Article

Yield and quality of forage of corn hybrids in High Valleys of Mexico

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Abstract

Twelve hybrids were evaluated to determine those that exhibit high yields and high forage quality to be used in livestock production. The origin is from the School of Higher Studies Cuautitlan (FESC-UNAM), the National Institute of Forestry, Agriculture and Livestock Research (INIFAP) and the collaboration of both institutions, compared to a commercial control. The research was conducted in the spring-summer cycle of 2013 experiments were established in the Agricultural Teaching Center of the FESC-UNAM and another in the Valley of Mexico Experimental Field (CEVAMEX-INIFAP) of the INIFAP. Each of the experiments consisted of 12 treatments (hybrids), four from the FESC, UNAM, two from INIFAP, five from INIFAP-FESC-UNAM and one control from ASGROW. The PUMA 1163, Buho and H-48 hybrids showed the highest green matter yields ($p < 0.05$). Buho, 501 x 497, 504 x 408 and PUMA 1163 the highest in dry matter ($p < 0.05$) and the highest plant height corresponded to the hybrids PUMA 1167 and PUMA 1163 ($p < 0.05$), so they can be considered alternatives for producers. PUMA 1163 and PUMA 1167 presented high forage quality, with acceptable values of digestibility, protein and low fiber content. In forage quality stood out the hybrids PUMA 1163, H-48 and PUMA 1167 with 63, 61 and 60% of digestibility, respectively. The values for protein, neutral detergent fiber and acid detergent fiber were 8.6 and 8.4%, 60 and 57% and 26 and 22.5% for PUMA 1167 and PUMA 1163, respectively.

Keywords: *Zea mays* L., forage quality, hybrids, productivity, protein.

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Introduction

Corn is a crop of great importance in Mexico, because it is used for human and animal consumption. In the case of animal consumption, it is used as fresh fodder, silage or stubble, and its use is mainly used during the dry season (Luna *et al*., 2013). In the milk basins of Mexico corn silage is commonly used in dairy cattle feeding, it can constitute 30 to 40% of the ration, on a dry basis, of cows in production (González *et al*., 2005). In 2017, 598 167 ha were planted in the country, 573 034 ha were harvested and 16 261 864 tons of forage were obtained, with an average yield of 28.4 t ha^{-1} (SIAP, 2017).

The nutritive value of corn silage depends on the hybrid used, the density of plantation used, growth conditions, degree of maturity and humidity at harvest time and silage conditions (Satter and Reiss, 2012).

The cultivation of maize for silage in Mexico has low yield of dry matter per hectare, low grain content and high fiber which cause that the digestibility and energy of the forage are low. This situation is due in part to the use of hybrids considered as fodder, of high height and high capacity to produce foliage, as well as practices in the management of the crop to obtain large volumes of green matter per hectare but, with poor nutritional value, because that in general these materials are sown at high densities of population, which causes a scarce quantity of grain, the latter being where the highest energetic value of forage corn is found as food for livestock (Nuñez *et al*., 2005).

The increase of the productivity of fodder maize without diminishing the quality of the forage is determinant for an efficient production of milk, consequently, with the increase of the quantity of quality silage in the rations for the feeding of the cattle, it would be expected a decrease in the production costs without decreasing milk production (Reta *et al*., 2000).

To obtain a silage of high nutritional value and high production of dry matter it is necessary to select the hybrid or variety to be planted. In recent years, it has been found, in various investigations, that through the proper selection of the forage maize genotypes for silage, the most outstanding materials can be obtained in dry matter yield and mainly of higher quality, since there are differences between hybrids of corn in terms of its contents of crude protein, fiber and digestibility of dry matter (Reyes and Reyes, 2000).

In the High Valleys of the State of Mexico a large number of maize varieties are used for silage; however, these were generated to produce grain, so it is necessary to determine the productive capacity of forage and its quality. Therefore, in this work twelve hybrids whose origin is the School of Higher Studies Cuautitlan (FESC-UNAM), as well as the National Institute of Forestry, Agriculture and Livestock Research (INIFAP) and the collaboration of both institutions, were evaluated. comparison with a commercial control, in order to determine the best genotypes, with high yields and high quality of forage for use in the milk production of cattle.

Materials and methods

The research was carried out in the spring-summer 2009 cycle, two experiments were established, one in the Agricultural Teaching Center of the School of Higher Studies Cuautitlan, of the National Autonomous University of Mexico (FESC-UNAM), (19° 41’ North latitude, 99° 11’ West longitude, 2 274 m altitude), whose soil is of clay-loam texture. The other locality corresponded to Santa Lucia de Prias, Coatlinchan, Municipality of Texcoco, State of Mexico (19º 27’ North latitude, 98º 51’ West longitude, 2 240 m altitude), with sandy-loam texture soil, in the Campo Experimental Valley of Mexico (CEVAMEX), of the INIFAP.

Each experiment consisted of 12 treatments (hybrids), four from the FESC-UNAM, two from INIFAP, five from INIFAP-UNAM and one from ASGROW (Table 1). The experiments were conducted under temporary conditions, in both cases the plantings were in the second half of June 2009, which is considered a delayed planting date. Prior to sowing the crop, the land was prepared in a conventional manner, consisting of fallow, two steps of harrowing and furrowing. When the furrow was made, it was fertilized with a dose of 80-40-00 (N, P, K), using urea and ammonium phosphate. The sowing was carried out at the top, depositing three seeds per bush, every 50 cm. The irrigation was rolled in furrows, the next day the sowing was done and, later in the CEVAMEX, a light irrigation was given to the ten days, to assure the germination of the seed.

Table 1. Hybrid corn of yellow and white grain of intermediate cycle used for the evaluation of grain and forage production in High Valleys of Mexico. Spring-summer 2013 cycle.

Hybrid	Type of hybrid	Grain color	Origin	Condition of recommendation
PUMA 1167	Fertile trilincob	White	FESC-UNAM	Irrigation
PUMA 1163	Fertile trilincob	White	FESC-UNAM	Irrigation
PUMA 1181 AE	Androsterile Trilineal	White	FESC-UNAM	Irrigation
PUMA 1075	Fertile trilincob	White	FESC-UNAM	Temporary
501 x 497	Fertile trilincob	Yellow	INIFAP-UNAM	Irrigation
501 x 555	Fertile trilincob	Yellow	INIFAP-UNAM	Irrigation
504 x 408	Fertile trilincob	Yellow	INIFAP-UNAM	Irrigation
501 x 410	Fertile trilincob	Yellow	INIFAP-UNAM	Irrigation
501 x 554	Fertile trilincob	Yellow	INIFAP-UNAM	Irrigation
H-48	Fertile trilincob	White	INIFAP	Temporary
H-51 AE	Androsterile Trilineal	White	INIFAP	Temporary
BUHO	Fertile trilincob	White	ASGROW	Irrigation

For weed control, the herbicide was applied twice: first, 15 days after irrigation, with the mixture of one liter of Hierbamina and two kg of Gesaprim, caliber 90, per hectare. The second application was 20 days after sowing, with a mixture of one liter of Sanson 4 SC, one liter of Hierbamina and two kg of Gesaprim caliber 90, per hectare. Once the crop was established, at approximately 40 days, it was thinned to obtain an approximate population density of 70 000 plants ha^{-1}.

The performance of the different hybrids was determined, for which the harvest was carried out when the optimum state of maturity was presented, which was determined visually, after taking five plants at random and observing the state of the grain (1/4 to 1/3 of the milk line advance) for each of the hybrids.

To determine the yield of green matter per ha, ten plants were cut, at a height of 7 to 10 cm from the ground level, from the three central meters of each experimental unit, weighed and the average weight per plant was obtained, that multiplied by the density of plants per hectare to obtain the yield in t ha^{-1} of green matter for each treatment. Ten harvested plants were used to obtain the yield in dry matter; which were cut into pieces of 3 to 5 cm, were mixed until a homogeneous sample was formed, a subsample of one kg was taken, placed in a forced air oven at 55 °C, until it reached constant weight, then the dry matter content was weighed and so, by the difference between the initial weight and the final weight, the average weight in dry matter per plant was determined and multiplied by the ha^{-1} plant population.

With the data of fresh weight and dry weight the percentage of dry matter for each experimental unit was determined by applying the following equation.

$$\text{Dry matter percentage}=\frac{\text{Dry weight of the sample}}{\text{Fresh weight of the sample}}*100$$

Five plants were taken from each treatment the cobs were separated, weighed, dried in a forced air oven until constant weight and weighed again. The average weight of cob for each treatment was obtained and the percentage of cob was determined by means of the following formula:

$$\text{Percentage of cob}=\frac{\text{Average dry weight of cobs}}{\text{Average dry weight of plant}}*100$$

To determine the height of the plant, the third, sixth and ninth plants of each repetition were measured, with a rule of 3 m, from the ground to the node where the growth of the spike begins. In both experiments the population density was 70 000 plants ha^{-1}, the experimental plot was constituted by a furrow five meters long by 0.8 m wide, which gave a total of 4 m^2 as a useful plot. An experimental design was used in randomized complete blocks, the statistical analysis was carried out in a factorial arrangement, with the factors genotypes and localities, as well as the interaction genotypes x localities (Steel and Torrie, 1988).

The *in vitro* digestibility of the dry matter was determined with the technique of Tilley and Terry (1963), for which samples of 0.5 g of ground corn forage were placed, as a substrate, in a tube equipped with valves for the escape of gases, McDougall's saliva and ruminal fluid were added, which was extracted from a bovine fasting from the Agricultural Teaching Center of the School of Higher Studies Cuautitlan, was incubated in a water bath for 48 hours, then added pepsin and acid hydrochloric to perform digestion equivalent to abomasal digestion, for another 48 hours.

Two repetitions were used for each experimental unit. To obtain the crude protein content, a subsample was used to determine the total nitrogen content, using the Microkjeldhal method (AOAC, 1984), and multiplied by the factor 6.25 to determine the crude protein content. The neutral detergent fiber and the acid detergent fiber were determined by the method of Goering and Van Soest (1970).

The data obtained from the experiment were analyzed with the Mixed and GLM procedures of the SAS for Windows program, version 8 (SAS Institute, 2001), for a random block design with factorial arrangement. The mean comparison test was performed using the Tuckey test (Steel and Torrie, 1988).

Results and discussion

In Table 2, the mean squares obtained from the results of the analysis of variance are presented, as well as the statistical significance for the variables green matter yield, dry matter yield, percentage of dry matter, percentage of cob and height of plant, evaluated in two locations to determine the productive capacity and quality of the different corn hybrids for forage production in two environments in High Valleys of Mexico.

Table 2. Mean squares and statistical significance when evaluating forage yield in maize hybrids from High Valleys in Cuautitlan and Texcoco in spring-summer 2013.

Source of variation	GL	Yield MV† CM	Yield MS†† CM	(%) MS†† CM	(%) cob CM	Height plant CM
Genotypes	11	386831275**	50406971**	20.67	102.83	0.11**
Locations	1	1622036184**	1615995274**	1556.87**	3954**	8.7**
Gen$*$Loc	11	237244653**	33706838**	25.34	42.4	0.02
Error		45799343	9683446	16.87	134.05	0.036
CV (%)		10.4	13.2	11.3	28.2	9
Mean		64760.6	23618.25	36.35	41.05	2.13

*= significant at 0.05 error probability; **= significant at 0.01 error probability; †MV= green matter; ††MS= dry matter; CM= medium square.

In yield of green and dry matter there were highly significant differences (p< 0.01) for hybrids, localities, as well as the interaction hybrids x localities, indicates that there was different behavior of the hybrids in the average of the two localities. The means of yield in green and dry matter were 64.8 and 23.6 t ha^{-1} and the coefficients of variation of 10.4% and 13.2%, respectively. The percentages of dry matter and cob were significantly different (p< 0.05) between localities, but there were no significant statistical differences between the hybrids evaluated and no interaction between genotype and locality was presented (Table 2). For plant height, there were highly significant differences (p< 0.01) between hybrids, localities and interaction between genotype x locality.

In the analysis of variance for the variable digestibility, in the factor of variation genotypes (hybrids) highly significant differences were found (p< 0.01) for genotypes, as well as in the genotype x locality interaction, however for localities no significant differences were found. The mean for this variable was 60.2% (Table 3). For protein percentage, there were highly significant differences between hybrids, localities and the genotype x locality interaction. For the variable neutral detergent fiber (FDN) and acid detergent fiber (FDA) there were highly significant differences in the hybrid variation factors, localities, as well as the genotype x locality interaction (Table 3).

Table 3. Mean squares and statistical significance when evaluating forage quality in maize hybrids from Valles Altos in Cuautitlan and Texcoco in spring-summer 2013.

Source of variation	GL	Digestibility CM	Protein CM	FDN (%)	FDA (%)
Genotypes	11	42.3**	1.01**	91**	34.9**
Locations	1	93.8	8**	79**	33.8**
Gen∗Loc	11	40.7**	1.1**	55.1**	24**
Error		4.5	0.26	13.7	3.42
CV (%)		3.5	6.1	6.7	7.44
Mean		60.2	8.4	54.9	25

*= significant at 0.01 error probability; **= significant at 0.0001 error probability; †MV= green matter; ††MS= dry matter; CM= medium square.

In the mean comparison test three groups of significance were defined, it was found that the hybrids PUMA 1163 and BUHO (75 and 74 t ha^{-1}) had the highest yields ($p< 0.05$) of green matter with respect to H 51 AE, 501 x 554, PUMA 1181 and PUMA 1075 (61, 59, 58 and 50 t ha^{-1}) and were not different ($p< 0.05$) from the other hybrids evaluated (Table 4). The yields of green matter obtained in this research with the best hybrids are high and were similar to those recorded by Nuñez *et al*. (2005) of 71 t ha^{-1}, when harvesting when the grain presented a ‘doughy’ state. Peña *et al*. (2008) with the hybrid H-376 INIFAP, in validation plots, produced from 78 to 91 t ha^{-1}.

The Buho hybrids, 501 x 497, 504 x 408, PUMA 1163, 501 x 555, H-48, 501 x 410 and H-51 AE, (26.4, 25.6, 25.5, 25.4, 24.7, 24.7, 24.3 and 23.4 t ha^{-1}) showed higher ($p< 0.05$) dry matter yield than PUMA - 1075 (17.6 t ha^{-1}) and similar to the other hybrids evaluated. The average yield of dry matter (24 t ha^{-1}) obtained in this experiment was higher than the average registered in the Aguascalientes, Zacatecas, Durango, Chihuahua and Bajio region of Mexico, where the average MS production of forage maize is of 20 t MS ha^{-1}, similar to the one obtained by Nuñez *et al*. (2006) under experimental conditions (Table 4).

With respect to the percentage of dry matter, the range was from 34.1 to 39.7, the average of 36%, which coincides with the percentage of dry matter recommended by various authors (Nuñez *et al*., 2005; Cox and Cherney, 2005) to perform the harvest of corn for silage, with which the highest nutritional quality and the highest dry matter yield are obtained. Silages made with values lower than 30% in dry matter have a high production of effluents and fermentation by Clostridium bacteria, resulting in a significant loss of soluble components, such as: soluble nitrogen, sugars, fermentation products and minerals (Mabio *et al*., 2015). Ensilages with higher values of dry matter inhibit the compaction of the material and the elimination of the air and consequently inadequate fermentation occurs (Table 4).

Table 4. Comparison of hybrid means considering the average behavior in Cuautitlan and Texcoco in the spring-summer 2013.

Genealogy	Green matter yield (t ha^{-1})	Dry matter yield (t ha^{-1})	(%) of matter dry	(%) of cob	Height plant (m)
PUMA 1163	75 a	25.4 a	34.1 a	39 a	2.3 ab
BUHO	74 a	26.4 a	34.8 a	38 a	2.18 bcd
H-48	69.4 ab	24.7 a	35.8 a	39 a	2.2 abc
504 x 408	68.8 ab	25.5 a	37.1 a	45.4 a	2.2 bc
501 x 410	65.8 ab	24.3 a	37 a	47.4 a	2.1 bcd
501 x 555	65.8 ab	24.7 a	37.4 a	45.2 a	2.16 bcd
PUMA 1167	65.2 ab	23 ab	35.2 a	40.1 a	2.4 a
501 x 497	64.1 ab	25.6 a	39.7 a	41.8 a	2 d
H-51 AE	61 bc	23.4 a	37.8 a	33 a	2.2 abc
501 x 554	59.1 bc	22.1 ab	37.3 a	45.1 a	2.1 bcd
PUMA 1181	58 bc	20.9 ab	31.5 a	45.1 a	2.1 cd
PUMA 1075	50 c	17.6 b	34.5 a	41 a	2.12 bcd
DSH (0.05)	11.4	5.3	7	19.6	0.32

Means with different literals in the same column are different ($p< 0.05$). DSH= honest significant difference ($p< 0.05$).

The average for percentage of cob 42%, similar to the percentages obtained by Nuñez *et al*. (2005) and Peña *et al*. (2002) with commercial hybrids. The 501 x 410 hybrid presented the highest values (47.4%) and the H-51 AE the lowest values (38%). These percentages of cob are considered adequate to constitute a sufficient substrate for the acetic and lactic fermentation by the bacteria and achieve an adequate fermentation of the silage. The percentage of cob is one of the most important characteristics that determine the energy value of corn silage (Nuñez *et al*., 2015).

The PUMA 1167 hybrid presented the highest plant height ($p< 0.05$), 2.4 m; however, it was not different with respect to PUMA 1163, H-48 and H-51 AE, but with respect to the other hybrids. The lowest plant height, 2.0 m, corresponded to the 501 x 497 hybrid (Table 4).

The PUMA 1163, BUHO and H-48 hybrids showed a certain relationship between plant height, yields in dry matter and in green matter, because the values of these variables, that is to say, height that they registered were located in the highest values of the different hybrids evaluated and corresponded to the hybrids with higher yield (Table 4).

The hybrid H-51AE presented the highest digestibility (65%) and was not different with respect to PUMA 1163, H-48, PUMA 1167, 501 x 410 (63, 61, 60, 59%, respectively) but it was with respect to the other hybrids evaluated. These hybrids presented high protein contents and relatively low values for FDA, which indicates that the crop was harvested at a suitable maturity, as observed in the values obtained for percentage of dry matter, and there was no excessive accumulation of hemicellulose and lignin, and consequently greater availability of nutrients (Table 5).

Table 5. Comparison of hybrid means considering their average behavior in Cuautitlan and Texcoco in spring-summer 2013.

Genealogy	Digestibility (%)	Protein (%)	FDN (%)	FDA (%)
H-51 AE	65 a	8.7 ab	54 abcd	26 ab
PUMA 1163	63 ab	9 a	60 a	25 ab
H-48	61 ab	8.1 bc	59 a	28 a
PUMA 1167	60 ab	8.6 abc	57 abc	22.5 c
501 x 410	59 ab	8.4 ab	57 abc	23.4 bc
501 x 554	58 b	8.1 abc	52 bcd	22 bc
504 x 408	58 b	7.8 c	50 d	23 bc
PUMA 1075	58 b	8.3 abc	52 bcd	25 abc
PUMA 1181	58 b	8.7 ab	53 bcd	26 ab
501 x 497	57 b	8 bc	56 abcd	22 c
501 x 555	57 b	8.5 abc	58 ab	28 a
BUHO	57 b	8 bc	51 bcd	26 ab
DSH (0.05)	3.6	0.9	6.3	3.1

Means with different literals in the same column are different ($p< 0.05$). P= PUMA; DSH= honest significant difference ($p< 0.05$).

The digestibility values obtained by H-51AE, H-48, PUMA 1163 and PUMA 1167 (60 to 65%) are considered within the range of other hybrids evaluated in the study region. In research conducted with lactating cows, it has been concluded that fiber digestibility is potentially the most important indicator that determines the nutritional quality of corn for silage, due to the fact that by increasing the availability of energy in more digestible fiber, increases the consumption of dry matter (Nuñez, 2015), which has an impact on increased milk production.

The PUMA 1163 hybrid presented a higher percentage of protein ($p< 0.05$) than the hybrids H-48, 501 x 497, BUHO and 504 x 408 and was not different with respect to the others. The protein values varied from 7.8 to 9% and the average was 8.8%. Excelling for its high content of protein PUMA 1163, PUMA 1181 and H-51 AE, PUMA 1167, 501 x 555, 501 x 410 and PUMA 1075 (with values of 9, 8.7, 8.6, 8.5, 8.4 and 8.3%, respectively). These crude protein values are considered to be within the average values recorded for good quality corn silage, which vary from a range of 7.5 to 8.6 (Mabio *et al*., 2015).

The FDN values varied from 50 to 60%, average 55%, the hybrids PUMA 1163 and H-48 (60 and 59%) had higher values, with respect to 501 x 554, 504 x 408, PUMA 1075, PUMA 1181 and BUHO and they were not different from the other materials evaluated.

These FDN values were higher than those obtained by Nuñez *et al*. (2006), who recorded averages of 44 to 48% in an experiment conducted in the Lagunera region and those of Juraček *et al*. (2012) who obtained values of 46 to 48%. However, they are considered adequate, since at higher values there is a negative correlation with the forage digestibility and the silage consumption by the animal is reduced, which causes the milk or meat productivity to be reduced.

The 501 x 497 hybrid presented the lowest value of FDA (22%) with respect to 501 x 555 (28%), H-48 (28%), H-51 AE, PUMA 1181 and BUHO (26% the last three). A group of intermediate significance was presented with values similar to 501 x 497, constituted by 504 x 408, PUMA 1167, 501 x 410 and PUMA 1163 (values of 22 to 25%). These FDA values are in the high quality range determined by Herrera (1999) and by Peña *et al*. (2002), because a high-quality forage maize is considered one that presents FDA values of 25 to 32% and FDN of 40 to 52% (Herrera, 1999).

When performing the mean comparison test for the two localities studied (Tables 6 and 7), it was found that in Cuautitlan higher values were presented for most of the evaluated variables (except FDN), which probably was a consequence of an environment more favorable (climate and soil). The yields of green and dry matter were higher ($p< 0.05$) in 13.5 and 39%, in Cuautitlan with respect to those obtained in Texcoco. The percentage of cob was 33% higher in Cuautitlan compared to that obtained in Texcoco.

Table 6. Comparison of means between the test locations for the different variables evaluated in maize hybrids that were used for forage production in spring-summer 2013.

Location	Green matter yield (t ha^{-1})	Dry matter yield (t ha^{-1})	Matter dry (%)	Cob (%)	Height plant (m)
Cuautitlan	68.9 a	27.7 a	40.4 a	47.5 a	2.43 a
CEVAMEX	60.7 b	19.5 b	32.3 b	34.6 b	1.8 b
DSH (0.05)	2758.2	1268.3	1.67	4.71	0.078

DSH= honest significant difference ($p< 0.05$).

Table 7. Comparison of means between test locations for the different variables evaluated in corn hybrids for forage production in spring-summer 2013.

Location	Digestibility (%)	Protein (%)	*FDN (%)	**FDA (%)
Cuautitlan	61.2 a	8.6 a	54 b	25.5 a
CEVAMEX	59.2 b	8.1 b	55.8 a	24.3 b
DSH (0.05)	0.86	0.21	1.5	0.75

*FDN= neutral detergent fiber; **FDA= acid detergent fiber; DSH= honest significant difference ($p< 0.05$).

The average percentage of dry matter, registered in Cuautitlan was 40.4%, which is within the recommended limit for the silage process and is an indicator that the harvest was carried out in an advanced stage of maturity, which influenced a greater accumulation of dry matter.

Regarding the forage quality obtained in the two locations, no significant differences are observed, reflecting a similar quality between the two.

In Figure 1, the yields of green matter (t ha^{-1}) and yield of dry matter (t ha^{-1}) of the twelve hybrids evaluated in the localities of Cuautitlán and Texcoco are presented, where it can be seen that in some materials such as the hybrid 504 x 508 and 501 x 554, the results show differences with the other materials, which confirms the significance in the genotype x locality interaction.

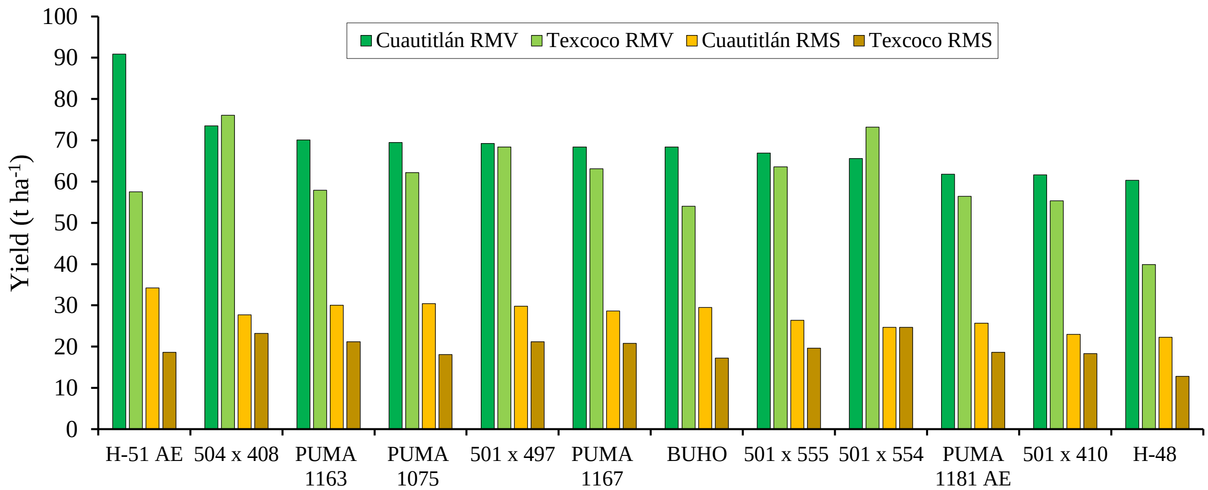

Figure 1. Green matter yield (t ha^{-1}) and dry matter yield (t ha^{-1}) of the 12 hybrids; through, from the two evaluation locations.

Conclusions

The PUMA 1163, BUHO and H-48 hybrids showed the highest yields of green matter (p< 0.05), BUHO, 501 x 497, 504 x 408 and PUMA 1163 the highest in dry matter (p< 0.05), the highest plant corresponded to the hybrids PUMA 1167 and PUMA 1163 (p< 0.05), so that alternative varieties can be considered for producers who cannot access the varieties offered in the market by international companies.

In percentage of cob there were no differences (p< 0.05) between treatments; however, in forage quality, the PUMA 1163, H-48 and PUMA 1167 hybrids with digestibility values of 63, 61 and 60%, respectively, protein values of 8.6 and 8.4 for P 1167 and P 1163. FDN values of 60 and 57%. FDA of 26 and 22.5%.

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