Review [Revisión]

FORAGE YIELD, CHEMICAL COMPOSITION AND POTENTIAL MILK YIELD USING MAIZE SILAGE FROM ASIA, EUROPE, NORTH AND SOUTH AMERICAN CONTINENTS: A SYSTEMATIC REVIEW †

[RENDIMIENTO FORRAJERO, COMPOSICIÓN QUÍMICA Y PRODUCCIÓN POTENCIAL DE LECHE UTILIZANDO ENSILADO DE MAÍZ DE ASIA, EUROPA, NORTEAMÉRICA Y SUDAMÉRICA: UNA REVISON SISTEMATICA]

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SUMMARY

Background. Corn (*Zea mays* L.) silage is the most widely used energy resource in dairy cattle diets worldwide, standing out mainly for its higher biomass yields, good palatability, homogeneous quality at harvest and ease of ensiling due to higher soluble sugar content, with respect to other grasses. **Objective**. To make a systematic review of the characteristics of silage production, its chemical composition, and its potential milk production in different parts of the world, according to the data obtained. **Methodology**. A search for studies on the production and chemical composition of maize silage was carried out worldwide. For this purpose, a search for information was carried out in the following databases, published between 2000 and 2020.The potential milk yield per hectare (kg milk/ha) was calculated using the MILK2006® program. To analyze the relationship between all variables a multivariate analysis approach was used implementing a Factorial Analysis of Mixed Data (FAMD). **Main Findings**. The overall maize silage yield median is 12.55 ton DM/ha, median density 80,000 plants per hectare. Median dry matter (DM) is 30.5 g/100 g DM, with median dry matter digestibility (DMD) 66.6 g/100 g DM. The median TDN is 64.7 g/100 g DM, producing a median of 506 kg milk/ton DM and 22968 kg milk/ha. Asia had the highest DM Yield/ton ha and DMD ($P < 0.001$) followed by Europe, and North America. No differences by continent ($P > 0.05$) were found in TDN, kg milk/ton DM and kg milk/ha. Asia and North America continent had the best silage characteristics (DM and DMD), but this did not affect milk production being similar among continents. **Implications**. The analysis was limited to published scientific contributions only, however, not all the articles in the survey could be used, because they did not meet the criteria for inclusion. **Conclusion**. The Asian and North American continents had the best silage characteristics (DM and DMD), but this did not affect milk production using the MILK2006® programme, being similar between continents.

Key words: Digestibility; Dry Matter; Milk Production; Corn Silage.

RESUMEN

Antecedentes. El ensilado de maíz (Zea mays L.) es el recurso energético más utilizado en dietas de vacuno de leche a nivel mundial, destacando principalmente por sus mayores rendimientos de biomasa, buena palatabilidad, calidad homogénea a la cosecha y facilidad de ensilado debido a su mayor contenido en azúcares solubles, respecto a otras gramíneas. **Objetivo**. Hacer una revisión sistemática de las características de la producción de ensilado, su composición química y su potencial de producción de leche en diferentes partes del mundo. **Metodología**. Se realizó una búsqueda de estudios sobre la producción y

† *Submitted January 16, 2024 – Accepted July 5, 2024.* http://doi.org/10.56369/tsaes.5406

ISSN: 1870-0462.
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composición química del ensilado de maíz a nivel mundial. Para ello, se realizó una búsqueda de información en las siguientes bases de datos, publicadas entre 2000 y 2020.El rendimiento potencial de leche por hectárea (kg leche/ha) se calculó utilizando el programa MILK2006®. Para analizar la relación entre todas las variables se utilizó un enfoque de análisis multivariante aplicando un Análisis Factorial de Datos Mixtos (AFDM). **Principales hallazgos**. El rendimiento global del ensilado de maíz su mediana es de 12.55 toneladas de MS/ha, la densidad mediana de 80,000 plantas por hectárea. La materia seca (MS) mediana es de 30.5 g/100 g MS, con una mediana de la digestibilidad de la materia seca (DMS) 66.6 g/100 g MS. El TDN mediana es de 64.7 g/100 g MS, produciendo una mediana de 506 kg de leche/ton MS y 22968 kg de leche/ha. Asia tuvo el mayor rendimiento de MS/ton ha y DMD ($P < 0.001$), seguida de Europa y Norteamérica. No se encontraron diferencias por continente ($P > 0.05$) en TDN, kg leche/ton MS y kg leche/ha. Los continentes asiático y norteamericano presentaron las mejores características de ensilado (MS y DMD), pero esto no afectó a la producción de leche siendo similar entre continentes. **Implicaciones**. El análisis se limitó únicamente a las contribuciones científicas publicadas, sin embargo, no todos los artículos encontrados pudieron ser utilizados, porque no cumplen con los criterios para la inclusión. **Conclusión**. Los continentes asiático y norteamericano presentaron las mejores características de ensilado (MS y DMD), pero esto no afectó a la producción de leche utilizando el programa MILK2006®, siendo similar entre continentes.

Palabras clave: Digestibilidad; Materia Seca; Producción de Leche; Ensilado de Maíz.

INTRODUCTION

Maize (*Zea mays* L.) silage is the most widely used energy resource in diets for dairy cattle and ruminants in general worldwide, standing out mainly for its higher biomass yield (ton/ha), good palatability, homogeneous crop quality and ease of ensiling due to its higher soluble sugar content compared to other grasses (Khan *et al.*, 2015), legumes or their association.

Maize was the most produced cereal globally during the 2023/2024 season, with a production of about 1163.5 million metric tons of grain with an average yield of 5.2 tons grain/ha, followed by wheat and rice. As to produce green fodder maize, 9868.4 million metric tons were produced, with a global area of 1 105 213 ha (FAOstat, 2022). However, there is currently no exact data on the amount of maize silage produced in the world, as this is focused on feeding ruminants.

The global maize silage market is projected to grow at a compound annual growth rate of 7.84% from 2021 to 2030.

The main producers of corn silage are North America (NA), followed by Europe, Asia-Pacific and Latin America (Statista, 2022), with the United States of America in first place, followed by China.

In recent years, the main focus of major maize producers has been on improving the quantity of grain maize and in silage maize only on improving stalk bolting resistance (Karnatam *et al.*, 2023), so many key characteristics of maize silages are unknown, and it is important to detect what are the characteristics of maize silages produced in different parts of the world in order to improve them (Statista, 2022).

Therefore, the aim of the present study was to make a systematic review of the characteristics of silage production, its chemical composition, and its potential milk production in different parts of the world, according to the data obtained.

MATERIAL AND METHODS

Search strategy and selection criteria

A search for studies on the production and chemical composition of maize silage was carried out worldwide. For this purpose, a search for information was carried out in the following databases (ScienceDirect 2021, Scopus, Di-alnet, SciELO, Science Research, PubMEd, Redalyc and Google Scholar), published between 2000 and 2020. The keywords used to search for information were corn silage, forage production, dry matter, hybrid silage, native silage, genetically modified silage, forage, milk production, and a search string with Boolean operators (“and", "or") was used.

Data extraction and analysis

This study followed PRISMA guidance and Figure 1 shows a flow chart (Moher *et al.*, 2009) of the data collected. After preliminary search and screening, 443 articles were assessed to be eligible. Sixty-seven were excluded due to the following reasons: Not providing the required statistical parameters (n = 42) and not having a control group (n = 25). Two reviewers assessed all articles using the inclusion and exclusion criteria.

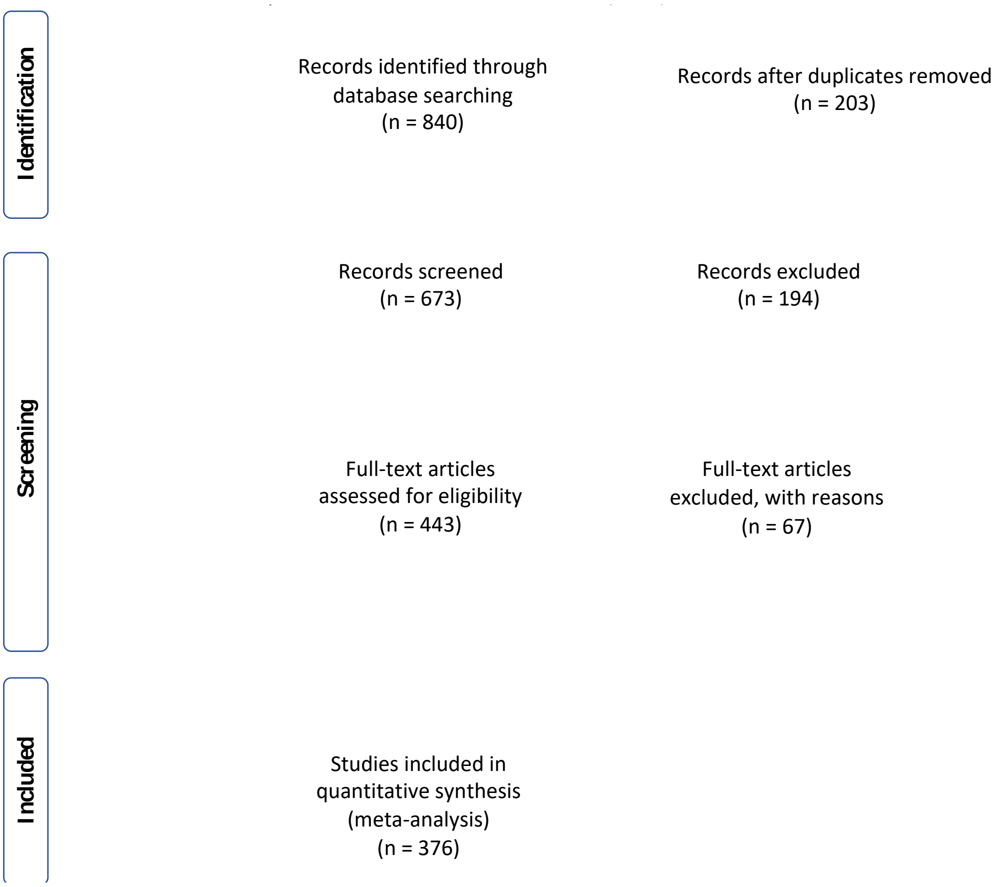

Figure 1. PRISMA flowchart from the initial search and screening to the final selection of publications to be included in the meta-analysis.

The database consisted of a total of 376 papers (Figure 1) reporting dry matter yield (ton/ha), plant density/ha, dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), digestible NDF (NDFD), non-fiber carbohydrates (NFC) and starch of different genetic lines of corn silages (native, hybrid and genetically modified organisms (GMOs)). The papers were obtained from Asia, North America, South America, and Europe. A descriptive analysis of the variables by continent and genetic line was analyzed. The descriptive analysis was performed using the "describe" function of the psychological package (Revelle, 2021).

Calculations and analysis

The potential milk yield per hectare (kg milk/ha) was calculated using the MILK2006® program. A descriptive statistical analysis of chemical composition and milk yield (mean, median, minimum, maximum, standard deviation) of corn silages was performed. An analysis of variance was performed with SAS (2007) between the different continents, and significant statistical differences ($P < 0.05$) were evaluated with a Tukey's comparison test.

To analyze the relationship between all variables a multivariate analysis approach was used implementing a Factorial Analysis of Mixed Data (FAMD). The FAMD is a principal component method that allows examining databases with both qualitative and quantitative variables (Pages, 2004). This methodology analyzes the similarities between individuals by considering a mixed type of variables. In addition, FAMD explores the association between quantitative and qualitative variables. The FAMD were carried out in the package FactoMineR version 2.8 (Le *et al.*, 2008) of the statistical program R version 4.2.2 (R core team, 2022). The results of FAMD are showed through a contributions plot of qualitative and quantitative variable. The contribution plots approximate the distribution of a multivariate sample in a generally two-dimensional reduced dimension space where angles and proximity among variables provide a measure of association.

RESULTS

The descriptive statistics of the maize silage are shown in Table 1, where the data are presented by median, the overall yield of maize silage is

12.55 tons DM and a density of 80,000 plants per hectare. The DM is 30.5 g/100 g DM, with a digestibility of 66.6 g/100 g DM. The median total digestible nutrient (TDN) is 64.7 g/100 g DM, yielding 506 kg milk/t DM and 22,968 kg milk/ha.

Asia had the highest DM/ton ha and DM digestibility (DMD) yield ($P < 0.001$) (Table 2), followed by Europe and North America, with the highest DM (g/100g), as well as starch, NFD and NDF digestible (NDFD) (Table 2). The lowest amount of ash was found in corn silage from South America (4.84 g/100g) (Table 2). On another hand, the highest DM yield (ton/ha) by genetic line was for native's corn silages (Figure 2). No differences by continent ($P > 0.05$) were found TDN (TDN, g/100g DM), net energy lactation (NEL, MJ/kg DM), DM milk yield (kg/ton DM) and milk yield (kg /ha) (Table 2).

Table 1. Variables considered for maize silage in the world (Mean, Median, Min, Max and standard deviation).

Variable	Mean ± SD	Median	Min-Max
DM Yield (ton /ha)	15.7 ± 8.3	12.55	2.75 - 53.6
Density/ ha	76,155 ± 15570	80,000	50,000 - 100,000
DM (g/100 g as FM)	33.1 ± 8.4	30.5	11.1 - 61.1
DMD (g/100 g)	63.6 ± 11.2	66.6	45.70 - 85.2
CP (g/100 g)	7.8 ± 1.4	7.7	4.4 - 14.9
TDN[1]xDM	66.6 ± 4.1	64.7	48.3 - 75.1
NEL, MJ/kg DM	5.85 ± 0.1	5.73	4.60 - 6.69
kg milk/ton DM	531.4 ± 55.6	506.7	269.4 - 650.0
kg milk / ha	19,190.8 ± 10217.9	22,968	2624 -52540.8
N	376		

DM Yield (ton/ ha) = Dry matter yield in tons per hectare, Density ha= Plant density per hectare, DM= Dry matter amount, DMD= Dry matter digestibility (dry matter), CP= Crude protein (dry matter), TDN[1]xDM= Total Digestible Nutrients (dry matter), NEL MJ/kg DM= the net energy of lactation per kg of Dry Matter, kg milk/t DM= Milk production (kg) per ton of Dry Matter per hectare, kg milk/ha = kg of milk per ton of Dry Matter.

Table 2. Least squares means and significance test of corn silages according with continent.

Variable	Continent					
	Asia	**Europe**	**North America**	**South America**	**SEM**	**P-value**
n	**20**	**10**	**340**	**6**		
DM yield (ton/ha)	19.17^{a}	16.82^{b}	13.17^{c}	13.22^{c}	1.65	0.001
DM (g/100g as FM)	28.65^{b}	28.79^{b}	32.76^{a}	24.76^{c}	0.63	0.001
DMD (g/100g)	73.74^{a}	66.21^{b}	65.43^{c}	67.84^{b}	2.30	0.002
TDN (g/100g)	68.99	67.13	66.82	66.17	0.33	0.136
Crude protein (g/100g)	6.03^{c}	11.03^{a}	7.74^{b}	7.36^{b}	0.31	0.001
Fat (g/100g)	4.2	4.2	4.0	3.79	0.16	0.170
Starch (g/100g)	23.0^{b}	25.5^{ab}	27.2^{a}	23.0^{b}	1.75	0.002
NDF (g/100g DM)	44.1^{b}	48.9^{ab}	49.3^{a}	52.2^{a}	1.91	0.030
NDFD (g/100g NDF)	62.1	60.3	60.2	59.2	1.05	0.060
Ash (g/100g)	6.15^{a}	6.15^{a}	5.98^{a}	4.84^{b}	0.19	0.001
NEL (MJ/kg DM)	6.10	5.98	5.94	5,94	0.004	0.211
DM milk yield (Kg/ton DM)	562.48	540.04	535.32	527.76	4.45	0.136
Milk yield (Kg/ha)	25,517.2	21,590.4	16,180.2	17,891.0	522.4	0.182

DM Yield/t ha = Dry matter yield in tons per hectare, DM= Dry matter amount, DMD= Dry matter digestibility (dry matter), TDN[1]xDM= Total Digestible Nutrients (dry matter), NEL MJ/kg DM= the net energy of lactation per kg of Dry Matter, milk yield (Kg/ha) = Milk production (kg) per ton of Dry Matter per hectare, DM milk yield (Kg/t DM) = kg of milk per ton of Dry Matter.

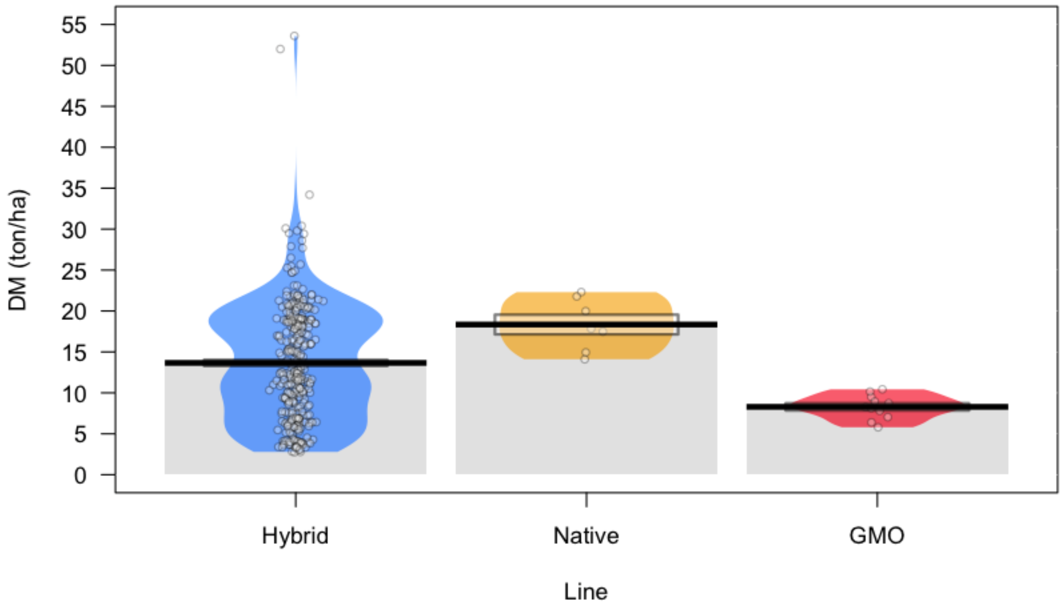

Figure 2. Dry matter yield (ton/ha) of corn silages according with corn line.

The FAMD analysis shows that the first two dimensions account for 20.9% and 12.5% of the variability in the original dataset, respectively (Figure 3). The dimension 1 showed a high contribution of quantitative variables (Figure 3a), which indicate that this dimension is closely to each of the quantitative variables such as NDF, NDFD, starch and DM yield. Also, we found a positive relationship between the NDF content and the DM yield of silage per ha. Contrary, the NDF content was negatively associated with the NDFD and starch content. According with our results, the DMD decrease as the content of ash increased. With respect to qualitative variables, the inertia of dimension 1 was mainly explained by the genetic corn line (native, hybrids or GMOs), with a negative relationship between the native and GMO lines (Figure 3b).

To evaluate the relationship between quantitative and qualitative variables we found a positive relation among the native corn silage lines and ash content of analyzed silages. The native corn silage lines also were related positively with the content of NDF and DM yield of silages. In another hand, the GMOs lines were positively associated with higher contents of starch and better digestibility of NDF. The continent variable was allocated near to centroid, which means that this variable was not associated with a particular quantitative and qualitative variable and had a low level of contribution to explain the total inertia of actual data (Figure 3a and 3b).

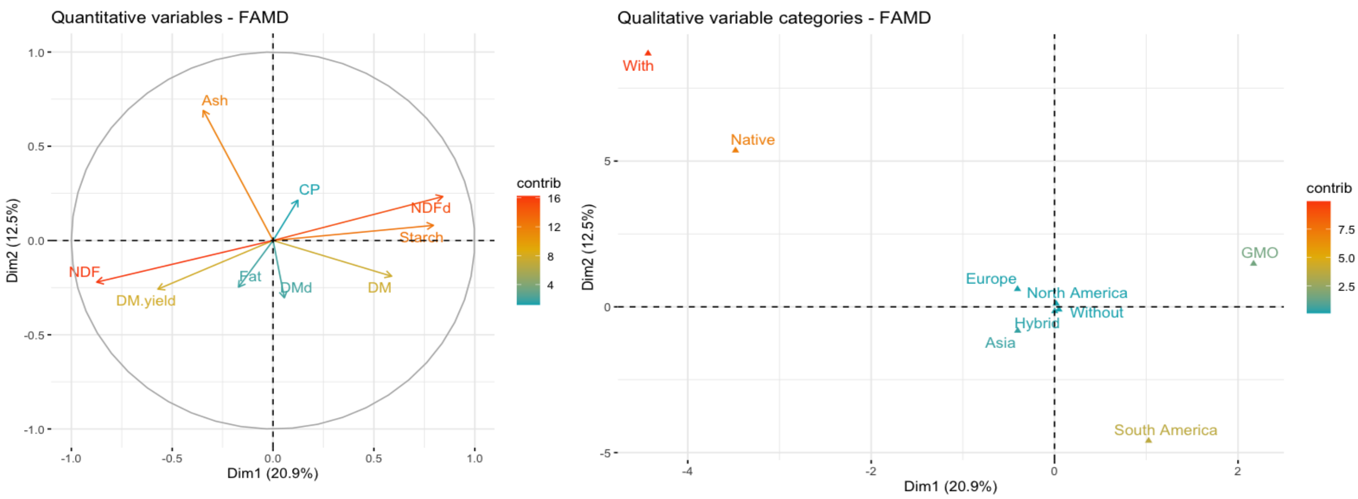

Figure 3. Contributions of the quantitative (a) and qualitative variables (b) in the first two dimensions of the FAMD and correlations between variables.

DISCUSSION

Silage is a method of forage preservation through a process of anaerobic fermentation. The use of the whole maize plant as silage is one of the most widely used forage resources in dairy cattle feeding worldwide, due to its easy fermentation and good green fodder yield (ton/ha), However, information is limited on its yield characteristics, digestibility, and chemical composition among others, because research has mainly focused on grain yield (Karnatam *et al.*, 2023).

When we observe the results obtained in the present study, we can highlight that Asia is the continent where the best forage yields, higher digestibility and the lower content of ash of silages (Table 2, Figure 2), this may be due to the large increase in population, which is generating a strong demand for quality food, generating a market impulse for the improvement of forage resources (Mordor intelligence, 2023). The main crop produced since 2013 in Asia (China) has been corn, so guaranteeing to improve its production has been essential in recent years (Mandic *et al.*, 2016), which we can see reflected in the results found in the present study.

Corn silage presents marked forage yield differences between regions, these differences may be due to the climatic conditions of each region (FAOStat, 2021; Erenstein *et al.*, 2022). For example, two thirds of the production in Asia is produced in temperate climate (China) and the other third is in tropical climate of South and Southeast Asia, the climate of South America is a tropical climate compared to the climate of North America which has a temperate climate (Erenstein *et al.*, 2022), so that the heterogeneity within each of the regions of each continent can be reflected in the observed characteristics of the silages in this study. The DM content of the silages coincides with those shown in other studies (Ramirez *et al.*, 2024), which varies from 29 to 35 g/100 g DM, also these values coincide with the energy concentration of corn silage, which is in the range of 6.2 to 6.5 MJ NEL/ kg DM (Ramirez *et al.*, 2024), remember that the NEL content is the result of the concentration of TDN, the NDFD and the NDF content (Robinson, 2001; Akins and Shaver, 2014), however, dairy producers have been selecting corn hybrids whole-plant corn silage production based on nutritional quality parameters (Lauer *et al.*, 2012). One point to note is that modern hybrids have been shown to have on average, 5.5% lower *in vivo* cell wall digestibility than native maize, resulting in a 2.0% reduction in dry matter digestibility, despite a trend towards an increase in grain content (Barrière *et al.*, 2005). Forage Yield (ton/ha) is an essential property, especially when maize is destined for forage production, as planting areas are generally located on dairy farms near urban centers or other marginal areas that are not ideal agronomic environments for potential yield expression. As a result, low and uneconomical yields can be obtained (Bertoia and Aulicino, 2014).

Therefore, NDF digestibility increased resulting in higher DM intake and milk production for cows fed brown midrib whole corn silage compared to conventional hybrids (Oba and Allen, 1999; Ebling and Kung, 2004). Better NDF digestibility allows for reduced physical rumen filling and therefore higher DMD and milk production (Oba and Allen, 2000), Cardozo (2013) mentions that a good quality forage has a DMD between 70 g/100 g DM, only silages from the Asian continent are in this range (Table 2). The DMD in South America is 67.8 g/100 g DM (Table 2) which is slightly higher than those reported by Ramirez *et al.* (2024), with a range of 59.5 to 62 g/100 g DM. These differences may be due to the harvest stage, as it has been mentioned that increasing plant maturity decreases *in vitro* DMD (Arriola *et al.*, 2012). The NDF content of a whole corn plant is 3.4 percentage units lower, and the starch content was 4.9 percentage units higher compared to the average of dual purpose and brown midrib mutation, who has been shown to influence the nutrient content of whole-plant corn silage and intake, digestion, and lactation performance by dairy cattle. The starch content of whole plant corn silage in previous studies is variable, Akay and Jackson (2001) find higher starch content and conversely Chase (2010) and Benefield *et al.* (2006) find lower starch content in whole plant corn silage compared to conventional hybrid maize. When the whole plant is harvested, the ear and stubble contribute to the final dry matter yield of the forage, both components should be considered, as has been done in the present study.

The highest amount of CP was found in silage from Europe (11.03 g CP/100 g) (Table 2). As mentioned above, season and maturity affect CP concentration. In Europe, corn production destined for silage is grown in cooler climates, as those in warmer climates aim to produce corn for grain (Taube *et al.*, 2020). Karnatam *et al.* (2023) mention that, compared to warmer months, cooler environments will produce forages with higher levels of CP, so it reflects what is happening in Europe in terms of CP quantity.

North American and European silages had starch contents of 27.2 and 25.5 g/100 g DM, respectively, being the highest for this characteristic. The increase or decrease of starch is related to plant maturity since as the plant reaches maturity its content increases (Salama, 2019), however, the grain presents a greater hardness at advanced ages of corn maturation due to the increase of the endosperm, which decreases the digestibility of starch and silage in general (Guyader *et al.*, 2018). Similarly, DMD decreases as ash content increases (Figure 5), which may be due to the fact that with the use of high ash maize silage, the uptake of endogenous minerals is decreased (Karnatam *et al.*, 2023).

Although no statistical differences in milk yield were founded, and can be seen numerically, which as observed in the figure 3, may be related to higher digestibility and higher starch content, being higher for the Asian continent, Ferraretto and Shaver (2015) and Nestor (2010) mention that high milk yield was mainly related to high DM intake of the skim, similarly starch is the main source of fermentable energy in the rumen (Khan *et al.*, 2015).

The Asian and North American continents had the best silage characteristics (DM and DMD), but this did not affect the milk production / ton forage yield or per hectare, being similar between continents, more information is needed to confirm the results obtained in this study, as well as the incorporation of data related to their fermentation characteristics, pH, Volatile Fatty Acids, Lactic Acid, and bacterial and fungal content in corn silages.

CONCLUSION

Since digestibility of plant components varies with genotype, maize quality should be determined by forage yield and chemical composition, DMD and NDFD). The Asian and North American continents presented the best silage characteristics (DM and DMD), but this did not affect the potential milk production, being similar between continents (19,190 kg milk/ha), it is important that more studies are conducted on silage considering its forage production, and chemical composition, considering its fat and starch content, and dry matter and NDFD.

Funding. This research was partially financed by the Universidad Autonoma del Estado de Mexico (Project UAEMex 4974/2020 and UAEMex 6663/2022 SF)

Conflict of interest statement. The authors declare that they have no competing interests.

Compliance with ethical standards. This work is a systematic review, with no local ethical approval required.

Data availability. Availability of data and materials' statement. At the request of the authors

Author Contribution Statement (CRediT). M. Gonzalez-Ronquillo - Conceptualization, methodology, validation, investigation, writing original draft preparation, review and editing, project administration., **L.E. Robles Jimenez** - Conceptualization, methodology, validation, investigation, writing original draft preparation, review and editing, formal analysis., **J. Osorio Avalos** - formal analysis, writing review and editing, visualization., **O.A. Castelan-Ortega** - investigation, writing original draft preparation, project administration., **J.C. Ángeles-Hernandez** - methodology, data curation, writing review and editing, visualization. All authors have read and agreed to the published version of the manuscript.

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