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Yield and stability in synthetic maize varieties for the humid tropic in Mexico

Rendimiento y estabilidad de variedades sintéticas de maíz para el trópico húmedo de México

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Abstract

Synthetic maize varieties present advantages in adaptability, they can be used for several planting seasons, without affecting the yield and is easier the seed production. Thus, with the main objective of knowing the yield and agronomic traits of synthetic maize varieties for the tropic, during 2013 to 2018 there was conducted an experiment in Cotaxtla and Carlos A. Carrillo in Veracruz and Huimanguillo in Tabasco state locations. The experiment was distributed in complete blocks at random design with 21 entries and three replications in plots of two rows 5m long and 62,500 pl ha^{-1}. The agronomic traits were: Grain yield, days to tassel and silking, plant and ear aspect and sanity, lodging, bad husk cover and ear rot. From the combined analysis for yield, there was found high significant differences for Varieties (V), For environments (E), and for the interaction VxE, and a coefficient of variation of 16.20%. The Carlos A. Carrillo, Ver., location in 2016B, recorded the highest yield with 6.94 t ha^{-1}. The best five synthetics at 0.05 of probability were: VS-536, Synthetic 2B, Synthetic 5B, Synthetic 2C and Synthetic 11C.

Synthetic, Maize, Varieties

Resumen

Las variedades sintéticas de maíz presentan ventajas de mayor adaptabilidad, pueden ser usadas por varios ciclos de siembra sin que se afecte el rendimiento y es más fácil la producción de su semilla. Así, con el objetivo de conocer el rendimiento y características agronómicas de variedades sintéticas de maíz para el trópico, entre 2013 y 2018 se condujeron experimentos en las localidades de Campo Cotaxtla y Carlos A. Carrillo en Veracruz y Huimanguillo en Tabasco. El diseño utilizado fue bloques completos al azar con 21 tratamientos y tres repeticiones en parcelas de dos surcos de 5 m de largo en una densidad de 62,500 pl ha^{-1}. Las variables agronómicas fueron: Rendimiento de grano, días a floración, altura de planta, aspecto y sanidad de planta y de mazorca, acame, mala cobertura de mazorca y mazorcas podridas. Del análisis combinado para rendimiento, se encontró diferencia altamente significativa para Variedades (V), para Ambientes (A) y para la interacción VxA y un coeficiente de variación de 16.20%. La localidad de Carlos A. Carrillo, Ver., en 2016B registró el rendimiento más alto con 6.94 t ha^{-1}. Los sintéticos superiores al 0.05 de probabilidad, fueron: VS-536, Sintético 2B, Sintético 5B, Sintético 2C y Sintético 11C.

Variedades, Sintéticas, Maíz

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Introduction

In México, there are planted 8.2 million of hectares with maize where farmers produce 22 million tons of grain and a per cápita apparent consume of 209.8 kg. (Morris and López, 2000). The principal use is the direct consume for human consumption, particulary, there were using 12.3 million of tons, which of them 36% correspond to flour industry and 64% to masa tortilla industry through the nixtamalization process (SAGARPA, 2016).

In the tropical region there are planted 3.2 million hectares with maize, which of them, one million are included in agronomic provinces of good and very good productivity, where is recommended the improved seed of synthetic maize varieties and hybrids (Sierra *et al.*, 2019).

In México exist 31 million of malnutrition people, which of them, 18 million with severe malnutrition (Espinosa *et al*., 2006). The consumption of high quality protein maize may contribute to get better the nutritional level in México, especially in children, mothers in lactation and old people (Espinosa *et al.*, 2005).

High quality protein maize is derived from the utilization of a mutant opaque gene o2o2, expressed in its homocigotic recessive version which present more Lysine and Tryptophan content, essential aminoacids for nutrition (Mertz, 1994; Vasal, 1994). Vasal and Villegas (2001), through traditional methods of maize breeding, incorporated special genes to the opaque gene o2o2 named modifiers genes in the endosperm texture. Maize with the opaque gene o2o2 content from 40 to 50% more Lysine and 35 to 40% more Tryptophan than the normal maize (Larkins *et al*., 1994; Sierra *et al*., 2011).

Reyes, *et al*., in 2021, found response in yield, Protein, Lysine and Tryptophan content, essential aminoacids for nutrition, when they apply different doses of Nitrogen and Phosphorus in maize.

Alternative management to conventional agriculture can be profitable, in addition to preserving the physical integrity, being beneficent to the environment, increasing the quality and added value for agricultural products and can be adopted by small, medium and great farmers (Álvarez, 2021).

Synthetic maize varieties present advantages of greater adaptability to clime and soil conditions and agronomic management by farmers in their traditional system of planting in the humid tropic of México, (Nuñez and Navarro, 2021), besides, they can be used for several planting seasons without affecting the grain yield and is easier and cheaper their seed production; with these advantages is feasible to increase the use the improved seed (Madera and Múnera, 2021; Sierra *et al*., 2016; Reyes, 1985).

The Synthetic maize varieties are the best way of using the good per se yield and general combining ability of inbred lines to form varieties with high yield and wide adaptation (Acevedo, 2021; Sierra *et al*., 2016; Andrés *et al*., 2017). Sprague (1955) define Synthetic maize varieties like the advance generations of a multiple hybrid, generally are formed for more than four inbred lines.

Busbice (1970) indicated that the number of inbred lines used to form a synthetic maize variety depends on the inbreeding of their parents; It is needed more inbred lines when inbreeding is greater. Márquez *et al.*, (1983), working with the basic inbred lines for the humid tropic in Campo Cotaxtla, Ver., and they found that the optimum number of inbred lines used for making a synthetic variety was between 8 to 12.

VS-536, was developed from 1984 to 1992, in Cotaxtla experimental station which belongs to INIFAP in México, and was formed through the genetic recombination of nine inbred lines, which were selected considering the per se behavior and the General Combining Ability (GCA): The inbred lines LE27, LE36, LE37, LE73, were formed in Cotaxtla, INIFAP; D471, D-539, D368, from Iguala, Gro., maize program; OCOT2 y LRB14-413-7 are lines from the Ocotlán, Jal., and Río Bravo, Tamps., programs respectively. The diversity in the genetic and geographic origin has been permitted to VS-536, greater adaptability (Sierra *et al.*, 2016).

Adaptability in genotypes permit to know the response to different environments, which are defined by clime and soil conditions, and agronomic management, (Eberhart and Russell, 1966).

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The genotype environment interaction is the relative differential behavior from genotypes through different environments (Márquez 1992; Reyes 1990; Andrés *et al.*, 2017; Sierra *et al.*, 2018). The objectives of this research were to know the yield and agronomic characteristics of synthetic maize varieties for the humid tropic.

Materials and Methods

Localization. This research was carried out during the spring summer season in 2013, 2016 and 2018 and autumn winter season 2013/14, in Cotaxtla Experimental Station and Carlos A. Carrillo in Veracruz and Huimanguillo Tabasco state locations; The clime conditions are Aw1, Aw2 and Am for each location respectively, according with the clime classification described by Köppen modified by García (2004) and correspond to humid and subhumid warm conditions.

Germplasm used. The germplasm used in this research were experimental synthetic maize varieties which were formed with experimental normal and quality protein inbred lines, which were selected through the *per se* grain yield and good general combining ability (GCA) (Acevedo, 2021), and they belong to the Tuxpeño race; Particulary, there are included 21 synthetic varieties, which of them, 11 have been formed with lines converted to high quality protein character, on which we added the letter "C" as nomenclature, the rest of synthetics have normal endosperm; Finally, the synthetic variety VS-536, the most used variety in the southeast of México and V-537C, high quality protein variety were used as checks.

Description of the experiments. The experiments of synthetic maize varieties were planted in plots of two rows 5 m long and 80 cm wide in a density of 62,500 pl ha^{-1}. The weeds were controlled by Atrazine applied before emerging and there were controlled pests during developing crop. The fertilization was made according the recommendations of INIFAP for each location. In Cotaxtla experiment station was utilized the formula 161-46-00, applying all the Phosphorus and a third part of Nitrogen at planting moment, the rest of Nitrogen in bunchy stage using Urea as Nitrogen source.

Variables and data recording. During the development of the crop and at the time of harvest, there were recorded in the experiments the following variables: Grain yield, days to tassel, days to silking, plant and ear height, plant and ear aspect, lodging, ears with bad husk cover, dry matter, and ear rot.

Statistical methods. The experimental designs used were complete blocks at random with 21 treatments and three replications in plots of two rows 5m long and 80 cm wide. Individual analysis of variance was made for each experiment and a combined analysis for grain yield in the synthetic varieties across the six locations (Reyes, 1990). The variables recorded were analyzed statistically and for the separation of means, the significant minimum difference test was applied at 0.05 and 0.01 of probability. Besides, a stability parameters analysis by Eberhart and Russell (1966) was applied for grain yield and the varieties were described according with their response through the evaluation environments.

Results and discussion

From the combined analysis for grain yield in the synthetic varieties across the six locations evaluated, there were found statistical significance at 0.01 of probability for Varieties (V), for Environments (E) and for the interaction VxE (Márquez, 1992), with a Coefficient of Variation of 16.20%, value relatively low, and suggest that the results gotten and the management of the experiments are reliable (Reyes, 1990). In addition, the significance for interaction VxE, suggest that the grain yield in the synthetic varieties across the six locations evaluated were different (Table 1). The highest variance was recorded for the source of variation environments, factor valued in 127.12**, which means that these environments were different and important in the behavior of synthetic maize varieties (Reyes, 1990).

Source of Variation	DF	SS	MS
Varieties (V)	20	81.92	4.10**
Environments (E)	5	635.61	127.12**
Interaction VxE	100	198.78	1.99**
Error	240		0.60
DF=Degree of freedom; SS=Square Sum; MS=Mean Square; **=Significance for source of variation at 0.01 of probability			

Table 1 Combined Analysis of Variance for grain yield in Synthetic maize varieties across six environments in the humid tropic. CIRGOC INIFAP 2013-2018

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Grain yield. In relation with grain yield (Table 2), and the stability parameters (Eberhart and Russell, 1966), Except Synthetic 3B, identified with better response in unfavourable environments and consistent, the rest of varieties were characterized as "Stables", among this group were: VS-536 the most used variety in the southeast of México, Synthetic 2B, Synthetic 5B, Synthetic 2C, and Synthetic 11C, these two last ones with high quality protein, were statistically the best at 0.05 of probability (Reyes, 1990); This is why are considering as "Desirables" (Márquez, 1992; Sierra *et al.*, 2018). These results indicate that exist synthetic maize varieties feasible in using by farmers in the southeast of México, where is recommended the use of improvement seed of hybrids and synthetic maize varieties (Nuñez y Navarro, 2021; Madera and Múnera, 2021; Sierra *et al.*, 2016; Andrés *et al.*, 2017; Sierra *et al.*, 2019).

Entry	Genealogy	Cot 2013B	Cot 2014A	Cot 2016B	Carrillo 2016B	Huim 2016B	Cot 2018B	Mean	Description
20	VS-536	3.47	5.40	5.67	7.99	4.09	7.1	5.62*	S
2	SYNTHETIC-2B	3.75	5.40	5.58	6.99	3.44	7.09	5.38*	S
5	SYNTHETIC-5B	3.75	5.20	6.17	8.05	2.21	6.63	5.34*	S
14	SYNTHETIC-2C	3.80	4.70	4.85	6.77	4.67	6.73	5.25*	S
17	SYNTHETIC-11C	3.75	5.40	5.82	7.78	1.25	7.21	5.20*	S
1	SYNTHETIC-1BQ	4.32	4.50	5.63	7.55	3.6	4.94	5.09**	S
16	SYNTHETIC-LPSC3	3.10	3.90	5.25	8.70	3.59	5.67	5.04**	S
13	SYNTHETIC-9C	3.15	4.70	5.34	7.43	3.62	5.76	5.00**	S
3	SYNTHETIC-3B	4.30	4.90	5.69	6.32	4.36	4.4	4.99**	BUC
19	SYNTHETIC-10C	3.10	4.60	4.52	6.30	4.56	6.7	4.96**	S
10	SYNTHETIC-7C	3.25	5.10	5.13	7.04	4.01	5.22	4.96**	S
18	SYNTHETIC-8C	3.30	4.80	5.80	6.35	2.97	5.77	4.83	S
21	V-537C	3.40	3.60	4.42	7.07	3.39	5.53	4.57	S
4	SYNTHETIC-4B	3.90	4.90	4.13	7.68	2.53	3.94	4.51	S
12	SYNTHETIC-1C	2.70	4.50	4.01	7.31	3.29	5	4.47	S
15	SYNTHETIC-3C	3.55	5.10	4.94	7.86	0.98	4.32	4.46	S
9	SYNTHETIC-4C	2.45	4.80	5.54	5.87	3.06	4.83	4.42	S
11	SYNTHETIC-TS-6	2.70	4.10	4.19	5.57	1.91	7.19	4.28	S
7	SYNTHETIC-5C	4.00	3.50	4.90	6.53	2.87	3.82	4.27	S
8	SYNTHETIC-3SEQ	2.40	5.30	3.15	5.29	2.4	5.58	4.02	S
6	SYNTHETIC-6C	2.55	3.60	5.48	5.33	2.86	3.1	3.82	S
	Mean	3.37	4.67	5.06	6.94	3.12	5.55	4.78	
	MSE	0.40	0.47	0.35	0.89	0.68	0.82	0.60	
	SMD 0.05	1.24	1.37	1.24	1.56	1.63	1.49	0.51	
	SMD 0.01	1.64	1.82	1.69	2.08	2.16	1.99	0.67	
	CV (%)	18.76	14.68	11.69	13.59	26.43	16.32	16.20	

* and **= Significance of the treataments al 05 and 0.01of probability; A= Autumn Winter season; B= Spring Summer season; Cot= Cotaxtla Experimental Station; Carrillo= Municipality of Carlos A. Carrillo; Huim= Huimanguillo, Tab.; S= Stable Variety; BUC= Better response in Unfavourable Environments and Consistent; MSE= Mean Square Error; CV= Coefficient of Variation; SMD= Significant Minimum Difference

Table 2 Grain yield in synthetic maize varieties across the six environments. CIRGOC INIFAP 2013-2018

Thus, it can be feasible to make use of the advantages in yield, adaptation and above all that these varieties can be used for several planting seasons without affecting the yield, in addition is easier and cheaper their seed production (Alvarez, 2021; Nuñez and Navarro, 2021; Madera and Múnera, 2021; Sierra *et al*., 2016; Sprague, 1955; Busbice, 1970; Marquez *et al.*, 1983; Reyes, 1985)

Environmental indexes. In relation with the environmental indexes by Eberhart and Russell (1966), the location of the municipality Carlos A. Carrillo in Veracruz in 2016B, recorded the highest yield with 6.94 t ha^{-1} and the greatest environmental index 2.16**. Also, the environments of Cotaxtla, Ver., in 2018B and 2016B and recorded high yield with 5.55 and 5.06 t ha^{-1}, for each environment respectively, with positive environmental indexes 0.77 and 0.28.

On the other hand, the locations Cotaxtla, Ver., in 2013B and 2014A and Huimanguillo, Tab., in 2016B, registered the lowest grain yield with 4.67, 3.37 y 3.12 t ha^{-1}, and negative environmental indexes of -0.12, -1.42 y -1.67 (Table 3). It suggest, that there are important differences in these environments in clime, soil and agronomic management for these experiments (Reyes, *et al.*, 2021; Sierra *et al.*, 2018).

Environment	Grain yield t ha^{-1}	Environmental Index
C.A. Carrillo, Ver. 2016B	6.94	2.16**
Cotaxtla, Ver. 2018B	5.55	0.77
Cotaxtla, Ver. 2016B	5.06	0.28
Cotaxtla, Ver., 2014A	4.67	-0.12
Cotaxtla, Ver. 2013B	3.37	-1.42
Huimanguillo, Tab 2016B	3.12	-1.67
Mean	**4.785**	

**=Significance for Environmental index at 0.01 of probability

Table 3 Environmental indexes in synthetic maize varieties CIRGOC INIFAP 2013-2018

Agronomic performance and characteristics. From the combined analysis for agronomic characteristics, in Cotaxtla, Ver., in 2016B and 2018B, there were found significant differences at 0.01 of probability for Varieties (V), for environments (E) and for interaction VxE for variables: Days to tassel, plant height, plant and ear aspect (Márquez, 1992); On the other hand, for plant and ear sanity there was found significance only for interaction VxE. Significance for the interaction, suggest that the agronomic characteristics of the synthetic maize varieties across the environments of evaluation was different (Table 4). The coefficient of variation recorded were 2.93, 7.76, 10.08, 12.98, 15.06 and 15.22% for variables: Days to tassel, plant height, plant and ear aspect, plant and ear sanity, respectively, are values relatively low, that suggest that the results gotten and the management of experiments are reliables (Reyes, 1990; Reyes, *et al.*, 2021). Also, with exception of the variables plant and ear sanity, in the rest four variables, the greater variance was doubt to environment source of variation with values of, 73.14**, 6051.42**, 2.05**, 0.738*, that indicates that the environments are significant different and important in the behavior of the synthetic maize varieties (Reyes, 1990).

Source of Variation	DF	DT	PH	Pl asp$^{1/}$	Ear asp$^{1/}$	Pl san$^{1/}$	Ear san$^{1/}$
Varieties (V)	20	4.20**	703.69**	0.263**	0.273 **	0.196 NS	0.174 NS
Environments(E)	1	73.14 **	6051.42 **	2.05**	0.738 *	0.029 NS	0.118 NS
Interaction VxE	20	10.50 **	1324.11 **	0.5055 **	0.48**	0.393**	0.444**
Error	40	2.27	259.18	0.0615	0.108	0.1231	0.1323
CV (%)		2.93	7.76	10.08	12.98	15.06	15.22
1/=Scale of qualification from 1 to 5 where 1 means the best and 5 the worst; *=Significance for the sources of variation at 0.05 of probability; **= Significance for the sources of variation at 0.01 of probability; DF=Degree of Freedom; DT=Days to Tassel; PH=Plant Height; Pl asp=Plant aspect; Ear asp=Ear aspect; Pl San =Plant sanity; Ear san=Ear sanity; CV=Coefficient of Variation							

Table 4 Mean square and significance in the combined analysis of variance for agronomic characteristics in Synthetic maize varieties Cotaxtla 2016B y Cotaxtla 2018B. CIRGOC INIFAP

In relation with the agronomic characteristics, the experimental synthetics recorded from 51 to 53 days to tassel, short plant height with 186 to 224 cm, which permit in natural way lodging tolerance promoted by the winds; Besides, they present good plant and ear aspect and plant and ear sanity (Table 5). The Synthetics 2B, 5B, 2C and 11C that were competitive in grain yield across the six evaluation environments, they present similar plant height than VS-536, the most used synthetic maize variety in the humid tropic in the southeast of México.

Entry	Genealogy	DT	PH	Pl asp$^{1/}$	Ear asp$^{1/}$	Pl san$^{1/}$	Ear san$^{1/}$
1	SYNTHETIC-1BQ	51	203	2.58	2.35	2.33	2.44
2	SYNTHETIC-2B	51	224	2.60	2.02	2.26	2.07
3	SYNTHETIC-3B	52	205	2.60	2.64	2.25	2.28
4	SYNTHETIC-4B	52	219	2.33	2.43	2.29	2.37
5	SYNTHETIC-5B	53	222	1.88	2.21	2.07	2.30
6	SYNTHETIC-6C	51	200	2.69	2.68	2.37	2.18
7	SYNTHETIC-5C	52	194	2.63	2.51	2.50	2.45
8	SYNTHETIC-3SEQ	52	215	2.44	2.59	2.45	2.43
9	SYNTHETIC-4C	51	220	2.44	2.44	2.33	2.36
10	SYNTHETIC-7C	52	204	2.62	2.58	2.58	2.44
11	SYNTHETIC-TS-6	50	196	2.42	2.63	2.37	2.27
12	SYNTHETIC-1C	50	196	2.78	3.03	2.78	2.76
13	SYNTHETIC-9C	51	207	2.64	2.71	2.25	2.65
14	SYNTHETIC-2C	52	215	2.42	2.31	2.50	2.28
15	SYNTHETIC-3C	52	186	2.48	2.81	2.25	2.69
16	SYNTHETIC-LPS-C3	50	207	2.61	2.55	2.42	2.31
17	SYNTHETIC-11C	51	201	2.44	2.56	1.99	2.42
18	SYNTHETIC-8C	51	196	2.22	2.50	2.09	2.44
19	SYNTHETIC-10C	52	204	2.16	2.61	2.25	2.16
20	VS-536	53	218	2.34	2.38	2.33	2.44
21	V-537C	53	221	2.31	2.53	2.16	2.47
	Mean	51.43	207.3	2.46	2.53	2.33	2.39
	MSE	2.27	259.18	0.0615	0.108	0.1231	0.1323
	CV (%)	2.93	7.76	10.08	12.98	15.06	15.22
DT=Days to Tassel; PH=Plant Height; Pl asp=Plant aspect; Ear asp=Ear aspect; Pl San =Plant sanity; Ear san=Ear sanity; MSE= Mean Square Error; CV=Coefficient of variation; 1/=Scale of qualification from 1 to 5 where 1 means the best and 5 the worst							

Table 5 Agronomic characteristics in synthetic maize varieties. Cotaxtla 2016B y Cotaxtla 2018B CIRGOC INIFAP

Quality protein. A sample of synthetics maize varieties formed with converted inbred lines to high quality protein character, among these, the synthetics 1C, 2C, 4C and 5C (Table 6). There was found that these synthetics obtained from 36 to 55% more Lysine and from 62 to 106% more Tryptophan than the normal maize (Sierra *et al*., 2011; Reyes, *et al*., 2021; Alvarez, 2021).

This information suggest that these synthetics are characterized as quality protein maize and represent a possibility to get better the nutrition in Mexican people specially children, lactating mothers and old people which diet is based on maize. (Espinosa *et al*., 2006; Espinosa *et al*., 2005; Mertz, 1994; Vasal, 1994; Larkins *et al*., 1994; Vasal and Villegas, 2001).

Genotype	% Lysine	% Relative	Genotype	% Tryptophan	% Relative
Synthetic 1C	0.390	155	Synthetic 5C	0.113	206
Synthetic 5C	0.375	149	Synthetic 1C	0.095	173
Synthetic 2C	0.359	142	Synthetic 4C	0.093	169
Synthetic 4C	0.342	136	Synthetic 2C	0.089	162
General mean	0.367			0.098	
Tuxpeño (normal)	0.252	100		0.055	100
B= Spring summer season; The nomenclature of the Synthetics 1C, 2C, 4C and 5C for indicating quality protein, it means that they were formed with converted inbred lines to quality protein character.					

Table 6 Lysine and Tryptophan content, in maize synthetics formed with inbred lines converted to high quality protein character. Cotaxtla 2010B. CIRGOC. INIFAP

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Conclusions

There were found experimental maize varieties with high grain yield and favourable agronomic characteristics across the six environments of evaluation.

The synthetics 2B, 5B, 2C and 11C are competitive in grain yield and recorded short height plant with good plant and ear aspect. Besides, these experimental synthetics were characterized as “Stables”.

The synthetic maize varieties represent an alternative of using in commercial maize production in tropical area for the southeast of México.

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