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Performance of white grain corn hybrids in five locations in High Valleys de México

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Abstract

Given the insufficiency in corn production, which translates into the import of up to 15 million tons of grain, it is urgent to increase the productivity of this crop, using more and better varieties. The objective of this work was to determine the agronomic characteristics of white hybrids in five different environments, the best response, as well as to define the effect of genotype × environment interaction on yield, and other characteristics evaluated for the High Valleys of Mexico (2 200 at 2 600 meters above sea level). In the spring-summer 2016 agricultural cycle, ten maize hybrids were evaluated in five locations using an experimental design of randomized complete blocks, with four repetitions. The analysis was factorial considering as factors the environments (5), the hybrids (10), as well as the environment × hybrid interaction. Eight agronomic variables were evaluated. Anovas and comparisons of Tukey means $p= 0.05$ were performed. Both factors presented differential responses and the variables evaluated were influenced by the effect of the environment. The hybrids with the highest average productivity were ATZIRI PUMA (12 t ha^{-1}) and TSIRI PUMA (11.8 t ha^{-1}) followed by the hybrids H-50, H-66 and H-70, which produced 11.5, 11.6 and 11.6 t ha^{-1} respectively. Considering that H-50 is one of the hybrids of greater commercial use in the High Valleys, the four referred hybrids of greater yield of white grain, could have perspectives of commercial use, in the environments managed in this study.

Keywords: *Zea mays* L., environment, male sterility, genetic improvement.

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Introduction

In Mexico, the cultivation of corn is the most important, since it is the basis of the Mexican diet, about 8.5 million hectares are sown. However, at the national level, only 22 million tons of corn grain are produced, which forces practically the import of 10 to 12 million tons of yellow grain, since the apparent total consumption of corn is 32 to 34 million of tons. The average yield that is reached is 2.8 t ha^{-1} (Turrent, 2009). Imports during the year 2018 are estimated to reach 15 million tons, placing Mexico as the importer of this number one grain worldwide, displacing Japan (Espinosa and Tadeo, 2018).

Particularly in the State of Mexico, maize grain is produced in an area of 530 thousand hectares, of which 84% are cultivated under rainfed conditions and the rest through irrigation. The state production is 2.3 million tons with an average yield of 4.4 t ha^{-1} (SIAP, 2016). The yield in the State of Mexico, due to the low production per unit area, could be increased if more improved varieties are used, with high yield potentials (Virgen *et al*., 2016). Therefore, it is urgent to take advantage of the available improved varieties generated by public research institutions.

The low production of maize is associated with irregular distribution of rainfall, early frost, hail, soil depth, texture of the topsoil, slope and low fertility of soils, high degree of erosion, as well as low yield, late and susceptible to lodging (María *et al*., 2003). Therefore, genotypes that maintain a stable response in different environments and years are required, in addition to a high yield, which is feasible depending on the genetic potential of the hybrid (Arellano *et al*., 2011). The increase in yield is 60% dependent on the genetic potential of the hybrid and 40% on crop management practices (Espinosa *et al*., 2008a; Arellano *et al*., 2011).

In recent years, constant work has been done in the genetic improvement program of the National Forestry, Agriculture and Livestock Research Institute (INIFAP), to increase the yield of maize grain with the release of new improved varieties (Espinosa *et al*., 2003, Espinosa *et al*., 2008b, Espinosa *et al*., 2010; Espinosa *et al*., 2012; Tadeo *et al*., 2016a; Espinosa *et al*., 2018), in parallel, research on the adoption of best practices in the chemical and foliar fertilization and management in the corn crop in High Valleys (Zamudio *et al*., 2015).

Since 1992, researchers from the National Institute of Forestry, Agriculture and Livestock Research (INIFAP) and the National Autonomous University of Mexico (UNAM) have worked with sources of male sterility and their incorporation into the progenitors of corn hybrids (Tadeo *et al*., 2010; Tadeo *et al*., 2014a; Tadeo *et al*., 2016a; Espinosa *et al*., 2018). Androsterility (AE) is the inability of plants to produce anthers, pollen or functional pollen grains; This scheme is used in the production of hybrid corn seed to increase the yield and the genetic quality of the seed (Martínez *et al*., 2005), which avoids the detasseling of the plants and favors the producer, because it generates seed with genetic quality and with lower price (Tadeo *et al*., 2015). In contrast, the use of fertile parents, where six rows of female lines are regularly alternated by two of male lines (Tadeo *et al*., 2013), is more expensive due to the manual removal of the male inflorescence before pollen release.

In this sense, one of the challenges in breeding programs is to obtain genotypes with higher yields, but often the yield potential is masked by the interaction genotype by environment (Lozano *et al*., 2015). To address these problems, maize breeding programs have generated a wide variety of stable genotypes that are not affected by environmental conditions.

A stable variety is one that has the ability to buffer or adjust to environmental conditions (Marquez, 1991). Reyes *et al*. (2017) mention that the substantive progress in increasing grain yield is based on achieving optimal adaptation of the genotype to each production environment, as well as the combination of desirable traits such as grain quality and resistance to abiotic stress and biotic.

Therefore, for the recommendation of corn cultivars for High Valleys of Mexico, it is necessary to evaluate the cultivars, in different localities, because the cultivars evaluated in different environments can present differentiated responses to different environmental conditions, which characterizes the interaction between genotypes × environments. In this context, the selection of improved varieties should be the starting point to achieve higher yields. The objective of this work was to determine the agronomic characteristics of ten white hybrids in five different environments, the best response, as well as to define the effect of genotype × environment interaction on yield and other characteristics for the High Valleys of Mexico.

Materials and methods

This work was carried out in the spring-summer 2016 agricultural cycle in five environments of the High Valleys (2 200 to 2 600 meters above sea level). The first experiment was located in Cuendó (length 19° 25’ 39”, latitude 99° 55’ 12” and altitude of 2 519 m) and was planted on April 5. The rainfall at this site was 837 mm, the second was located at Jocotitlan (length 19° 25’ 39”, latitude 99° 55’ 12” and altitude 2 519 m) and was planted on April 13. The precipitation was 837 mm, the third was located in Ixtlahuaca (longitude 19° 36.937’, latitude 99° 51.023’ and altitude of 2 535 m), whose sowing date was 23 April, with a precipitation of 839 mm. The fourth experiment was located in Temascalcingo (longitude 19º 56’¸ latitude 100º 0’ and altitude 2 377 m) and was planted on May 3, with a precipitation of 1 181 mm. The last experiment was located in Jilotepec (longitude 19° 25’ 39”, latitude 99° 55’ 12” and altitude of 2 519 m) and was planted on May 25, with a precipitation of 885 mm.

Plantings were carried out with ‘irrigation tips’ once the soil had reached a moisture point, except for Cuendó, which was sown dry. After sowing, the dependence and exposure to the climate of the five study sites was total rainy weather and in general there were no negative meteors such as hail or frost at the end of the crop cycle. The results of soil analysis are presented in Table 1.

The interpretation of the physical-chemical composition of the soils shows low fertility, due to low contents of organic matter and cation exchange capacity, as well as nutrient deficiency; except the sites of Jocotitlan and Jilotepec that present soils of medium fertility because they contain organic matter (2.12 and 2.48 respectively), both with clay loam texture, but in low interchangeable cations (Table 1).

Table 1. Physical and chemical conditions of the soils in five environments of the High Valleys of the State of Mexico in which 10 hybrids of white grain corn were evaluated.

Characteristics	Cuendo	Jocotitlan	Ixtlahuaca	Temascalcingo	Jilotepec
pH in water	5.06	5.6	5.13	6.75	5.45
MO (%)	1.89	2.12	1.69	1.91	2.48
DA (g cm^{-3})	1.02	1.13	1.01	1.02	1.12
Texture	Loam	Clay loam	Loam	Loam	Clay loam
CIC (meq 100 g^{-1} SS)	11	10.1	13.9	11	14.8
CE (dS m^{-1})	0.22	0.34	0.68	0.83	0.6
CC (%)	19	22.9	21.4	22.3	27.2
PMP (%)	11.3	13.6	12.7	13.3	16.2
Porosity (%)	35.8	43	40.2	42	51
Ca (meq 100 g^{-1} SS)	3.25	5.25	7.57	6.64	10.3
Mg (meq 100 g^{-1} SS)	1.33	2.39	4.07	3.24	3.84
K (meq 100 g^{-1} SS)	0.28	0.51	0.45	1.01	0.41

MO= organic matter; DA= bulk density; CIC= cation exchange capacity; CE= electrical conductivity; CC= field capacity; PMP= permanent running point.

In the five environments, ten hybrids of white grain corn were evaluated, six with androsterility technology (ATZIRI PUMA, TSIRI PUMA, H-47 AE, H-49 AE, H-51 AE, H-53 AE), the first two generated in the FESC UNAM (Tadeo *el al*., 2016a), the other four in the INIFAP (Espinosa *et al*., 2018), three with fertile versions (H-50, H-66, H-70) and a commercial witness (Albatross) by ASGROW, these last four are frequently used in the High Valleys of Mexico.

The precision planter was calibrated for 95 thousand seeds per ha^{-1} in furrows at 0.80 m width. The seeds were treated with Cruiser® 5 FS (Thiamethoxam: 3-(2-Chloro-1,3-thiazol-5-ylmethyl)-1,3,5-oxadiazinan-4-ylidene (nitro) amino 50 ml 20 kg^{-1}) for soil pest control. Fertilization to the soil was 250-60-60 of NPK + micronutrient mixture in two moments, in the sowing the soil was fertilized with the formula 100-60-40 of NPK, respectively. The rest of the nitrogen (150N) was applied between stage V_{4-10}, divided in equal parts according to the occurrence of rainfall and humidity in the soil.

The control of weeds was mechanical with the weeds in the initial vegetative stage and later, the herbicides Callisto® Xtra (S Atrazine and Mesotrione 5 L ha^{-1}) were applied to control insects of the foliage Karate Zeon® (Lambda cyhalothrin 250 mL ha^{-1}) and Denim® (Emamectin 100 mL ha^{-1}), Priori® Xtra (Azoxystrobin, Ciproconazole 350 mL ha^{-1}) against diseases and Quilt (Azoxystrobin Propiconazole 800 mL ha^{-1}) at flowering. This last product acts as a regulator of growth promoting vigor and lengthening the life of the plant with an increase in the filling of grains, this because it improves the assimilation of CO_2 to stay 'green' and with it the process of the photosynthesis, water absorption and translocation of nutrients to the ear, reduces the rate of transpiration and inhibits the release of ethylene, delaying the senescence of the plant.

During the crop cycle, the climatic conditions were favorable, with adequate rainfall distribution, which allowed an adequate vegetative and reproductive development, until reaching its physiological maturity. As an experimental useful plot, the two central lines of each repetition were considered with two furrows of 3 m in length and 0.8 m between furrows. The design of the treatments was formed by combining the factorial of 5 environments × 10 hybrids, with four repetitions, considering as sources of variation the hybrids, environments and their interactions.

The variables evaluated were the following: grain yield (kg ha^{-1}), calculated with the formula: yield= (PC × % MS × % G × FC)/8600. Where: PC= weight of ears harvested (kg) in the experimental unit, % MS= percent of dry matter of a grain sample of five ears of corn just harvested, % G= percent of grain estimated from five ears of corn, FC= conversion factor to obtain the yield of grain per hectare, the quotient of dividing 10 000 m^2 between the size of the useful plot in m^2 and 8 600= is a constant to estimate the yield of commercial grain with humidity of 14% (Tadeo *et al*., 2014a). Representative samples were taken to calculate grain weight (kg hL^{-1}), number of rows, grains per row, grains per ear, ear weight (g), grain weight per ear (g), and grain index. The variables evaluated were analyzed with the statistical package SAS, version 9.3. The comparisons of the means were separated with the Tukey test at 0.05 probability.

Results and discussion

The analysis of combined variance detected highly significant differences for the environmental factor for the following variables: grain yield, hectolitre weight, weight of ear grain, ear weight and grain index (Table 2). For the hybrid factor, highly significant differences were observed for grain yield, hectolitre weight, grains per ear, weight of corn per ear, weight of ear and for number of rows and grains per row they had statistical significance. There was no significant difference in the grain index variable for this factor (Table 2).

Table 2. Mean squares and statistical significance for seven evaluated variables of ten hybrids of white grain corn in five environments of the High Valleys of Mexico. Spring-summer 2016.

Source of variation	GL	Variables							
		RG	PH	NH	GH	GM	PM	PGM	IG
Environment - A	4	67.11**	8106.8**	4.7 ns	13.4 ns	11282.3 ns	87720.5**	41401.5**	0.0221**
Repetition (A)	15	1.65**	147.5 ns	3.9 ns	10.9 ns	6268.3 ns	878.16**	372.5**	0.0012*
Hybrid - H	9	8.89**	1905.8**	16.3*	27 *	23758**	2906.5**	1775.5**	0.0006 ns
AxH	36	2.78**	683.9**	4 ns	13.9*	7270 ns	953.3**	513.3**	0.001*
Error	135	0.33	177.5	3.47	8.1	6162.1	99.77	61.7	0.0005
Total	199	-	-	-	-	-	-	-	-
Average	-	11.2	783.6	16.8	32.5	534.6	201.4	159.5	0.8
CV %	-	5.1	1.70	11.3	8.7	14.7	4.96	4.93	2.98

**= significant at 1% by the F test; *= significant at 5%; ns= not significant. GL= degrees of freedom; CV= coefficient of variation; RG= grain yield; PH= hectoliter weight; NG= number of rows; GH= grains per row; GM= grains per ear; PGM= weight of grain per ear; PM= ear weight; IG= grain index.

In the hybrid × ambient variation factor, a highly significant difference was detected, for all the variables except number of rows and number of grains per ear (Table 2). These results indicate that in the environments the hybrids presented differential responses and the variables evaluated were influenced by the effect of the environment. The coefficients of variation for the measured variables were of the order of 1.7 to 14.7%. The coefficient of variation for yield was 5.1% and the arithmetic mean was 11.2 t ha^{-1}, adjusted to 14% humidity (Table 2).

In environments, five groups of significance were identified, which define the contrasting responses of the environments. The highest average yield corresponded to Jocotitlan with 12.4 t ha^{-1} of grain, with a difference of 3.4 t ha^{-1} in relation to Cuendó that yielded less (9 t ha^{-1}) (Table 3). The technological package of this last environment was of low investment related to the dose of fertilization and control of weeds; which reduced the average grain yield and vigor of the plants. In addition to the physical-chemical conditions of the soil, it is considered to be of low fertility (Table 1). In parallel, in Jocotitlan, yields were observed in a range of 9.9 to 14 t ha^{-1} among the hybrids evaluated (Table 3), because they were better adapted to the soil-climatic conditions and to an appropriate agronomic management. in irrigation point and there was a regular and sufficient rainfall during the cycle and this allowed a positive response of grain yield.

Table 3. Comparison of grain yield averages (t ha^{-1}) at 14% humidity, in five sites of the High Valleys of the State of Mexico. INIFAP, 2016.

Hybrid	Ixtlahuaca	Jilotepec	Temascalcingo	Jocotitlan	Cuendo	Hybrid average
H-50	11.8 ab	12.2 ab	11.3 ab	13.3 bcde	9 a	11.5 abc
ATZIRI PUMA	12.4 a	12.8 a	11.7 a	14 abcd	8.9 a	12 a
TSIRI PUMA	11.3 abc	12.8 a	12.4 bcd	12.5 ab	9.9 a	11.8 ab
H-47AE	10.2 cd	12 abc	11.8 d	11.8 abcd	10.1 a	11.1 c
H-49AE	10.3 cd	12 abc	11 cd	12.9 cde	7.2 b	10.5 d
H-51AE	10.4 cd	11.9 abc	10.1 e	9.9 e	9.4 a	10.4 d
H-53AE	11.5 abc	10.8 c	10.7 e	10 de	7.1 b	10 d
H-66	11.2 abc	12.2 ab	11.9 ab	13.3 abcd	9.4 a	11.6 abc
H-70	10.8 bcd	11.4 bc	12.6 ab	13.5 a	9.5 a	11.6 abc
ALBATROS	9.6 d	11.6 abc	12.1 abc	13.3 abc	10.1 a	11.3 bc
Environments average	10.9 D	12 B	11.5 C	12.4 A	9 E	11.2
CV (%)			5.1			

Means with the same lowercase letter in the column and the capital letter in the line are statistically equal (Tukey, 0.05). CV= coefficient of variation.

These contrasting responses to the environmental effect are justified because the environments are in agroclimatic conditions, soil types, different sowing date, mainly due to the characteristics of the materials that are genetically different, so it is pertinent to carry out research works with these genotypes in specific environment and management in the High Valleys of the State of Mexico (Canales *et al*., 2017; López *et al*., 2017).

In the comparison of hybrid means considering the five environments, similar responses were observed and with higher performance in the following hybrids, ATZIRI PUMA, TSIRI PUMA, H-50, H-66 and H-70 with 12, 11.8, 11.5, 11.6 and 11.6 t ha^{-1} grain, respectively. The hybrids that showed the lowest yield were: H-49 AE, H-51 AE and H-53 AE with 10.5, 10.4 and 10 t ha^{-1}, respectively (Table 3). With a difference of 1.5 to 2 t ha^{-1}. The ATZIRI PUMA, TSIRI PUMA hybrids that showed higher yields were generated by the UNAM (Tadeo *et al*., 2016a) and lower yields were released by the INIFAP (Espinosa *et al*., 2008b; Espinosa *et al*., 2012; Espinosa *et al*., 2018) and are considered to be of male sterility scheme (AE). This technology is possible due to the mixture of male sterile and fertile seed (F), allowing male sterility in other materials (Espinosa *et al*., 2009; Tadeo *et al*., 2010; Tadeo *et al*., 2014 b). The above, is justified in the similar results of the hybrids H-49 AE, H-51 AE and H-53 AE in the present work, also that between the three materials there is a coincidence in one or two of the lines that make up its structure as hybrids (Tadeo *et al*., 2014a).

However, when hybrids are compared by specific environment, these androsterile hybrids (H-AE) showed the same and in some cases higher production when compared to the fertile version genotypes (Table 3), verifying only a small variation of the response of genotypes in some environments. This corroborates the results of previous research in which male sterile versions equal or surpass those of fertile ones (Martínez *et al*., 2005; Tadeo *et al*., 2007; Tadeo *et al*., 2014 a; Tadeo *et al*., 2014b; Canales *et al*., 2017). This is because the male sterile versions are isogenic of the fertile ones, they only differ in the production or not of pollen grains (Martínez *et al*., 2005; Ramírez, 2006; Tadeo *et al*., 2007; Tadeo *et al*., 2014a; Tadeo *et al*., 2014b). Hybrids H-49 AE, H-51 AE and H-53 AE surpassed the yields reported in recent works (Tadeo *et al*., 2013; Tadeo *et al*., 2014a; Tadeo *et al*., 2016b; Canales *et al*., 2017), which confirms the productive capacity of these materials accompanied by better agricultural practices in different production environments (Zamudio *et al*., 2015).

In the comparison of hybrid means, the H-47AE (Espinosa *et al*., 2018) presented a statistically similar performance with the following hybrids; H-50, H-66, H-70, and the commercial control ALBATROS, which are commonly used by the producers of High Valleys. The superior yields shown in this study due to male sterility in the hybrids (AE) ratify these genotypes as competitive with favorable agronomic advantages to promote their use by producers (Tadeo *et al*., 2016a).

Regarding the other agronomic variables, when comparing means of the environment factor, a significant difference was identified in most of the variables except number of rows, grains per row and grains per ear (Table 4); however, for the hybrid factor, all the variables were contrasting with the exception of a grain index that was similar in all the hybrids (Table 5). These statistical differences observed in the agronomic characteristics, especially when comparing the genotypes (Table 5), are due to the fact that the hybrids showed different genetic expression except the materials with male sterility scheme that present gene-cytoplasmic genes related to male type C sterility that causes pollen to not occur in the male sterile version (Tadeo *et al*., 2007; Tadeo *et al*., 2010; Tadeo *et al*., 2014b).

Table 4. Average comparison for eight variables in five sites in the High Valleys of the State of Mexico. Average of 10 white hybrids. INIFAP, 2016.

Environment	RG	PH	NH	GH	GM	PM	PGM	IG
	(t ha^{-1})	(g hL^{-1})	(num)	(num)	(num)	(g)	(g)	(%)
Temascalcingo	11.5 c	797 a	16.5 a	31.5 a	519.7 a	174.5 d	141 d	0.8 a
Cuendó	9 e	778 c	16.1 a	32.2 a	519.8 a	155 e	124.1 e	0.8 a
Ixtlahuaca	10.9 d	787 b	16.9 a	32.5 a	549.9 a	209.8 b	167.7 b	0.8 a
Jocotitlan	12.4 a	794 ab	16.2 a	32.6 a	528.7 a	190.7 c	155 c	0.81 a
Jilotepec	12 b	762 d	16.8 a	33.1 a	555 a	277 a	209.1 a	0.75 b
General average	11.2	784	16.8	32.5	534.6	201.4	159.4	0.8
CV (%)	5.1	1.7	11.3	8.7	14.7	4.96	4.93	2.98

Means with the same letter in each column are not statistically different (Tukey, 0.05). CV= coefficient of variation; RG= grain yield; PH= hectoliter weight; NG= number of rows; GH= grains per row; GM= grains per ear; PGM= weight of grain per ear; PM= ear weight; IG= grain index.

The average values of ear characteristics were: 78.5 kg L^{-1} hectolitre weight, row number 16.8, grains per row 32.5, grains per ear 534.6 g, weight of corn per ear 201.4 g and the grain index was of 0.8%, but without presenting a significant difference in the hybrid factor (Table 4 and 5).

Table 5. Average comparison of eight variables of ten hybrids, considering the averages of five environments of High Valleys of the State of Mexico. INIFAP, 2016.

Hybrids	RG	PH	NH	GH	GM	PM	PGM	IG
	(t ha^{-1})	(g hL^{-1})	(num)	(num)	(num)	(g)	(g)	(%)
H-50	11.5 abc	783 bcd	18 a	34 a	590 a	212.2 ab	168 abc	0.79 a
ATZIRI PUMA	12 a	783 bcd	16 ab	33 ab	540 abc	217.7 a	173 a	0.8 a
TSIRI PUMA	11.8 ab	794 ab	16 ab	34 a	548 abc	203.9 bc	162 cd	0.8 a
H-47AE	11.1 c	788 abc	16 ab	32 ab	504 bc	196.7 cde	155 def	0.79 a
H-49AE	10.5 d	793 ab	16 ab	32 ab	526 abc	186.9 ef	148 fg	0.79 a
H-51AE	10.4 d	779 cd	18 a	30 b	529 abc	184.5 f	147 g	0.8 a
H-53AE	10 d	774 d	16 b	32 ab	488 c	190.9 def	150 efg	0.79 a
H-66	11.6 abc	771 d	18 a	33 ab	562 abc	203.3 bc	163 bcd	0.8 a
H-70	11.6 abc	772 d	18 a	33 ab	571 ab	218.3 a	171 ab	0.78 a
ALBATROS	11.3 bc	800 a	16 b	32 ab	488 c	199.5 cd	158 de	0.79 a
General average	11.2	784	16.8	32.5	534.6	201.4	159.5	0.8
CV (%)	5.1	1.7	11.3	8.7	14.7	4.96	4.93	2.98

Means with the same letter in each column are not statistically different (Tukey, 0.05). CV= coefficient of variation; RG= grain yield; PH= hectoliter weight; NG= number of rows; GH= grains per row; GM= grains per ear; PGM= weight of grain per ear; PM= ear weight; IG= grain index.

Of the eight measured variables, the hectolitre weight stands out when exhibiting very dense grains in the majority of the genotypes ranging from 771 (H-66) to 800 g L^{-1} (Albatros). These values exceed the minimum value required in both the nixtamal flour industry (IHN) and the tortilla mass industry (IMT) that demand grains with a PH greater than 740 gh L^{-1} (SE, 2002), even excel with Values reported by Vázquez *et al*. (2015); Virgen *et al*. (2016), which indicates that the hybrids evaluated in this paper are suitable for the industry.

Regarding the number of rows, grains per row and grains per ear, significant differences were detected for the hybrid variation factor (Table 5), evidencing consistent data in the three variables, which probably influenced grain yield in both hybrids most outstanding (ATZIRI PUMA, TSIRI PUMA, H-50, H-66 and H-70) as in the less productive hybrids (H-49 AE, H-51 AE and H-53 AE) (Table 3 and 5). The number of rows, grains per row and grains per ear led to values of the order of 16-18; 30-34; 488-590, respectively (Table 5).

These previous results surpass data recently reported by López *et al*. (2017) when evaluating productivity of simple crosses of corn with protein quality in High Valleys of Mexico observing values in average of 15 (number of rows), 31 (grains per row) and 476 (grains per ear). Likewise, they surpass what reported by Tadeo *et al*. (2016b); Canales *et al*. (2017), with androsterile (AE) and fertile (F) hybrids. These results are probably due to the favorable climatic conditions during the agricultural cycle, the adequate agronomic management that considered the opportune fertilization in the stages of higher demand of nutrients and the genetic quality of the seeds sown. In this way, the higher yields of these genotypes are associated with the increase in the number of rows and grains per row in the ear (Zamudio *et al*., 2015).

For the sources of ambient variation and hybrids, the weight of the ear and ear grain showed significant differences (Table 4 and 5). For both variables, the hybrids ATZIRI PUMA, H-70 and H-50 with 217.7, 218.3 and 212.2 g of the ear, respectively, stand out, while for weight of ears of corn, the averages for the genotypes mentioned were 171, 168 and 173. g, respectively. Therefore, it is proven that the weight of the grains of the cob directly influenced the yield of the grain. The hybrids H-47 AE, H-49 AE, H-51 AE and H-53 AE presented lower values Environment compared to the hybrids evaluated in weight of grains per ear; however, they presented higher yields in relation to various works shown in the literature, these increases in the performance of the male sterile versions attributed to physiological changes are associated with the mobilization of photo assimilated to the grain in the absence of the demand represented by production of pollen grains (Stamp *et al.*, 2000; Martínez *et al.*, 2005).

The grain index did not present a significant effect, the average was 0.80, that is 80% of the total weight of an ear corresponds to the grain, while 20% is of the ear. This indicates that in general the ears have a grain/ear ratio of 8:2 in all genotypes, regardless of the environment and genotype. These data corroborate those reported by Hernández and Esquivel (2004); Pecina *et al*. (2011).

Conclusions

The highest yield hybrids in this study were ATZIRI PUMA (12 t ha^{-1}) and TSIRI PUMA (11.8 t ha^{-1}) followed by hybrids H-50, H-66 and H-70, which produced 11.5, 11.6 and 11.6 t ha^{-1} respectively. Considering that H-50 is one of the hybrids of greater commercial use in the High Valleys, the four referred hybrids of greater yield of white grain, could have perspectives of commercial use, in the environments managed in this study.

The grain yield in hybrids in the androsterile version presented similar or superior responses in its fertile version per specific environment, ratifying the expected yields of these isogenic materials. The evaluated hybrids presented higher yields than the commercial H-50 control and the region average, which is an alternative for seed and beneficial companies so that farmers have access to improved seeds with greater agronomic and economic advantages for production of grains in the High Valleys of Mexico.

The positive interactions of hybrid environments observed in this work, shows the differential response of each hybrid in production environments, this necessarily implies increasing the number of specific genotype evaluation environments with appropriate agronomic management considering the soil-water factor, and other controllable factors.

Cited literature

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