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Predicted milk production per hectare based on yield and chemical composition of native and hybrid maize silage varieties on temperate and tropical regions

Predicción por hectárea de la producción de leche en función del rendimiento y la composición química de las variedades de ensilaje del maíz nativo e híbrido en regiones templadas y tropicales

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Abstract

The objective of the present study was to characterize maize silage according to chemical composition, maize silage yield, as well as their predicted milk production. A search was made on studies related to maize silage yield, density, chemical composition (DM, CP, NDF, starch), and dry matter digestibility (DMD). In this study, 41 maize varieties from temperate regions and 101 maize varieties from tropical origin were analyzed. The net energy of lactation (NEL Mcal/kg DM), kilograms of milk per t of silage (kg of milk/t DM), and kilograms of milk per hectare of silage (kg of milk/ha) were determined. A cluster (CL) analysis was performed, and six CL of maize silage were obtained. The CL1 included digestibility for dry matter, crude protein, neutral detergent fiber, NEL, and kg of milk/t DM. CL2 was characterized by maize silage with the highest number of plants per hectare and NDF. CL3 included the highest ash content. CL4 consisted of intermediate values for all variables. CL5 included the highest forage yield (t DM/ha) and kg of milk/ha whereas CL6 included the highest kg of milk/t. Overall, CL1 resulted in the highest DMD and NEL, producing more milk per t DM. Results suggested that the ideal option is maize silage with a higher forage yield and more than 35 % DM (CL5) since this produces more kg of milk per hectare.

Keywords: production systems, dairy, cows, starch, fiber, conserved forage.

Resumen

El objetivo del presente estudio fue caracterizar el ensilaje de maíz acorde a su composición química, a su rendimiento, así como a su producción de leche prevista. Se realizó una búsqueda en estudios relacionados al rendimiento del ensilado de maíz, a la densidad, a la composición química (MS, PB, FDN, almidón) y a la digestibilidad de materia seca (DMS). En este estudio fueron analizadas 41 variedades de maíz de regiones templadas y 101 variedades de maíz de origen tropical. Se determinaron la energía neta de lactancia (ENL Mcal/kg MS), los kilogramos de leche por t de ensilaje (kg de leche/t MS), y los kilogramos de leche por hectárea de ensilaje (kg de leche/ha). Se llevó a cabo un análisis cluster a partir del cual fueron obtenidos seis CL del ensilaje de maíz. El CL1 incluyó digestibilidad de materia seca, proteína bruta, fibra detergente neutro, ENL y kg de leche/t MS. El CL2 se caracterizó por ser el ensilaje de maíz con el mayor número de plantas por hectárea y FDN. El CL3 incluyó el mayor contenido de ceniza. El CL4 se compuso de valores intermedios en todas las variables. El CL5 incluyó el mayor rendimiento de forraje (t MS/ha) y kg de leche/ha, mientras que el CL6 incluyó el mayor kg de leche/t. En general, el CL1 fue el que presentó el mayor valor de DMS y ENL, produciendo como resultado más leche por t MS. Los resultados sugirieron que la opción ideal es el ensilaje de maíz con mayor rendimiento de forraje y más del 35 % MS (CL5), puesto que produjo más kg de leche por hectárea.

Palabras claves: sistemas de producción, lácteos, vacas, almidón, fibra, forraje conservado.

Introduction

Maize production and the production of dairy milk represent two of the main economic activities in Mexico (Reta *et al.*, 2015; Espinoza *et al.*, 2007). According to SAGARPA (2016), there is a population of 2.3 million dairy cows, of which 85 % are located on small-scale farms, contributing to approximately 70 % of the national milk supply per year, with a reported annual production per cow of 5190 L (Posadas et al., 2016). In addition, the national production of dairy milk for the second quarter of 2017 reached 5670 million liters (SIAP, 2017). In 2016, Mexico imported 209,803 t of milk powder to cover national supply needs, a number which is expected to increase (Brio Agropecuario, 2016).

In 2013, Mexico was identified as one of the countries most affected by climate change (SEMARNAT, 2014). Furthermore, maize production is the main farming activity in Mexico. Nearly 2 million producers participate in this activity, and 85 % have less than 5 ha of land. In Mexico, maize represents the main use crop to produce dairy milk and human consumption (Jiménez-Leyva *et al.*, 2016), and an undetermined amount is allocated as straw, green fodder, and to a lesser extent for the preparation of silages for cattle feed (Celis Álvarez *et al.*, 2016; Jiménez Leyva *et al.*, 2016). According to the SIAP (2016) reports, in Mexico in 2015, an area of 445,775 ha was planted in the rainy season and 161,623 ha in irrigation for fodder maize, with yields of 19.29 and 47.55 t/ha of dry matter (DM) and green matter (GM), respectively. Given the great heterogeneity of agroclimatic conditions that present negative impacts on agricultural-animal production, this results in a disparity of yields per hectare and per animal, which is why there is a need to optimize the use of forage.

The StAnD (sustainable animal diets) method (FAO, 2014) is a tool that integrates several dimensions of sustainability, including the three P (people, planet, and profitability) dimensions, and gives an overall picture of the current state of a production system. The indicators corresponding to each dimension allow for the detection of specific problems or limitations that may be addressed to improve the sustainability of the system (FAO, 2014). One indicator of the StAnD method is “do not use cereals in animal diets and improve the use of native resources” (Planet dimension). This study used the StAnD method to evaluate the sustainability of native and hybrid silages in Mexico and can help to guide agricultural practices and policies in accordance with the economic and environmental performance of different maize production systems. The objective of the present study was to perform a literature search on the yield and chemical composition of maize silage samples produced in tropical and temperate regions of Mexico and to characterize maize silage according to chemical composition, forage yield (t/ha), as well as predicted milk production.

Materials and methods

Data collection. The selection process limited the results to studies published from 2001 to 2016. For inclusion in the final database, the studies had to include agronomic and chemical variables such as: yield of dry matter (t/ha), density of plants (number of plants/ha), dry matter content (DM), crude protein (CP), neutral detergent fiber (NDF), non-fibrous carbohydrates soluble (NFCS), ash or organic matter (OM), dry matter digestibility (DMD), and neutral detergent fiber digestibility (NDFD). Thus, in this study, 142 maize silage samples were included (135 hybrids and seven native varieties); 41 maize varieties from temperate regions and 101 maize varieties from tropical origin.

Calculations. Studies with missing values for starch and fat were calculated according to the National Research Council (2001). The net energy for lactation (NEL, Mcal/kg DM), total digestible nutrients (TDN), kilograms of milk per t of dry matter (kg of milk/t DM) and kilograms of milk per hectare (kg milk/ha) were determined using the MILK2006®spreadsheet. The model utilizes the concentration of NEL, estimated from adaptation of the equations for NEL provided by the National Research Council (NRC, 2001), in combination with the NDF in vitro digestibility (NDFD), to predict the milk yield with a fat content of 35 g/kg. The estimated fat-corrected milk yield (FCM) is a means of adjusting the milk yield for the amount of fat in the milk to reflect the relative energy concentration in the milk, thus it reflects the energy required to produce the given amount of milk. The feed value of the fiber affects the supply of NEL, both through altering the concentration of NEL and through its effect on forage intake. In the model, milk production is estimated from a cow with a live weight of 612 kg, fed a diet with 300 g/kg dietary NDF concentration, with maize silage as the only forage, and a production of 35 kg of milk (kg per day) (Shaver, 2006). The missing values for NDFD were calculated using the regression equation derived from both NDF and NDFD data available in the papers used in the present study as:

$$\text{NDFD (\%)} = 77.96\ (\pm\ 1.85) + [(\text{NDF}) * (-\ 0.36\ (\pm\ 0.95))],\quad R^2 = 0.40 \quad \textbf{(Eq. 1)}$$

A descriptive analysis of the chemical composition, forage yield (t/ha), as well as the potential milk production of the maize silage was carried out using the SAS statistical software (Statistical Analysis System [SAS], 2004). To identify differences between varieties of maize silage, Kolmogorov-Smirnov tests were applied to determine if the resulting scores varied significantly with respect to a normal distribution. The data were normally distributed and analyzed with a completely randomized design model, using the Tukey’s test ($P < 0.05$).

Statistical analysis. The analysis of the variables described above was carried out in two independent stages: 1) With the information of the sixteen variables, an analysis was made of the interrelationships between the variables (multivariate analysis) and their estimated contribution to the total variance, applying a Principal Components Analysis (PCA) (PROC PRINCOMP, SAS Institute INC., 2007). 2) The grouping of information sources into homogeneous levels was done through the hierarchical clustering analysis (PROC CLUSTER, WARD method) from SAS Institute INC., (2007) using the selected variables. One hundred and forty-two maize silages were evaluated by taking the mean of treatments of each, to determine which groups of variables were correlated with each other. Six clusters were obtained. According to the six integrated groups, an analysis of variance was carried out to determine if there were significant statistical differences between the six levels ($P < 0.05$). From the maize silage samples included in this study, 101 varieties were from tropical zones and 41 varieties from temperate zones.

Finally, maize groups that had similar productive conditions were determined from the variables considered for this study. The effects were considered significant if they were lower than $P < 0.05$. To determine if there were differences between the effects, the Tukey test was used for multiple comparisons of means (Steel & Torrie, 1997, pp. 179-180).

Results

Descriptive statistics of chemical composition, forage yield, and milk production potential are shown in Table 1. The PCA results are presented in Table 2. Five factors (F) were obtained and named according to the variables included in each of them. Factor 1 (F1) refers to kg milk/t DM integrated by the variables NDF, NDFD, NFCS, starch, TDN, and kg milk/t DM, and F1 had the highest contribution (38.48 %) to the total variance. Factor 2 (F2) refers to DM yield/t and kg milk/ha, factor 3 (F3) to fat content, factor 4 (F4) to CP and OM, and factor 5 (F5) to DM and DMD. F2-F5 contributed 15.24 %, 11.49 %, 8.09 %, and 7.57 %, respectively, of the total variance.

In the PCA, 16 groups were obtained, however only the first five have an eigenvalue greater than one (Table 2), and they explained 81 % of the overall variance. Subsequently, the variables were used to perform a cluster analysis (cluster, CL) (Table 3) and resulted in a hierarchical dendrogram program (Figure 1), forming six cluster groups (CL) of maize silage. The first group (CL1) (22 varieties) was called "Digestibility", the variables associated to it were: DMD, CP, NDFD, NEL, and kg of milk/t DM. The second cluster (CL2) (40 varieties) was characterized by maize silage varieties with the highest number of plants per hectare and NDF content. The third (CL3) (21 varieties) called "Ash" had varieties with the highest ash content; the fourth (CL4) (24 varieties) was called "Average" because it was made up of the average of all variables. The fifth (CL5) (7 varieties) was called "milk yield per ha", which had the highest forage yield (t DM/ha), and kg of milk/ha, and the sixth cluster (CL6) (7 varieties) was called "kg Milk/t" which had the greater DM, NDF, and NEL digestibility (Mcal/kg DM), and kg milk/DM t.

Discussion

Maize silages were characterized by the variability in their chemical composition due to different factors such as the use of local varieties (natives), hybrids, the agronomic management carried out with the crop, and the content of dry matter (Darby & Lauer, 2002; Komainda *et al.*, 2016). In Mexico, different maize genotypes are cultivated, however, most of them are planted for their yield (t DM/ha) rather than for their nutritional quality, which is very common in most countries producing maize (Núñez *et al.*, 2003). Similarly, for the different types of silage, development and characterization should be considered as a function of their chemical composition, maize varieties, and harvesting management (fertilization rate, irrigation, crop labors)

Table 1. Descriptive statistics of the maize silage in Mexico.

Variable	N	Mean	Min	Max	SD
1.Yield DM ton/ha	142	19.19	9.40	34.20	4.19
2.Plant density/ha	142	79764	62500	100000	11238
3.DM	142	29.86	11.13	44.81	5.59
4.DMD	142	66.51	47.71	78.30	4.80
5.CP	142	7.72	4.40	10.30	1.23
6. NDF	142	56.78	31.00	69.90	7.27
7.NDFD	142	57.51	43.00	68.35	3.31
8.NFCS	142	25.13	13.00	25.13	6.87
9.Ash	142	6.15	1.70	9.90	0.72
10.OM	142	93.84	90.10	98.30	0.73
11.Fat	142	4.20	4.22	4.21	0.01
12.Starch	142	23.0	22.00	23.00	0.82
13.TDN	142	63.61	47.14	72.73	3.22
14.NEL, Mcal/kg DM	142	1.34	1.10	1.56	0.07
15.kg of milk per ton DM	142	494.40	327.64	615.54	39.91
16.kg milk per ha	142	22402	9153	38829	4734

DM

Chemical composition is expressed in g/100 g Dry Matter.

t/ha = yield in tons per hectare of dry matter; Plant density/ha = highest plant density; DM = dry matter content; DMD = dry matter digestibility; CP = crude protein; NDF = neutral detergent fiber; NDFD = neutral detergent fiber digestibility; NFCS = non fibrous carbohydrates soluble; OM = organic matter content; TDN = total digestible nutrients; NEL = net energy for lactation (Mcal/kg DM).

Table 2. Analysis of principal components (PC) of the corn silages variables.

PC	Eigen value	%	% Accumulated
1	4.85	26.92	26.92
2	3.21	17.85	44.77
3	2.05	11.39	56.15
4	2.02	11.23	67.38
5	1.59	8.83	76.21
6	1.30	7.25	83.47
7	0.91	5.05	88.50
8	0.58	3.25	91.75
9	0.36	2.00	93.74
10	0.29	1.63	95.73
11	0.28	1.52	96.89
12	0.25	1.38	98.27
13	0.16	0.92	99.18
14	0.13	0.74	99.92
15	0.01	0.07	99.98
16	0.01	0.01	99,99
17	0.01	0.01	100

CL1_DMD, CP, NDFD, NFCS, TDN, NEL, and kg milk/t DM, C2_highest CP content, C3_highest plant density (number plats/ha), NDF and the lowest NFCS, TDN, NEL, kg milk/t DM and kg milk/ha, C4_highest NDF and OM content, C5_higher forage yield (t DM/ha), DM % content and kg milk/ha C6_higher DM digestibility and the lowest OM content.

(Darby & Lauer, 2002; Lynch *et al.*, 2012; Marchesini *et al.*, 2019). These aspects play a key role in the development of a good silage (silage processing after cutting, *i.e.* particle size, pressing, bailing, fermentation rate) with a potential for improving milk production.

Productivity of maize varieties in Mexico has been reported to range from 10 to 22 t/ha, whereas plant density varies between 58,000 to 96,000 plants/ha. In addition, DM digestibility of those cultivars ranged from 63 to 79 % (Núñez *et al.*, 2001; Elizondo & Boschini, 2002; Núñez *et al.*, 2003; SAGARPA, 2016). In Mexico, maize silage is considered a secondary product since the main use is the production of grain for human consumption.

In this study, the PCA help to characterize maize silage according to its chemical composition, forage yield and milk production potential, resulting in five factors, which could be used for the selection of high and low-quality maize silages. F1 grouped most of the variables such as kg milk/t DM as well as chemical composition variables, for example the NDFD, which is useful for the characterization of forages quality (Gallo *et al.*, 2013).

Six cluster groups were obtained from the chemical and productive characteristics of the different maize silages. One of the main factors determining the nutritional quality of the silage is the

Table 3. Corn forage production, plant density, chemical composition of the silage and its potential milk production of corn silages sown in Mexico.

Variables	CL1	CL2	CL3	CL4	CL5	CL6	SEM	P value
Yield DM, t/ha	21.31[b]	17.45[c]	18.35[bc]	18.31[c]	27.49[a]	15.58[c]	2.97	0.0001
Density/ha	63055[d]	91816[a]	65714[cd]	80517[b]	70577[c]	82333[b]	4900	0.0001
DM	26.48[c]	30.16[b]	20.95[d]	30.22[b]	39.21[a]	24.71[cd]	2.77	0.0001
DMD	63.20[c]	68.64[ab]	65.56[bc]	67.04[b]	60.34[c]	72.16[a]	2.5	0.0001
CP	5.63[d]	7.71b[c]	6.98[c]	8.24[ab]	8.01[abc]	9.01[a]	1.25	0.0001
NDF	60.41[ab]	61.84[a]	52.56[cd]	54.49[c]	55.25[bc]	45.11[d]	5.2	0.0001
NDFD	55.92[c]	55.70[c]	58.73[abc]	58.34[b]	58.26[bc]	62.59[a]	4.0	0.0001
NFCS	24.11[bc]	20.09[c]	29.41[ab]	26.91[b]	26.12[b]	35.29[a]	5.99	0.0001
ASH	5.63[b]	6.01[ab]	6.85[a]	6.03[ab]	6.32[ab]	6.31[ab]	1.03	0.004
OM	94.32[a]	93.55[b]	93.14[b]	93.58[b]	93.32[b]	93.21[b]	0.54	0.0001
TDN	63.07[cd]	60.39[e]	65.33[bc]	65.25[b]	61.88[de]	70.88[a]	2.2	0.00001
NEL MJ/kg DM	1.34[c]	1.27[c]	1.39[bc]	1.38[b]	1.29[c]	1.51[a]	0.115	0.00001
kg milk/t DM	489.39[cd]	453.98[e]	516.85[bc]	515.51[b]	466.05[de]	589.61[a]	30.15	0.0001
Kg milk/ha	24672[b]	18830[c]	22471[bc]	22353[b]	30230[a]	21672[bc]	672.34	0.00001

[abc] Different letters in the same row, P > 0.0001.

DM = dry matter content; DMD = dry matter digestibility; CP = crude protein; NDF = neutral detergent fiber; NDFD = neutral detergent fiber digestibility; NFC = nonfibrous carbohydrates; OM = organic matter; TDN = total digestible nutrients; NEL = net energy for lactation (MJ/kg DM); kg milk/t DM = kilograms of milk per t of dry matter; Kg milk/ha = kilograms of milk per hectare; CL1_DMD, CP, NDFD, NFCS, TDN, NEL, and kg milk/t DM; CL2_highest CP content; CL3_ highest plant density (number plats/ha), NDF, and the lowest NFCS, TDN, NEL, kg milk/t DM and kg milk/ha; CL4_highest NDF % and OM % content; CL5_higher forage yield (t DM/ha), DM % content, and kg milk/ha; CL6_higher DM digestibility and the lowest OM content.

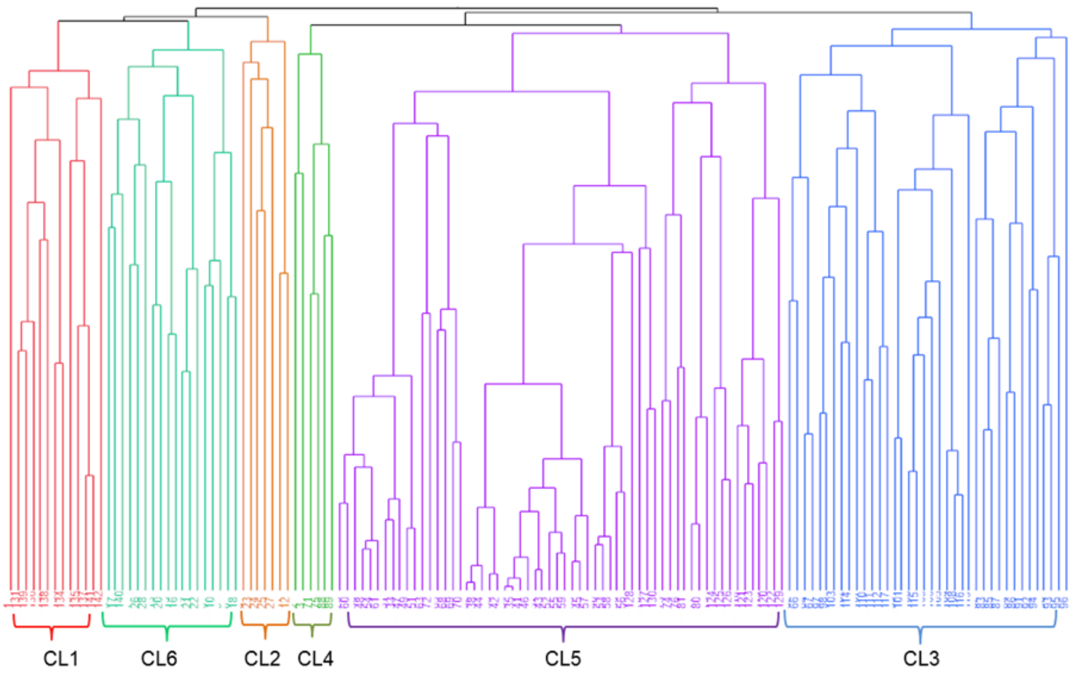

Figure 1. Integral hierarchical dendrogram of the 142 maize silages according to the chemical composition descriptors and milk yield production in Mexico. CL1: Digestibility, CL2: Density, CL3: Ash, CL4: Average, CL5: Milk yield per ha, CL6: kg milk per ton

NDF digestibility, which has variable degradability and influences the energy value and animals' intake (Spanghero *et al*., 2008; Khan *et al*., 2015). In a study on forage yield and quality of maize silage, Lynch *et al*. (2012), reported an increase in NDF in maize harvested at 22 days of maturity, which indicates that the determination of maize harvesting time is a key factor for silage quality according to its chemical characteristics and its potential for milk production.

In CL2, maize silage varieties were grouped according to characteristics for greater density, which is consistent with the tropical maize varieties from this study. The forage maize of tropical origin, known for having smaller stems and fewer leaves, decreased DM production, in addition to requiring more plants to reach an optimal yield. Some authors reported that this increase is due to the lower number of leaves and the fibrous and highly lignified stems (Núñez *et al*., 2001; Elizondo & Boschini, 2002). A disadvantage of this group is the high NDF concentration in the forage, which limits total DM intake, due to a filling effect at the ruminal level, as well as a decrease in the degradation of the forage (Spanghero *et al*., 2008).

The amount of ash is the inorganic content of the forage, which can be affected by maturity stage. It has been reported that maize harvested in the last phenological stages has higher contents of ash than in early growth stages (Darby & Lauer, 2002; Komainda *et al*., 2016). In this sense, it has been indicated that maize silages can be harvested around 115 days post sowing when 95 % of OM is present (Filya, 2004). Marchesini *et al*. (2019) reported how the effects of yield potential and maturity at harvest vary depending on whether early or late hybrids are considered resulting in a progressive reduction in the fermentation quality at higher maturity stages by increasing their ash and NDF contents. However, it has been reported that neither the density of plants by area, nor the use of higher densities of maize plants allow an increase in crop yield per unit area (Khan *et al*., 2015).

In Mexico, the selection of maize silage for livestock feed does not consider varieties based on nutritional quality. Instead of selecting maize varieties for grain production, determining the fermentation quality index (QFI) could be a better option, which is an index with values ranging from 1 to 100 and is calculated based on the concentrations of lactic acid, ammonia, ethanol, butyric, acetic acids (Kung *et al*., 2018), and pH. However, this information is not always available for comparison or to determine with greater certainty the yield, quality, and production potential of silage maize varieties.

In this sense, it has been shown that when the percentage of dry matter of maize silage increases from 25 % to 30 %, the intake and production of milk are higher (Khan *et al*., 2015). This increase is related to the percentage of DM, the intake and nutritional value of the maize, due to a higher content of grains, water structural carbohydrates, and energy. Similarly, higher concentrations of NEL and CP stimulate the production of microbial crude protein in the rumen, increasing the concentration of protein in the milk (Ferraretto & Shaver, 2015; Lascano *et al*., 2016), positively influencing milk yield production (kg of milk/t DM).

The results of the CL6 may be due to DMD and NDFD contents resulting from the degree of maturity obtained at the time of cutting and by the variety of maize, as well as the factors affecting forage yield and milk production per t of dry matter (kg of milk/t of DM) (Lynch *et al.*, 2012; Khan *et al.*, 2015).

Conclusion

Cluster five (CL5) was characterized for having a higher forage yield (t DM/ha), DM content, and kg milk/ha. CL5 also showed the highest DM and energy to produce milk (kg of milk per t of DM). Our results suggest that the most suitable option was the maize silage that had a higher forage yield (t DM per ha) and more than 35 % DM, since it produced more kg of milk/ha. In the same way, the characteristics of CL6 were of interest, considering its DM and NDF digestibility. Results from this review could help farmers when decisions are needed for silage conservation.

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