitrogen in bunchy stage using Urea as Nitrogen source; The weeds were controlled by Atrazine applied before emerging and there were controlled pests during developing crop.

Variables and data recording. During the development of the crop and at harvest time, there were recorded in the experiment the following agronomic variables: Grain yield, days to tassel and silking, Plant and ear height, qualification of plant and ear aspect and sanity, using a scale from 1 to 5, where, 1 correspond to the best phenotypic expression and 5 for the worst; lodging, ears with bad husk cover, total number of ears, dry matter and ear rot.

Statistical methods. The experimental design used was complete blocks at random with 28 entries and three replications in plots of two rows 5m long and 80 cm wide in a plant density of 62,500 pl ha^{-1}. Individual and combined analysis of variance was made for all variables recorded and were analyzed statistically and for the separation of means, the Significant Minimum Difference test was applied at 0.05 and 0.01 of probability (Reyes, 1990). On the other hand, comparisons of cross groups and synthetic parent varieties were made and the t-test at 0.05 and 0.01 probability was applied. Besides, the percentages of heterosis with respect to the best parent (Reyes, 1985), were calculated as follows:

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$$\% \text{ of Heterosis} = \frac{\text{F1} - \text{Best parent}}{\text{Best parent}} \text{ x } 100$$

Results and discussion

Advances in selection. Actually, there has been completed the four cicle of mass selection in the synthetic maize varieties, VS-536, the most used maize variety in the southeast of México. V-537C and SINT4B; The criteria of mass selection have been short plant and ear height for reducing lodging risk, Good husk cover, lodging tolerance, good plant and ear aspect and sanity, regular ears, white grain and dent texture in VS-536 and V-537C and semident texture in the SINT4B (Sierra *et al.,* 2019); The next agriculture season will start the characterization and the proceeding for official deliver of the new improved version of synthetic variety VS-536. This new versión of VS-536, present good plant and ear aspect and sanity; The relation ear height/plant height of 0.54, it is very important for lodging tolerance, present ears with 14 regular rows, good sanity white color and dent texture (Figures 1 and 2)

Figures 1 - 2 The new version of VS-536 present good plant and ear aspect and sanity with white grain and dent texture

Grain yield. From the combined análysis for grain yield in varietal hybrids across the 10 environments of evaluation, it was found statistical signifficance, at 0.01 of probability for Genotypes (G), for environments (E) and for interaction GxE. The signifficance for the interaction suggest that grain yield of the varietal hybrids across the environments is different (Reyes, 1990; Andrés *et al.,* 2017; Sierra *et al.,* 2018).

In this analysis, the mayor variance was registered for environments with value of 68.84**, it means that environments are different and important in the behaviour of varietal crosses; Besides, the coefficient of variation registered was of 13.44%, value relatively low, that suggest that the results of these experiments are reliables (Reyes, 1990). (Table 1)

Source of variation	DF	SS	MS
Genotypes (G)	27	92.07	3.41**
Environments (E)	9	394.78	68.84**
Interaction GxE	243	306.14	1.26**
Error	455		0.7151
CV (%)			13.44%

DF= Degree Free; SC= Sum of square MS= Mean Square; CV= Coefficient of variation; **= Signifficance for source of variation at 0.01

Table 1 Combined analysis of variance for grain yield of varietal maize hybrids across the 10 environments in Veracruz and Tabasco states. 2016 a 2023

The yield of varietal hybrids across the 10 environments identified the best ones at 0.01 of probability; These ones were: SINT2BxVS536, SINT4BxVS536, SINT4BxSINT2B, SINT5Bx VS-536, SINT5BxVS537C, SINT1BQxVS-536 and SINT3BxSINT1BQ, with grain yield from 6.39 to 6.96 t ha^{-1}, statistically similar to the commercial hybrid H-520, the most used in the southeast of México (Sierra *et al.,* 2019) Table 2

In the heterosis for the best varietal hybrids with respect to the best parent there were found values from 4.85 to 17.70%; The highest percentages of Heterosis were gotten for SINT2BxVS536 (17.70%), SINT4BxVS-536 (15.80%), SINT4B xSINT2B (10.78%), V537CxVS536 (11.21%).

Entry	Genealogy	Grain Yield[1/] t ha^{-1}	% Relative	% Heterosis
1	SINT2BxVS-536	6.96*	103	17.70
14	SINT4BxVS-536	6.84*	102	15.80
28	H-520	6.73*	100	
17	SINT4BxSINT2B	6.55*	97	10.78
16	SINT-5B x VS-536	6.48**	96	5.93
9	SINT-5B xV-537C	6.42**	95	4.91
13	SINT1BQxVS-536	6.41**	95	5.25
10	H-518	6.39**	95	
18	SINT3BxSINT1BQ	6.39**	95	4.85
12	SINT4BxSINT3B	6.37	95	7.75
19	SINT2BxVS537C	6.34	94	7.32
4	V-537CxVS-536	6.34	94	11.21
20	VS536xV537C	6.33	94	11.07
15	SINT5BxSINT1BQ	6.32	94	3.28
3	SINT5BxSINT4B	6.32	94	3.27
6	SINT3BxVS537C	6.31	94	7.24

Entry	Genealogy	Grain Yield[1/] t ha-1	% Relative	% Heterosis
11	SINT3BxSINT2B	6.30	94	6.54
2	SINT5BxSINT2B	6.29	93	2.81
25	SINT-5B	6.12	91	
5	SINT4BxVS537C	6.10	91	3.27
8	SINT4BxSINT1BQ	6.09	90	-0.03
21	SINT-1BQ	6.09	90	
7	SINT5BxSINT3B	6.07	90	-0.76
22	SINT-2B	5.91	88	
24	SINT-4B	5.91	88	
23	SINT-3B	5.88	87	
27	V-537 C	5.70	85	
26	VS-536	5.46	81	
	PROMEDIO	6.26		
	CV (%)	13.44		
	CME	0.7151		
	DMS 0.05	0.4279		
	DMS 0.01	0.5633		

[1/]= Mean Grain yield in 10 environments of evaluation; *and **/= Signifficance of genotypes at 0.05 and 0.01 of probability;

Table 2 Grain yield of varietal maize hybrids across 10 environments in Veracruz and Tabasco states 2016-2023

These Heterosis values suggests genetic divergence between the parental varieties (Reyes, 1985; Córdova *et al.*, 2007; Sierra *et al.*, 2004; Palemón *et al.*, 2012; Velasco *et al.*, 2019) (Figure 3).

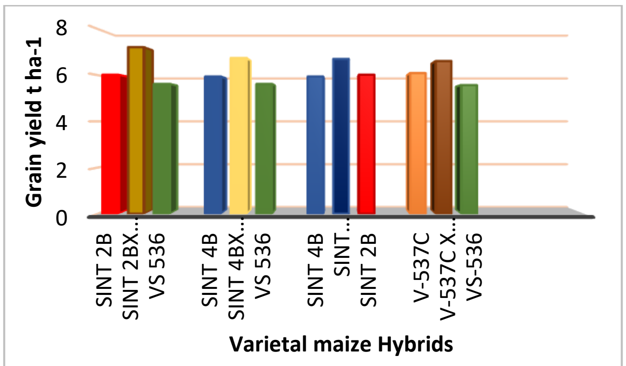

Figure 3 Heterosis in varietal maize hybrids Veracruz and Tabasco states 2016-2023

The best varietal hybrids were statistically similar to H-520, commercial hybrid used as check, and is the most used in the southeast of México; Besides these varietal hybrids take the advantage of maintaining only two parents, which are open pollinating maize varieties with greater yield, reliability, and easier for seed production (Sierra *et al.*, 2018; Sierra *et al.*, 2016; Gómez *et al.*, 2017; López *et al.*, 2021; Ramírez *et al.*, 2019; Tadeo *et al.*, 2021). In the best varietal hybrids participate VS-536, the synthetic maize variety of greater use in the Mexican southeast (Sierra et al., 2016).

Instead of grain yield and agronomic traits, it is suggested that the varietal cross SINT4BxVS-536, can be registered as new maize hybrid for the humid tropic in México. This varietal hybrid, present good yield, adaptation to the humid tropic of México, short plant and ear, good plant and ear aspect and sanity and good husk cover (Figures 4 and 5).

Environmental indexes. Instead of environmental indexes, Carlos A. Carrillo, Ver. 2016B and Cotaxtla, Ver., 2016B, recorded the highest yield with 7.29** and 7.27** t ha^{-1} and the greatest environmental indexes, 1.03** and 1.01** for each environment, respectively.

Figures 4 - 5 SINT4BxVS-536 present short plant and ear, good plant and ear aspect and, Good husk cover, white grain and semident texture

On the other hand, the locations Huimanguillo Tabasco in 2018 and 2016B registered the lowest grain yield with 5.40 and 5.18 t ha^{-1}, and negative environmental indexes of -0.86 and -1.08, (Table 3). It suggest, that there are important differences in these environments in clime, soil and agronomic management for these experiments (Reyes, *et al.*, 1990; Sierra *et al.*, 2018).

Environment	Grain yield t ha-1	Env indexes
Carlos A. Carrillo, 2016B	7.29**	1.03
Cotaxtla 2016B	7.27**	1.01
Cotaxtla 2018B	6.48	0.22
Carlos A. Carrillo, 2023A	6.46	0.20
Huimanguillo 2023A	6.39	0.13
Cotaxtla 2022B	6.36	0.10
Cotaxtla 2017B	6.03	-0.23
Cotaxtla 2023A	5.72	-0.54
Huimanguillo 2018B	5.40	-0.86
Huimanguillo, Tab 2016B	5.18	-1.08
Mean	6.26	

Table 3 Environmental indexes in varietal maize hybrids 2016-2023. CIRGOC INIFAP

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Comparisons and t test. From the comparisons and t test at 0.05 and 0.01 of probability, there was found that the varietal hybrids recorded an average grain yield of 6.38 t ha^{-1} , 9 % more than the synthetic varieties parents with value for the calculated t test of 5.07**; Besides, there was registered advantages in plant and ear aspect (Reyes, 1990). It suggests that there is genetic divergence between the parents, which is also reflected in the values of heterosis with respect to the best progenitor that varied from 4.85 to 17.70 % (Reyes, 1985; Sierra *et al.,* 2004; Córdova *et al.,* 2007; Palemón *et al.,* 2012; Velasco *et al.,* 2019) (Table 4).

Comparison	Grain yield t ha^{-1}	% Rel	t Calc	Plant heigh	% Rel	t Calc	Plant Asp[2/]	% Rel	t Calc	Ear Asp[2/]	% Rel	t Calc
Crosses	6.38	109	5.07**	231.75	103	0.93NS	2.25	100	0.92NS	2.43	100	0.57NS
Parents	5.87	100		225.57	100		2.37	105		2.51	103	

t0.05 (54 GL) = 2.00; t0.01 (54 GL) =2.66. % Rel= Relative percentage; t Calc= t calculated; plant asp= plant aspect; ear asp = Ear aspect; [2/]= Qualification scale from 1 to 5, where, 1 correspond to plants and ears with the best phenotypic expression and 5 for the worst

Table 4 Comparisons and t test for varietal maize hybrids and their parents. CIRGOC 2016-2023

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Conclusions

The outstanding varietal hybrids at 0.05 probability were: SINT-2BxVS-536, SINT-4BxVS-536, SINT-4BxSINT-2B, with grain yield from 6.55 to 6.96 t ha^{-1}, yield statistically similar to that recorded by the commercial hybrid H-520.

Heterosis percentages with respect to the best parent in the outstanding varietal crosses were: SINT-2BxVS-536 (17.70%), SINT-4BxVS-536 (15.80%), SINT-4BxSINT-2B (10.78%), V-537CxVS-536 (11.21%).

The crosses recorded an average yield of 6.38 t ha^{-1}, 9% more in relation to the parents, as well as better plant and ear aspect scores.

Based on grain yield and agronomic characteristics, the cross SINT-4BxVS-536 is proposed for official registration with SNICS as HV-570, New maize hybrid for the humid tropics of Mexico.

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