Article

Production and quality of grain and stubble in maize in the Puebla highlands

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Abstract

The majority of the ruminant production units in the high valleys in various regions of Mexico integrate maize stubble as a source of fodder. Therefore, this crop must be a high yielding of both grain and stubble of quality. Thus, the objective of the present research was to evaluate the performance of 36 genotypes of maize in the highlands of Puebla in the aspects mentioned above, during the year 2017. The genotypes screened were seven commercial hybrids, a synthetic variety, nine free-pollinated populations and nineteen experimental simple-cross hybrids derived from local varieties. The sowing was carried out in three experiments with lattice design 6x6 in experimental units of two furrows 80 cm wide by five meters long. Variables related to the characteristics of the plants and chemicals from the stubble produced were evaluated. The main discriminatory variable was useful yield (USY) that included grain yield (GRY), stubble production and digestibility. The genotypes were different ($p< 0.001$) in all the measured variables. In USY, the outstanding genotypes were: HS-2®, Aguila 215W®, SM-16 60x66, SM-16 5x64, SM-16 64x66, SM-16 53x64, SM-16 13x44, SM-16 23x60, SM-16 58x21, SM-16 44x64, SM-16 136x142, Niebla® and SM-16 21x64. However, this variable manages to mask genotypes that have high yields of grain and stubble but that have low digestibility. Only the SM-16 5x64 had superiority in digestibility, but had average yield of stubble dry matter, which gives it greater potential to be a dual purpose genotype.

Keywords: crop-livestock integration, digestibility, high valleys, stubble quality.

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Introduction

Maize (*Zea mays* L.) is a crop that is used as food for humans and animals. In the case of ruminant livestock, it can be supplied in grain, in green forage, in silage or in stubble (leftovers from the corn plant once the grain is collected). In this way, the crops in the production systems where the agricultural part is integrated with the livestock must fulfill the function of producing grain and stubble at the same time. From this it follows that the dual-purpose function is defined as the ability of crops to produce both stubble and grain in quantity and quality (eg. greater digestibility) sufficient for human and livestock food (Peña *et al*., 2008; Blümmel *et al*., 2013).

In the highlands of Puebla there are problems for the production of corn, mainly due to the limited availability of land, the phenomenon of importing this grain, little support to the field, and effects attributed to climate change. Therefore, having new corn cultivars, resistant (or with greater tolerance to climate change) and that fulfill the dual function of providing food for human (grain) and animal (grain and forage) consumption, is essential.

In this regard, research has been carried out in Asia, in the dry tropics (Anandan *et al*., 2013; Ravi *et al*., 2013; Zaidi *et al*., 2013), where it was found that there is variation in grain production, stubble and its quality. In Mexico, some authors (Aceves *et al*., 2002; Muñoz *et al*., 2013) have compared local (also called native) populations of maize with hybrid varieties in grain and forage yield under seasonal conditions. These authors found that local populations have higher grain yield (up to 30% more) and stubble dry matter (up to 45% more) than hybrids. However, no varieties with dual-purpose potential have been identified, only possible varieties with higher stubble yields have been described.

Based on the above, this research was proposed, in order to detect dual-purpose corn genotypes, which have greater functionality for mixed production systems where crop production is integrated with livestock and can serve as genetic base material for future breeding programs with this approach.

Materials and methods

Study area and location of experiments

In three municipalities of the State of Puebla, Mexico, during the year 2017, three experiments were established under storm conditions. The localities were San Mateo Capultitlan, Huejotzingo municipality, in the parallels 19° 12’ 14” north latitude and 98° 25’ 38” west longitude at an altitude of 2 281 m; San Nicolás Zecalacoayan, Chiautzingo municipality, at coordinates 19° 12’ 27” north latitude and 98° 29’ 41” west longitude, at an altitude of 2 489 m, and San Juan Cuautlancingo, at coordinates 19° 04’ 58” north latitude and 98° 17’ 03” west longitude with an altitude of 2 164 m.

Genetic material

Nine outstanding local populations (OLP), 19 experimental single-cross hybrids (SCH), one synthetic variety (SV) and seven commercial hybrids (CH) were used (Table 1).

Table 1. Corn cultivars evaluated in the Puebla highlands, 2017.

Cultivate	Denomination	Origin	Type	Grain color
1	Experimental hybrid	SM-16, 5x64	SCH	White
2	Experimental hybrid	SM-16, 13x44	SCH	White
3	Experimental hybrid	SM-16, 21x64	SCH	White
4	Experimental hybrid	SM-16, 22x64	SCH	White
5	Experimental hybrid	SM-16, 23x60	SCH	White
6	Experimental hybrid	SM-16, 44x64	SCH	White
7	Experimental hybrid	SM-16, 53x64	SCH	White
8	Experimental hybrid	SM-16, 58x21	SCH	White
9	Experimental hybrid	SM-16, 60x66	SCH	White
10	Experimental hybrid	SM-16, 61x21	SCH	White
11	Experimental hybrid	SM-16, 63x21	SCH	White
12	Experimental hybrid	SM-16, 64x66	SCH	White
13	Experimental hybrid	SM-16, 121x142	SCH	Yellow
14	Experimental hybrid	SM-16, 122x142	SCH	Yellow
15	Experimental hybrid	SM-16, 123x142	SCH	Yellow
16	Experimental hybrid	SM-16, 124x142	SCH	Yellow
17	Experimental hybrid	SM-16, 125x142	SCH	Yellow
18	Experimental hybrid	SM-16, 136x142	SCH	Yellow
19	Outstanding local population (OLP)	SM-16, 166 #	PL	Red
20	Outstanding local population (OLP)	SM-15, 218 #	PL	Blue
21	Experimental hybrid	SM-15, 137x135	SCH	White
22	Outstanding local population (OLP)	HQ-15, 25 #	PL	Yellow
23	CPue-00089 (OLP)	ZAC-CP-14, 21 #	PL	Blue
24	CPue-00157 (OLP)	ZAC-CP-14, 22 #	PL	White
25	CPue-00174 (OLP)	ZAC-CP-14, 23 #	PL	White
26	CPue-00369 (OLP)	ZAC-CP-14, 28 #	PL	White
27	CPue-00406 (OLP)	ZAC-CP-14, 29#	PL	Yellow
28	Tropical-1®	Colpos	SV	White
29	CPue-00316 (OLP)	Altzayanca, Tlax.	PL	Yellow
30	HS-2®	ColPos	CH	White
31	Imparable®	Berentsen	CH	White
32	Aguila 215W®	Semillas Lobo	CH	White
33	SB 352 Deseado®	Berentsen	CH	White
34	SBA 404 Bárbaro®	Berentsen	CH	Yellow
35	SBA-470 Conquistador®	Berentsen	CH	Yellow
36	Niebla®	Ceres	CH	White

Agricultural management and experimental driving

At each experimental site, a deep fallow and two harrow steps were performed. It was furrowed with animal traction and planted with a shovel, at a distance between bushes of 0.4 m. Three seeds per matte were deposited and after the first weeding, thinning was performed to leave two plants per matte, with a density of 62 500 plants ha^{-1}. It was fertilized with the formula 120-50-50, applying 1/3 of nitrogen, all phosphorus and all potassium to the seed; the rest of the nitrogen was applied in the second weeding. The sources of fertilizers were Triple 17 and Urea. Weed control was performed manually with two weeds in each experiment.

Environmental conditions during the development of the experiment

In San Mateo Capultitlan, the temperature and relative humidity were measured with a LogTag® model datalogger. Precipitation data in the three locations were obtained from SMN-CNA (2018) and INIFAP (2018). There were no prolonged droughts or frosts. The accumulated precipitation from April to November was 810 mm, with a progressive increase from May to August (from 126 to 196, respectively), which represented 82% of the total. In September it decreased to 80 mm, in October there were only 8 mm and in November it was the minimum (2 mm). The highest mean temperature value was in May (26 °C) and the lowest in November (16 °C), remaining in the other months of the period between 18 and 20 °C.

Plant sampling and preparation for laboratory analysis

At harvest, four plants representative of phenotypic variation and with complete competence were cut from each experimental unit. They were cut flush with the ground and chopped to a size of 10 to 35 cm, without chopping ears, leaves and ears; then they were placed in raffia bags and the fresh weight per sample was recorded. All the samples were exposed to the sun for one week to dry until reaching between 30 to 35% humidity. Subsequently, they were dried in a forced air stove at 60 °C for 72 h, until all the moisture was removed. Each sample was separated into leaf, stem, peduncles and 'totomoxtle' (bracts that wrap around the ear) and weighed. The samples were pre-milled to 3 mm, after that, they were ground in a Foss Tecator® brand cyclone mill, with a 1 mm mesh, for laboratory bromatological analysis.

Variables

Days to male flowering (DMF) and days to female flowering (DFF)

At the beginning of flowering, plants that had anthems (pollen emission by the anthers on the spikes) and exposed stigmas were counted every three days, until 50% of the plant population of the experimental unit were in the same condition.

Plant height (PLH) and Ear height (EAH)

During the formation of the corn, four plants were measured per experimental unit, from the base of the soil to the beginning of the ear for ALP, while the EAH went from the base of the soil to the insertion node of the upper ear.

Grain yield (GRY)

Field weight was recorded and a sample was taken from five ears that were weighed fresh; then they were dried in the sun for 15 days until much of the moisture was removed, they were shelled and the percentage of grain was obtained, as well as the final weight of the sample. By weight difference, the moisture percentage was determined. The yield was obtained after adjusting the weight obtained in the field by the percentage of grain and percentage of humidity of the sample. Finally, the yield obtained was standardized to 14% humidity as the grain is commonly commercialized.

Dry matter yield (DMY) of stubble and Leaf-stem ratio (LSR)

It was estimated by dividing the weight of the dry sample by the number of plants in the sample and multiplying by the population density per hectare. For LSR, the leaf and stem were weighed separately, and division was performed.

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin in acid detergent (LAD)

In duplicate, a ground forage sample of 0.5 ±0.0015 g of dry matter was weighed, for NDF it was washed with a neutral detergent solution to dissolve the cell contents. To determine ADF, an acidic detergent solution was used to extract the hemicellulose. To determine LAD, 72% sulfuric acid (H_2SO_4) was used. The determination of these components was carried out sequentially, using the protocols of Ankom Technology (Ankom Technology, 2011) and expressing the results in percentage.

***In vitro* digestibility of dry matter (IVDDM)**

It was determined by enzymatic digestibility in vitro with the two-stage pepsin-cellulose technique (Jones and Hayward, 1975; Clarke *et al*., 1982). 0.3 ±0.0015 g of DM was weighed in ANKOM F57 bags, in duplicate, expressing the result in percentage.

Crude protein (CP)

It was determined with 0.2 g of dry matter sample, under the Micro Kjeldahl procedure (AOAC, 1995). It was performed in duplicate and the result was presented as a percentage of nitrogen.

Useful performance (USY)

The percentage of IVDDM was multiplied by the DMY in stubble, to which the GRY of each of the evaluated maize was added.

Experimental design and statistical analysis

The triple 6x6 latex was used in San Mateo Capultitlan and San Nicolás Zecalacoayan, and the simple latex in San Juan Cuautlancingo. The experimental unit consisted of two grooves of 0.8 x 5.2 m, with an area of 8.32 m^2 for each one. The data of the variables were subjected to an analysis of variance and Tukey's mean comparison test, with significance of α = 0.05 (Steel and Torrie, 1981), using the Statistical Analysis System (SAS) version 9.4 (SAS, 2008).

Results and discussion

Days to male flowering and Days to female flowering

Corn cultivars (Table 1) were different ($p< 0.0001$) to reach 50% male flowering. The average was 83 days; the group that presented the least number of days ($p\leq 0.05$) was that of cultivars 29, 20, 27, 35, 15, 22, 18, 13, 14, 16 and 17, with a range of 78 to 76 days. Regarding female flowering, they were also different ($p< 0.0001$) reaching an average of 85 days. The group that presented the least number of days ($p\leq 0.05$) was that of cultivars 35, 22, 18, 15, 13, 14, 16 and 17 with a range of 80 to 77 days. Based on the variation that occurred among the evaluated materials, 8.3% corresponded to the late layer, 61.1% to the intermediate layer and 30.5% to the early layer. The earliest materials were SM-16 122x142, SM-16 124x142 and SM-16 125x142. These cultivars were earlier than those shown in high valley environments as Aceves *et al*. (2002) reporting a range of 107-110 for DFF and Muñoz *et al*. (2013) who reported a range of 121 to 132 days for the same variable.

Height of the plant and Height to the ear

Corn cultivars were different ($p< 0.0001$) in ALP, with an average of 2.4 m. The group that presented the highest ALP ($p\leq 0.05$) was that of cultivars 2: SM-16 13x44 with 2.78 m, 30: HS-2® with 2.75 m, 25, 19, 12, 7, 6, 24, 27 , 26, 1, 31, 8, 3, 36, 9, 28, 5, 21 and 11, with a range of 2.7 to 2.4 m. They were also different ($p< 0.0001$) in ALM, whose average was 1.2 m. The group with the highest ALM ($p\leq 0.05$) was the genotypes 19: SM-16 166 # with 1.57 m, 25: CPue-00174 with 1.53 m, 2, 12, 28, 6, 1, 9, 27, 7, 24, 30, 26, and 3; with a range of 1.5 to 1.37 m.

The variation that existed between the evaluated genotypes indicates that 48% corresponded to the upper stratum, 19% to the medium stratum and 33% to the lower stratum. Anandan *et al*. (2013) and Vinayan *et al*. (2013) found lower variations in ALP in tropical environments where hybrids and lines dominated. The highest materials in ALP were SM-16 13x44 and HS-2® and the highest in ALM SM-16 166 # and CPue-00174. The results shown in this investigation indicate that these materials were higher than those shown by Muñoz *et al*. (2013) in high valleys who found variations between 221-130 cm and 147-54 cm in ALP and ALM, respectively.

Grain yield

Maize genotypes were different ($p< 0.0001$) in GRY (Figure 1). The average was 6 277 kg ha^{-1}. The group with the highest GRY ($p\leq 0.05$) was that of cultivars 30, 32, 9, 6, 1, 5, 2, 12 and 8 (HS-2®, Aguila 215W®, SM-16 60x66, SM- 16 44x64, SM-16 5x64, SM-16 23x60, SM-16 13x44, SM-16 64x66 and SM-16 58x21); in an interval between 10 464 to 7 743 kg ha^{-1}.

There was variation in grain yield, which indicates that between cultivars there are genetic differences of their own and of interaction with environmental conditions. The single-cross hybrids and two commercial hybrids showed a higher average GRY than the free-pollinated varieties. This is related to hybrid vigor, although it shows that not all commercial hybrids work the same, and not all simple or free-pollinated crosses.

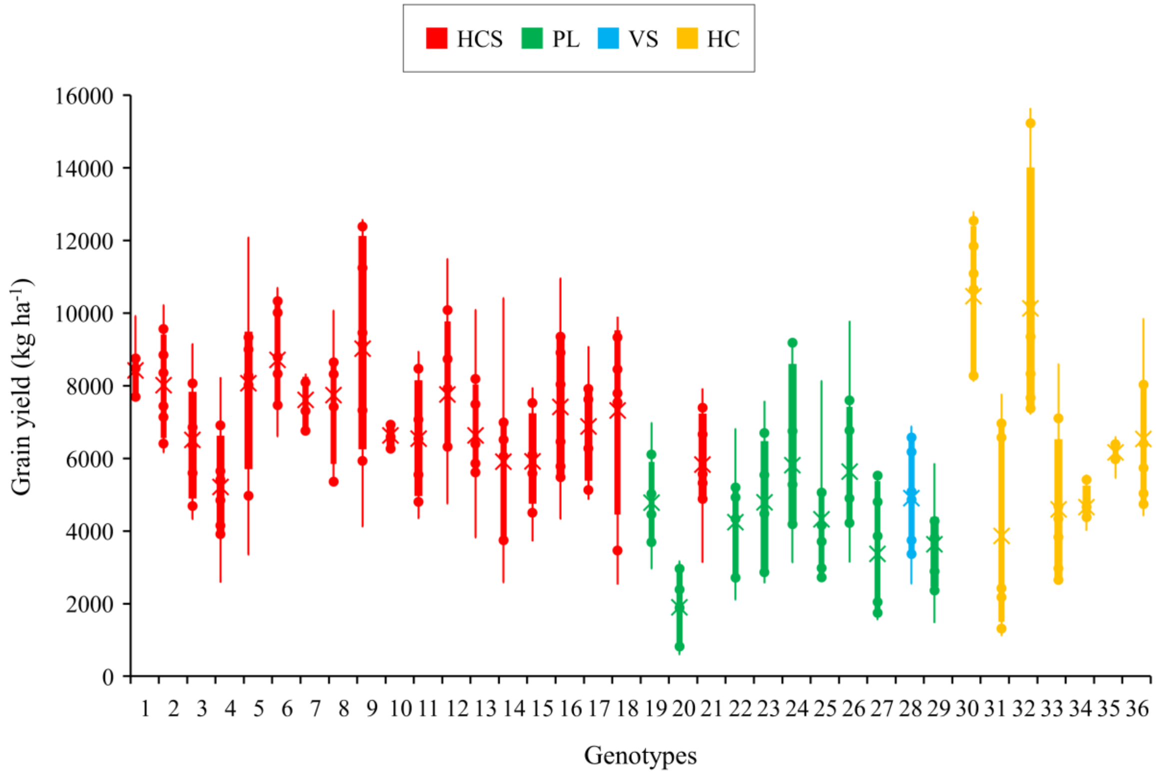

Figure 1. Distribution of grain yield in each of the genotypes established during the experimental period. The bars indicate the statistical range of values, the dots represent the maximum and minimum values of each genotype and the 'x' indicates the statistical mean value for each material. Single-cross hybrids (SCH), free-pollinated (PL), synthetic variety (SV), commercial hybrids (CH).

The average GRY value of the cultivars in this investigation were slightly higher 3% than that reported by Aceves *et al*. (2002) in conditions of residual humidity and 46.6% to that reported by Muñoz *et al*. (2013); also higher than that reported to the lines with the highest performance in tropical environments in 42 and 46% (Vinayan *et al*., 2013; Reddy *et al*., 2013; Zaidi *et al*., 2013) and lower in 22% to hybrids commercials tested by Anandan *et al*. (2013) in the tropics.

Stubble dry matter yield

Corn cultivars were different ($p< 0.0001$) in DMY (Figure 2). The average was 11 566 kg DM stubble ha^{-1}, where the group with the highest DMY ($p\leq 0.05$) was that of the genotypes 26, 36, 12, 9, 31, 2, 7, 30, 28, 24, 3, 27, 19, 18, 21, 10, 4, 25, 8, 23, 5 and 1 (CPue-00369, Niebla®, SM-16 64x66, SM-16 60x66, Imparable®, SM-16 13x44, SM-16 53x64, HS-2®, Tropical-1®, CPue-00157, SM-16 21x64, CPue-00406, SM-16 166 #, SM-16 136x142, SM-15 137x135, SM-16 61x21, SM-16 22x64 , CPue-00174, SM-16 58x21, CPue-00089, SM-16 23x60 and SM-16 5x64.), in a range of 14 063 to 11 465 kg ha^{-1}, of which 12 are single-cross hybrids, six are free-pollinated populations, a synthetic variety, and three are commercial hybrids.

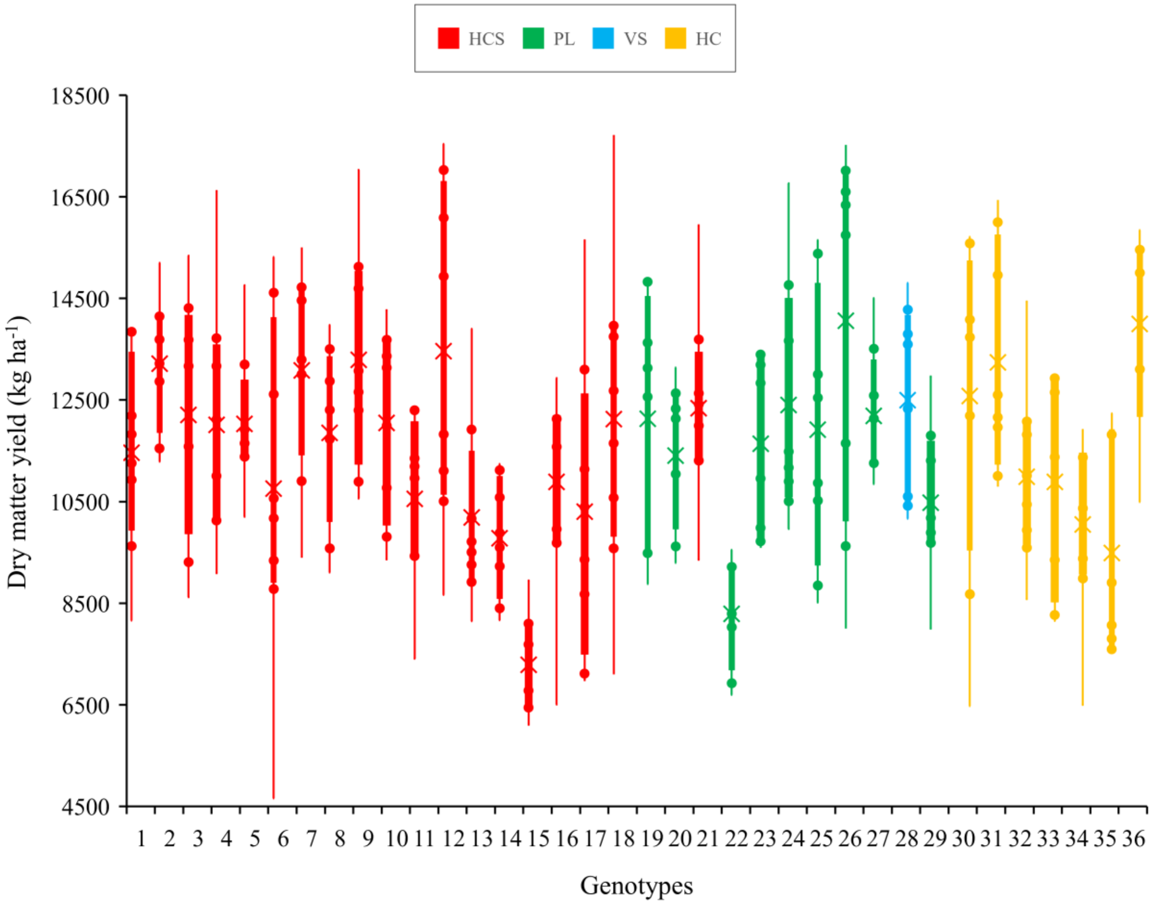

Figure 2. Distribution of stubble dry matter yield in each of the genotypes established during the experimental period. The bars indicate the statistical range of values, the dots represent the maximum and minimum values of each genotype and the 'x' indicates the statistical mean value for each material. Single-cross hybrids (SCH), free-pollinated (PL), synthetic variety (SV), commercial hybrids (CH).

The variation in stubble dry matter yield indicates that between genotypes there are genetic differences possibly modified in their expression by interaction with their evaluation environment. In this variable there was dominance of the simple cross hybrids and it was observed that only three commercial hybrids appeared in the upper group. It became clear that such hybrids are selected towards low bearing and more attention is given to grain yield. In works carried out to evaluate varieties in similar environments, variations have also been found (Aceves *et al*., 2002; Muñoz *et al*., 2013).

The average value of the cultivars evaluated in this investigation were higher than that reported by Muñoz *et al*. (2013) in 60%, although they had a lower plant density per final hectare (40 000), they were also superior to works carried out with hybrids and with lines in tropical environments in a range of 37 to 58% (Anandan *et al*., 2013; Vinayan *et al*., 2013; Reddy *et al*., 2013; Zaidi *et al*., 2013).

Leaf-stem relationship

Maize genotypes were different ($p< 0.0001$) in the LSR and had an average of 1.6. The group with the highest LSR ($p\leq 0.05$) was that of cultivars 24: CPue-00157, 6: SM-16 44x64, 1: SM-16, 5x64, 25: SM-16 5x64, 8: SM-16 58x21 and 19: SM-16 166 #; with a range of 2.3 to 2.18. Muñoz *et al*. (2013) in similar environments found variations between 1.3 to 3.0.

Fiber content

Corn cultivars were different ($p< 0.0001$) in NDF concentration. The average was 75% and the group with the lowest values ($p\leq 0.05$) was that of cultivars 14, 3, 7, 10, 32, 19, 16, 28, 22, 27, 25, 24, 20, 23: CPue-00316 and 29: CPue-00089, with an interval of 74.8 to 70%.

In the ADF concentration also the cultivars were different ($p< 0.0001$) reaching an average of 45.7%. The group with the lowest concentration ($p\leq 0.05$) was that of cultivars 6, 20, 14, 31, 22, 32, 24, 30, 10, 18: SM-16 136x142 and 12: SM-16 64x66, with an interval of 43.6 to 38.4%. Regarding the concentration of LAD, the corn cultivars were different ($p< 0.0001$) having an average of 11%. The group with the lowest concentration of LAD ($p\leq 0.05$) was that of cultivars 5, 29, 17, 20, 11, 19, 18, 32, 22, 15, 23, 13, 24: CPue-00157 and 14: SM-16 122x142, with an interval of 6.9 to 9.8%.

The variation that was shown among the cultivars evaluated indicates that 58% corresponds to the most fibrous layer and 42% to the least fibrous layer. The results in NDF and ADF agree with several investigations (Anandan *et al*., 2013; Vinayan *et al*., 2013; Reddy *et al*., 2013; Zaidi *et al*., 2013), but for the concentration of LAD, the results found indicate that there was a higher concentration between 50 to 60%.

***In vitro* digestibility of dry matter**

Corn cultivars were different ($p< 0.0001$) in IVDDM (Figure 3). The average was 49% of IVDDM and the group that presented higher values ($p\leq 0.05$) was that of materials 31, 34, 1, 17, 14, 28, 3, 15, 27, 11 and 4 (Imparable®, SBA 404 Barbaro®, SM-16 5x64, SM-16 125x142, SM-16 122x142, Tropical-1®, SM-16 21x64, SM-16 123x142, CPue-00406, SM-16 63x21 and SM-16 22x64); in a range of 55.6 to 51.2%. These results agree with those reported by Zaidi *et al*. (2013); Vinayan *et al*. (2013) who used lines in tropical environments and also with Anandan *et al*. (2013) who used hybrids.

Crude protein

The CP concentration in the corn cultivars was different ($p< 0.0001$), having an average of 2.3%. The group with the highest CP ($p\leq 0.05$) was that of cultivars 1: SM-16 5x64, 2: SM-16 13x44, 3, 23, 20, 18, 14, 11, 19, 35, 25, 31 , 6, 34, 10; with a range of 3.2 to 2.45%. Variation was expressed in the concentration of CP, which indicates that between cultivars there are genetic differences. Variations in CP concentration have been found in tropical environments, as in the investigations carried out by the authors Anandan *et al*. (2013); Vinayan *et al*. (2013); Reddy *et al*. (2013); Zaidi *et al*. (2013) although they show a range from 3.1 to 10.0. The cultivars with the highest CP in the present investigation were SM-16 5x64, SM-16 13x44 and SM-16 21x64.

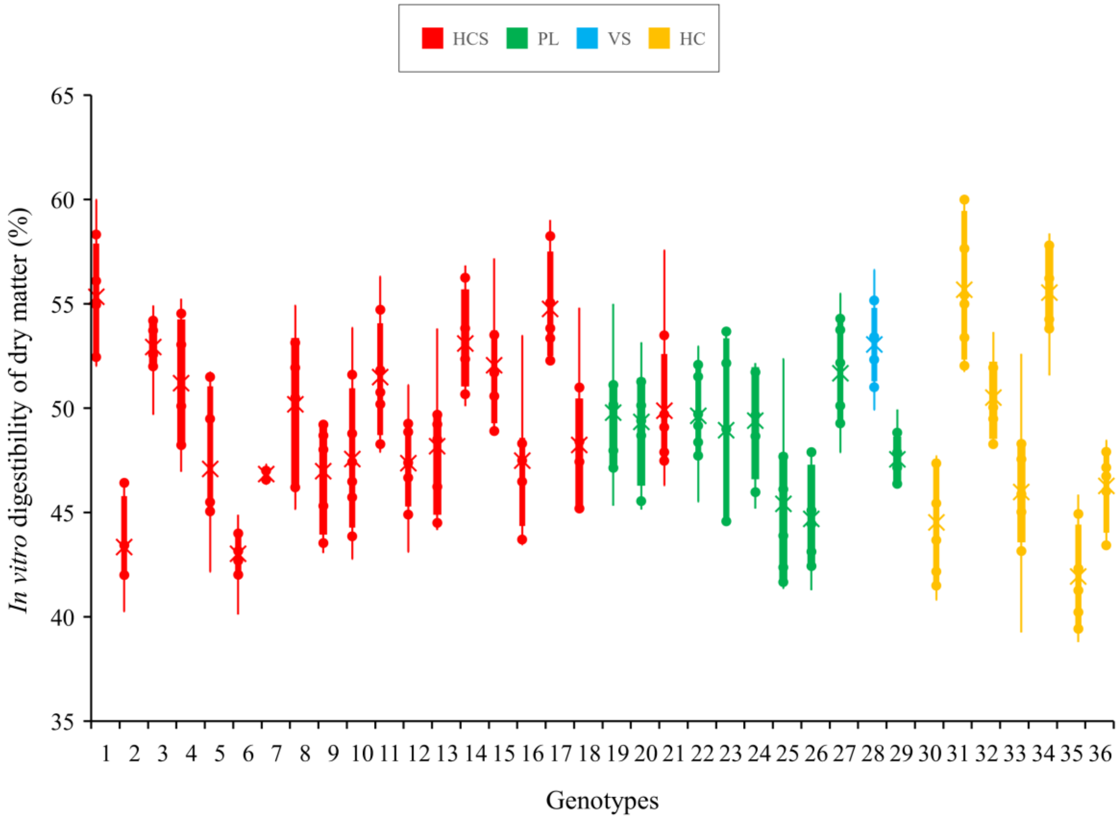

Figure 3. ***In vitro*** **digestibility percentage of the stubble of each of the genotypes established during the experimental period.** The bars indicate the statistical range of values, the dots represent the maximum and minimum values of each genotype and the 'x' indicates the statistical mean value for each material. Single-cross hybrids (SCH), free-pollinated (PL), synthetic variety (SV), commercial hybrids (CH).

Dual-purpose fitness: useful performance

The useful yield of the corn cultivars was different ($p< 0.0001$) as shown in Figure 4. The average was 11 879 kg ha^{-1}. The group with the highest USY ($p\leq 0.05$) was that of genotypes 30, 32, 9, 1, 12, 7, 2, 5, 8, 6, 18, 36 and 3 (HS-2®, Aguila 215W ®, SM-16 60x66, SM-16 5x64, SM-16 64x66, SM-16 53x64, SM-16 13x44, SM-16 23x60, SM-16 58x21, SM-16 44x64, SM-16 136x142, Niebla® and SM-16 21x64), with an interval of 16 047 to 12 963 kg ha^{-1}. Some genotypes had low digestibility (eg HS-2®, SM-16 44x64, SM-16 13x44), but due to their production of grain and stubble dry matter, they resulted in a high USY, they would have to find variation in digestibility to increase their quality as dual-purpose genotypes.

For example, the commercial hybrid Aguila 215W® had a high grain yield (10 132 kg ha^{-1}), but an average dry matter production value (10 988 kg ha^{-1}) and an average digestibility value (50.5%). On the other hand, the SM-16 5x64 single-cross hybrid had a higher grain yield (8 425 kg ha^{-1}), as well as higher digestibility (55.3%), but it requires increasing its dry matter production (11 465 kg ha^{-1}). None of the genotypes evaluated had superiority in the three characteristics, but they allow giving higher useful yields per unit area.

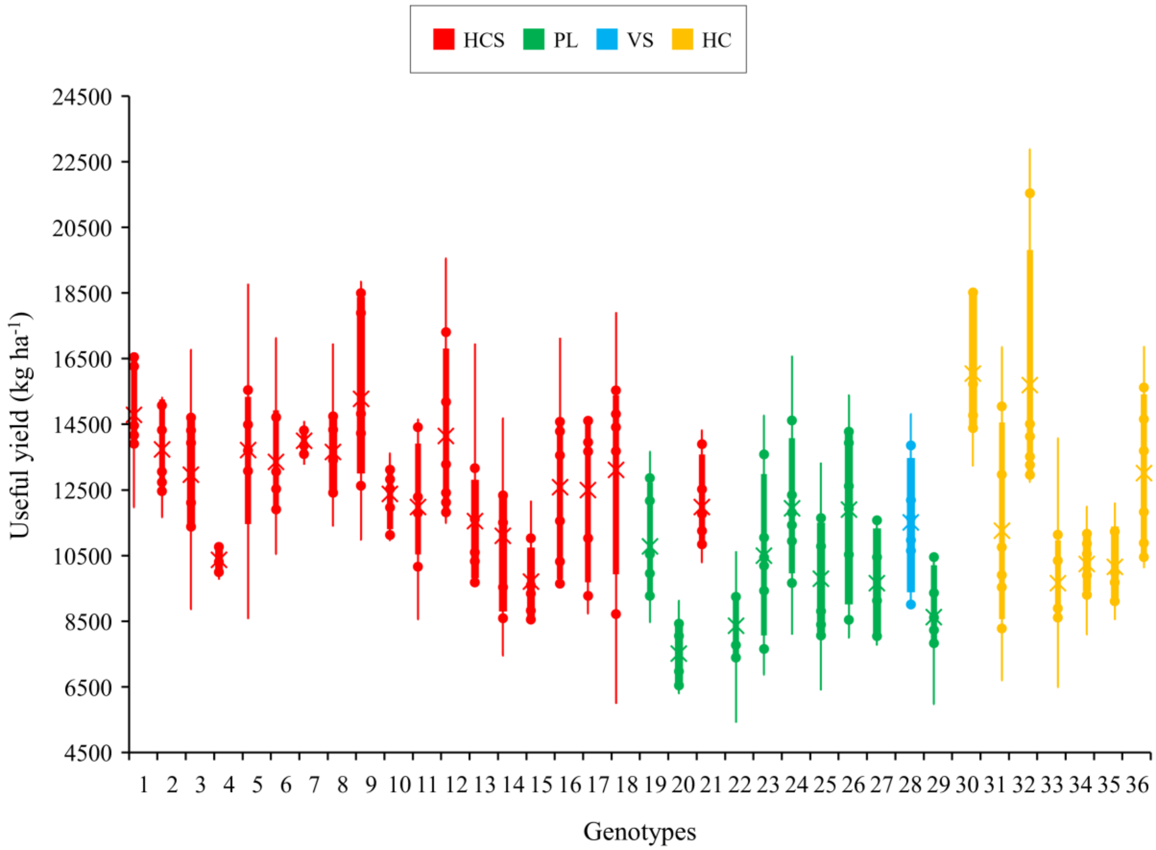

Figure 4. Useful performance concentration (USY) of each of the genotypes established during the experimental period. The bars indicate the statistical range of values, the dots represent the maximum and minimum values of each genotype and the 'x' indicates the statistical mean value for each material. Single-cross hybrids (SCH), free-pollinated (PL), synthetic variety (SV), commercial hybrids (CH).

Conclusions

The genotypes evaluated were different in the production of stubble dry matter, its nutritional value and grain production. Commercial hybrid genotypes and synthetic varieties do not necessarily yield more grain and stubble than free-pollinated, single-cross hybrid genotypes. Nor are free-pollinated, single-cross hybrid genotypes superior to commercial hybrids and synthetic varieties in terms of nutritional quality.

Regarding the detection of genotypes for dual purpose, only one single cross hybrid managed to appear in the outstanding groups in grain yield and digestibility (the SM-16 5x64). The variable 'useful yield', although it detects outstanding materials for a dual purpose, masks the most productive grain and dry stubble that have low digestibility.

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