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Analysis of the nutritional quality of maize silage in the years 2011-2019 and the relationship between the microclimatic conditions and nutritive value of silage from Slovakia

Analýza nutričnej kvality kukuričných siláží v rokoch 2011-2019 a vzťah medzi mikroklimatickými podmienkami a nutričnou hodnotou siláží zo Slovenska

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ABSTRACT

The aim of the experiment was to analyze the nutritive value of maize silage through the 9-year monitored period in relationship to precipitation and temperature during the growing season in Slovakia. In the maize silage samples (1204) the basic nutrients were analyzed according to 3 regions and 8 counties according to the statistical analysis methods. The statistical evaluation of results was realized by IBM SPSS ver. 26.0. The descriptive statistics of nutritive value of maize silage by One-Way ANOVA, the significant differences by POST HOC Tukey test ($P < 0.05$), and for the relationship between the nutrients and microclimatic conditions Pearson correlation test (r) was realized. The results confirmed that the nutritive value of maize silage is significantly affected by year, region, and county. The strongest effect of precipitation on the dry matter (DM), ether extract (EE), nitrogen-free extracts (NFE), crude fiber (CF), acid detergent fiber (ADF) and neutral detergent fiber (NDF) was observed. In contrast, the effect of temperature on the content of dry matter and etheric extract was reflected. The positive significant effect of precipitation during April and July on the starch content was determined. Then, temperatures in June significantly increased the DM and NFE content. On the other hand, temperatures caused a significant decrease in EE, CF, ADF, and NDF in maize silage in June.

Keywords: *Zea mays* L., conserved feed, climatic factors, nutritive value, quality

ABSTRAKT

Cieľom pokusu bolo analyzovať výživnú hodnotu kukuričnej siláže počas sledovaného obdobia 9 rokov v závislosti od zrážok a teploty počas vegetačného obdobia na Slovensku. Vo vzorkách kukuričných siláží (1204) boli analyzované základné živiny podľa 3 regiónov a 8 krajov využitím základných štatistických metód. Štatistické vyhodnotenie výsledkov sa realizovalo pomocou programu IBM SPSS ver. 26.0. Deskriptívna štatistika nutričnej hodnoty kukuričnej siláže sa realizovala metódou One-Way Anova, preukaznosť rozdielov testom POST HOC Tukey ($P < 0,05$) a pre vzťah medzi živinami a mikroklimatickými podmienkami sa realizoval Pearsonov korelačný test (r). Výsledky potvrdili, že výživnú hodnotu kukuričnej siláže významne ovplyvňuje rok, región a okres. Okrem toho sa zistil významnejší vplyv zrážok v porovnaní s teplotou. Najsilnejší vplyv zrážok sa zaznamenal na obsah sušiny, tuku, bezdusíkatých látok výťažkových, hrubú vlákninu, acidodetergentnú vlákninu a neutrálnedetergentnú vlákninu. Na druhej strane,teplota výrazne ovplyvnila obsah sušiny a tuku. Ďalej sa pozoroval signifikantne pozitívny vplyv zrážok na obsah škrobu počas mesiaca apríl a júl. Teplota v júni významne ovplyvnila zvýšenie obsahu sušiny a obsah bezdusíkatých látok výťažkových. Na druhej strane teploty v júni sa prejavili v poklese obsahu tuku, hrubej vlákniny, acidodetergentnej vlákniny a neutrálnedetergentnej vlákniny v kukuričnej siláži.

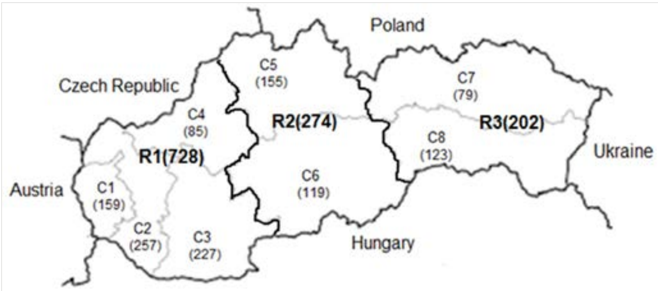
Kľúčové slová: *Zea mays* L., konzervované krmivo, klimatické faktory, výživná hodnota, kvalita

INTRODUCTION

It is well known that maize silage is an important forage used as a basic component of the feeding mixtures of ruminants (Juráček et al., 2012; Rajský et al., 2020). Starch in maize silage is an economical source of energy for the animals and fermentable energy for rumen microbes (Poštulka and Doležal., 2010). Since silage from whole maize plants represents a unique forage containing high levels of starch and dietary fiber at the same time it increases use for dairy farmers. The physiological maturity of maize cob by harvest time is the most considerable factor that influences starch content. According to the knowledge of agricultural practice, drought affects the physiological maturity of the corn cob, and the starch content (Rajský et al., 2020). According to Mansoor et al. (2021), even though there are other factors (e.g. fertility level, plant management, and insect, disease, and weed pressures, etc.) that can affect the production of maize, there is no doubt that precipitation is one of the most important factors controlling maize yield both for grain and silage. Furthermore, water deficit with the combination of precipitation and temperature (which is one of the most important parameters for climate change) is even more significant and critical for maize (both for grain and silage) production. According to the results, agro regions of the Slovak Republic will become more sensitive to conditions of climate change on drought occurrence as compared with climate conditions of the last normal period 1961-1990. While there were recognized 5 categories of drought conditions on the territory of the Slovak Republic in the reference period 1961-1990, the next 2 very dry can be recognized in agro regions of Slovakia according to both the climatic index of drought and evapotranspiration deficit. This fact has serious effects on the potential acreage of some crops. High totals of potential evapotranspiration can evoke the occurrence of drought more frequently. This fact should be considered in the future both on the levels of crop selections and water-saving rotations (Šiška and Takáč, 2009). Increasing drought and extreme rainfall are major threats to maize production (Li et al. 2019). Overall, the quality of maize silage is influenced not only by the nutritional value of maize, but also by the silage additives, the course of the fermentation process and technological factors (mowing height, chop length, mechanical processing, degree of mass compaction, used storage technologies, anaerobic stability, management of feed out and aerobic stability) (Bíro et al., 2020; Mitrík, 2021). The experiment aimed to analyze the nutritive value of maize silage through the 9 years in relationship to precipitation and temperature during the growing season with an emphasis on the year, region, and county in Slovakia.

MATERIAL AND METHODS

The nutritive value of 1204 samples of maize silages from the territorial division of Slovakia according to Figure 1 from 2011 to 2019 were determined. The territory was split into 8 counties in terms of valid self-government with 3 regions, which represent more homogenous area units in terms of cultivation conditions. The microclimatic characteristics from April to August during the growing season (Table 1 and 2) were provided for this analysis by the Slovak Hydrometeorological Institute Bratislava.



Regions (R): R1-Western Slovakia (WS), R2-Central Slovakia (CS), R3-Eastern Slovakia (ES); Counties (C): C1-Bratislava (BA), C2-Trnava (TT,), C3-Nitra (NR), C4-Trenčín (TR), C5-Žilina (ZA), C6-Banská Bystrica (BB), C7-Prešov (PO), C8-Košice (KE)

Figure 1. Territorial division of Slovakia according to the sources of analyzed maize silage samples (n = 1204)

In the feed samples, the following indicators of nutrition value by the applicable legislative regulations (Decree of the Ministry of the Slovak Republic No. 2145/2004-100 on official sampling and laboratory assessment and evaluation of feed and Commission Regulation (EC) No. 152/2009 of January 27th, 2009) were determined:

- Dry matter (DM) content: by weighting, by drying at a temperature of 103 ± 2 °C (Venticell, f. BMT Medical Technology Ltd.),
- Crude protein (CP): Kjeldahl method (N x 6.25) (Kjeltec 8400, f. FOSS),
- Ether extract (EE): by extraction method according to Soxhlett-Henkel (SER 148, f. Velp Scientifica),
- Crude ash (CA): by weighting, after burning the sample at a temperature of 550 °C (muffle furnace P330, f. Nabertherm GmbH),
- Nitrogen free extract (NFE): by calculating NFE = DM – (CP + EE + CF + CA),
- Organic matter (OM): by calculating, organic matter = DM – CA,
- Crude fiber (CF): by gravimetrically after hydrolysis (FIBERTEC 8000, f. FOSS),
- Acid detergent fiber (ADF): by gravimetrically after hydrolysis in an acid detergent reagent (FIBERTEC 8000, f. FOSS),
- Neutral detergent fiber (NDF): by gravimetrically after hydrolysis in a neutral detergent reagent (FIBERTEC 8000, f. FOSS),
- Starch: polarimetrically after release and decomposition with dilute hydrochloric acid by hot (ADP 220, Bellingham + Stanley Ltd.).

The statistical evaluation of results was realized by Grofík and Fľak (1990) and IBM SPSS ver. 26.0. (IBM Corp. Released, 2019) The descriptive statistics of the nutritive value of maize silage by One-Way Anova were realized. For the signification of the statistically different results post-hoc Tukey test between the regions, counties and years was used. For the evaluation of the relationship between the nutrients and microclimatic conditions Pearson correlation test was performed. Also, the Pearson correlation test (r) for the relationship between the nutrients was calculated.

Table 1. The microclimatic conditions during the growing seasons (April-August) of maize in Slovakia

Year	Precipitation in mm			Temperature in °C		
	Mean ± SEM	Minimum	Maximum	Mean ± SEM	Minimum	Maximum
2011	77.74 ± 7.45	16.74	220.50	16.24 ± 0.56	7.93	21.37
2012	60.05 ± 6.48	7.46	148.11	16.95 ± 0.68	7.41	22.84
2013	61.66 ± 6.55	6.43	150.46	16.54 ± 0.67	7.42	22.81
2014	93.83 ± 6.51	23.53	191.33	15.85 ±0.59	8.03	22.14
2015	51.56 ± 4.77	10.57	133.02	16.86 ± 0.84	5.99	24.02
2016	79.77 ± 6.30	22.93	179.19	16.33 ± 0.64	7.60	22.05
2017	64.17 ± 4.63	21.70	137.28	16.64 ± 0.80	5.47	22.73
2018	63.29 ± 5.42	15.80	166.82	18.28 ± 0.50	11.40	23.27
2019	72.37 ± 6.27	15.39	147.85	16.94 ± 0.77	7.78	23.35
Total	69.38 ± 2.11	6.43	220.50	16.74 ± 0.23	5.47	24.02

Data are presented as mean value ± SEM (standard error of the mean)

Table 2. The microclimatic conditions during the growing seasons (April-August) of maize in regions of Slovakia

Region	Year	Precipitation in mm			Temperature in °C		
		Mean ± SEM	Minimum	Maximum	Mean ± SEM	Minimum	Maximum
R1	2011	68.74 ± 7.90	23.45	146.37	17.33 ± 0.69	11.94	21.37
	2012	48.02 ± 7.49	7.46	102.81	18.23 ± 0.92	10.60	22.84
	2013	51.57 ± 7.66	6.43	99.11	17.67 ± 0.92	10.65	22.81
	2014	76.32 ±6.58	23.53	123.87	17.02 ± 0.79	10.99	22.14
	2015	45.99 ± 5.78	14.24	94.41	18.23 ± 1.15	9.31	24.02
	2016	71.86 ± 8.40	22.93	149.90	17.47 ± 0.86	10.57	22.05
	2017	42.70 ± 3.87	21.70	84.90	18.11 ± 1.12	8.83	22.73
	2018	52.53 ± 5.76	15.80	98.24	19.68 ± 0.61	14.81	23.27
	2019	60.96 ± 9.35	15.39	147.85	18.18 ± 1.11	11.64	23.35
	Total	57.63 ± 2.48	6.43	149.90	17.99 ± 0.31	8.83	24.02
R2	2011	85.59 ± 16.62	17.56	172.61	14.97 ± 1.15	8.17	19.74
	2012	66.62 ± 15.00	11.80	148.11	15.51 ± 1.34	7.41	20.38
	2013	72.03 ± 15.95	21.54	149.51	15.20 ± 1.34	7.42	20.12
	2014	108.63 ± 12.55	52.88	166.46	14.45 ± 1.15	8.16	19.74
	2015	58.81 ± 10.21	19.02	114.41	15.40 ± 1.68	6.02	21.35
	2016	90.09 ± 13.03	41.29	176.57	14.98 ± 1.25	7.60	19.79
	2017	83.52 ± 7.39	57.66	137.28	15.03 ± 1.58	5.47	20.25
	2018	68.14 ± 9.84	22.13	116.77	16.84 ± 0.92	11.52	20.88
	2019	79.08 ± 12.59	34.40	145.95	15.92 ± 1.40	9.62	21.16
	Total	79.17 ± 4.36	11.80	176.57	15.37 ± 0.43	5.47	21.35
R3	2011	87.88 ± 19.68	16.74	220.50	15.32 ± 1.25	7.93	20.36
	2012	77.55 ± 13.96	18.54	139.92	15.84 ± 1.42	7.51	21.55
	2013	71.48 ± 14.05	26.85	150.46	15.61 ± 1.35	7.71	20.79
	2014	114.06 ± 15.98	46.47	191.33	14.92 ± 1.23	8.03	20.75
	2015	55.44 ± 11.61	10.57	133.02	15.58 ± 1.73	5.99	22.42
	2016	85.25 ± 13.88	25.81	179.19	15.40 ± 1.31	7.83	20.60
	2017	87.76 ± 6.88	48.90	115.35	15.32 ± 1.57	5.70	20.97
	2018	79.96 ± 14.58	25.51	166.82	16.94 ± 0.99	11.40	21.47
	2019	88.48 ± 9.55	56.58	144.91	15.49 ± 1.55	7.78	21.42
	Total	83.10 ± 4.66	10.57	220.50	15.60 ± 0.45	5.70	22.42

Data are presented as mean value ± SEM (standard error of the mean); R1 - Western Slovakia, R2 - Central Slovakia, R3 - Eastern Slovakia

RESULTS AND DISCUSSION

The impact of the region had a significant effect on DM, CP, CF, starch, and EE (*P* < 0.05) (Table 3). Likewise, Zhao et al. (2022) confirmed the effect of region on nutritive value. The DM contents in the maize silage from regions in Slovakia ranged from 34.16 to 36.71%, while the average value was 35.00%. Compared to the R3, significantly (*P* < 0.05) lower DM content was found by 5% in R1 and by 7% in R2. The value of 35% dry matter is consistent with the recommendation of Ferrareto et al. (2018) for maize silage from the point of view of optimizing the nutritional value and milk production of dairy cows. While the optimal range of dry matter content for maize silage is 30-35% (Khan et al., 2015). The crude protein content in maize silage is often low (Khan et al., 2015), and its content has little effect on the quality of silage (Zardin et al., 2017). The highest CP content was determined in silage R3, significantly higher vs. silage R1 (*P* < 0.05). The CF percentages in maize silages were very similar with a range of values 19.94-20.56% (R3-R1) with a total value of 20.34%. Crude fiber values were lower than the threshold value for maize silage (21%) according to Lád et al. (2003). The development of the kernels and the accumulation of starch in the kernels during the grain-filling stage are related to the increase in starch content (Khan et al., 2015). The primary source of energy in corn silage, starch, is recognized as a determining qualitative factor (Khan et al., 2015). Analyzed samples from all regions overall had higher average starch content than the reference value of 30% (de Oliveira et al., 2017). The highest starch content was found in silages with the highest dry matter content (R3), while differences were significant (*P* < 0.05) only between R1 and R3. Silages with the lowest DM content (R2, DM 34.16%) were characterized by significantly the highest EE content in comparison with other regions, which is consistent with the results of Khan et al. (2015), who reported increasing EE content up to DM content 35%. No effect of regions on CA, NFE, NDF, ADF, or OM content was observed in the present study (*P* > 0.05). The NDF content ranged from 41.96 to 42.75% (total 42.46%) and ADF from

Table 3. Nutrient content in maize silage in the years 2011-2019 overall and according to regions in Slovakia

Nutrients in % DM	Total	Regions			*P* - value
		R1	R2	R3	
	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM	
DM	35.00 ± 0.18	34.85^{a} ± 0.23	34.16^{a} ± 0.29	36.71^{b} ± 0.53	0.000
CP	7.93 ± 0.02	7.87^{a} ± 0.03	7.97^{ab} ± 0.04	8.07^{b} ± 0.05	0.004
CF	20.34 ± 0.10	20.56 ± 0.14	20.06 ± 0.18	19.94 ± 0.20	0.037
EE	2.82 ± 0.03	2.74^{a} ± 0.01	3.02^{b} ± 0.11	2.87^{a} ± 0.02	0,000
CA	4.08 ± 0.03	4.08 ± 0.03	4.03 ± 0.06	4.12 ± 0.12	0.220
NFE	64.82 ± 0.12	64.76 ± 0.15	64.81 ± 0.22	65.04 ± 0.27	0.896
OM	95.90 ± 0.12	95.92 ± 0.11	95.92 ± 0.13	95.76 ± 0.17	0.219
ADF	22.76 ± 0.11	22.98 ± 0.15	22.44 ± 0.20	22.38 ± 0.22	0.053
NDF	42.46 ± 0.20	42.75 ± 0.28	42.08 ± 0.37	41.96 ± 0.41	0.347
Starch	31.90 ± 0.22	30.77^{a} ± 0.30	33.06^{b} ± 0.34	34.38^{b} ± 0.45	0.000

R1 - Western Slovakia, R2 - Central Slovakia, R3 - Eastern Slovakia; DM - dry matter, CP - crude protein, CF - crude fiber, EE - ether extract, CA - crude ash, NFE - nitrogen-free extract, OM - organic matter, ADF - acid detergent fiber, NDF - neutral detergent fiber, data are presented as mean value ± SEM (standard error of the mean); ^{ab} - means within a row with different superscripts are significant at *P* < 0.05.

22.38 to 22.98% (total 22.76%). Maize silages from R3 with the highest DM content had the lowest values of NDF and ADF. The trend of NDF decrease with DM content increase is consistent with the results of Khan et al. (2015) and Lehtilä et al. (2023). Maize silage of the 1st quality class has an NDF less and equal to 38%, 2nd quality class >38 to ≤42%, and 3rd quality class >42 to ≤48% (Mitrík, 2021). According to the listed NDF criteria, only silage from R3 was of the 2nd and the others of the 3rd quality class. A previous study by Bernardi et al. (2019) reported an average ADF of 28.2% ± 0.32, which was a higher value compared to the detected values in regions and total. The OM values in silages were very similar (95.76 - 95.92%) with a total value of 95.90%.

In maize silages, the content of DM negatively correlated with the content of CA, CP, NDF, ADF, and CF (Table 4). The content of DM in maize silage samples moderately positively correlated to NFE content and starch content (r = 0.511; $P < 0.01$). Consistent with the results of Zhao et al. (2022) was EE content negatively correlated with CA, CF, NDF, ADF, and NFE contents.

The results confirmed the evident influence of counties on the content of DM, CP, CF, CA, NFE, starch, ADF, and EE in maize silage from Slovakia (Table 5).

Mitrík (2021) consider min. DM content of 30% to produce high-quality maize silage and according to Guyader et al. (2018) higher DM than 40% is too dry for the increased risk of the presence of oxygen due to the difficult compaction which negatively affects silage quality. Maize silage C8 had significantly the highest content of DM ($P < 0.05$), while in individual counties ranged from 33.43 to 38.76%. The highest CP content was found in county C7, and the differences compared to C2, C3, and C6 were significant ($P < 0.05$). In the presented study was noticed CP content was 7.83-8.19% according to counties, which was lower in comparison with the NRC (2001) value of 8.8±1.2% in normal silage (at a comparable DM 32-38%). The fiber and its fractions (NDF, ADF) significantly affect the digestibility of nutrients and dry matter intake of feed (Owens et al., 2010; Allen et al., 2019). The CF content was relatively balanced in all samples from individual counties (19.79-20.89%),

Table 4. Relationship between the nutrients in maize silages

Nutrients	DM	CP	CF	EE	CA	NFE	OM	ADF	NDF	Starch
DM	1	-0.210**	-0.385**	0.088**	-0.205**	0.407**	-0,011	-0.384**	-0.353**	0.511**
CP		1	0.096**	-0,011	0.075**	-0.301**	0,040	0.089**	0.083**	-0.229**
CF			1	-0.191**	0.318**	-0.919**	-0,021	0.975**	0.951**	-0.807**
EE				1	-0.090**	-0.035	0,022	-0.195**	-0.190**	0.223**
CA					1	-0.919**	-0.066*	0.321**	0.302**	-0.411**
NFE						1	0.021	-0.894**	-0.868**	0.797**
OM							1	-0.034	-0.042	0,032
ADF								1	0.966**	-0.806**
NDF									1	-0.778**
Starch										1

DM - dry matter, CP - crude protein, CF - crude fiber, EE - ether extract, CA - crude ash, NFE - nitrogen-free extract, OM - organic matter, ADF - acid detergent fiber, NDF - neutral detergent fiber; **Pearson Correlation is significant at the 0.01 level; *Pearson Correlation is significant at the 0.05 level.

which was consistent with the results of Mitrík (2021) (CF 17.00-23.00%). Content of NDF and AFD ranged from 41.61 to 43.65% and from 22.10 to 23.33% depending on individual counties. The values of NDF corresponded with the previous study by Khan et al. (2015) that noticed ranging from 37.7 to 54.5%, and Bernardi et al. (2019) reported an ADF scale of 13.70-44.80%, and Mitrík (2021) detected ADF range 21.00-35.00% in maize silage. The primary source of metabolizable energy in maize silage is starch, which has been regarded as the most significant aspect of maize silage. The main source of energy in maize silage is starch, which also supports microbial activity in the rumen (Khan et al., 2015). The silages of county C8 had significantly ($P < 0.05$) the highest starch content in comparison with silages from other counties (except for C6). The silages from all counties were characterized by a higher CA content than 4%, except for the counties C2 and C5. In silages of county C2 (with the second highest DM 35.64%) was the highest content of NFE and OM.

Table 5. Nutrient content in maize silage in the years 2011-2019 according to counties in Slovakia

Nutrients in % DM		Counties								*P* - value
		C1	C2	C3	C4	C5	C6	C7	C8	
DM	Mean	35.27^{a}	35.64^{a}	34.01^{a}	33.86^{a}	33.43^{a}	35.13^{a}	33.52^{a}	38.76^{b}	0.000
	SEM	0.49	0.42	0.33	0.76	0.38	0.45	0.61	0.72	
CP	Mean	7.93^{ab}	7.84^{a}	7.84^{a}	7.96^{ab}	8.07^{ab}	7.83^{a}	8.19^{b}	8.00^{ab}	0.002
	SEM	0.06	0.04	0.07	0.11	0.04	0.08	0.09	0.05	
CF	Mean	20.89	20.10	20.81	20.60	20.14	19.95	20.19	19.79	0.034
	SEM	0.32	0.24	0.23	0.39	0.25	0.25	0.33	0.25	
EE	Mean	2.82^{ab}	2.73^{ab}	2.66^{a}	2.80^{ab}	3.03^{c}	3.02^{bc}	2.95^{abc}	2.82^{ab}	0.000
	SEM	0.03	0.02	0.02	0.04	0.19	0.03	0.03	0.03	
CA	Mean	4.20^{ab}	3.91^{a}	4.17^{ab}	4.17^{ab}	3.95^{ab}	4.12^{ab}	4.08^{b}	4.15^{ab}	0.024
	SEM	0.06	0.06	0.06	0.08	0.10	0.05	0.29	0.05	
NFE	Mean	64.17	65.43	64.52	64.50	64.60	65.08	64.72	65.25	0.023
	SEM	0.34	0.27	0.26	0.46	0.32	0.28	0.51	0.29	
OM	Mean	95.80	96.13	95.83	95.77	95.97	95.87	95.67	95.81	0.228
	SEM	0.06	0.05	0.06	0.08	0.48	0.05	0.29	0.06	
ADF	Mean	23.17	22.46	23.33	23.28	22.62	22.21	22.82	22.10	0.017
	SEM	0.34	0.25	0.25	0.44	0.29	0.26	0.37	0.27	
NDF	Mean	43.65	41.91	43.13	42.54	42.44	41.61	42.34	41.71	0.198
	SEM	0.67	0.46	0.47	0.80	0.54	0.49	0.70	0.50	
Starch	Mean	30.86^{ab}	31.88^{abc}	29.53^{a}	30.57^{ab}	32.39^{bc}	33.94^{cd}	32.41^{abc}	35.64^{d}	0.000
	SEM	0.67	0.52	0.53	0.84	0.42	0.55	0.80	0.50	

C1-Bratislava, C2-Trnava, C3-Nitra, C4-Trenčín, C5-Žilina, C6-Banská Bystrica, C7-Prešov, C8-Košice; DM-dry matter, CP-crude protein, CF-crude fiber, EE-ether extract, CA-crude ash, NFE- nitrogen-free extract, OM-organic matter, ADF-acid detergent fiber, NDF-neutral detergent fiber, data are presented as mean value and SEM (standard error of the mean); $^{a-d}$ - means within a row with different superscripts are significant at $P < 0.05$.

Likewise, Khan et al. (2015) reported differences in OM depending on DM content. By the results of the effect of region on EE content, it was confirmed that the silages with the lowest dry matter content within the counties (C5) were characterized by the highest EE content, which is consistent with Ferrareto et al. (2018). The differences between EE content were significant ($P < 0.05$) compared to all counties except for C6 and C7. The results confirmed the variability of the chemical composition of maize silage depending on the county, following the findings from Zicarelli et al. (2023) which reported that important factors affecting silage quality include environmental conditions, sampled area, and maturity stage.

Changes in the nutrient content of maize silage are closely related to the nutritional composition of forage maize, which depends on many factors, among others on the ripening of the maize, but also on the climatic conditions (temperature, precipitation) during the growth (Quan et al., 2020). On the base of the three factorial analyses of covariance, results confirmed that the content of nutrients in maize silage is affected by year, region, and county but also between the counties within the years. The impact of the year had a significant effect ($P < 0.05$) on all determined parameters (DM, CP, CF, CA, NFE, starch, NDF, ADF, and EE) except for OM content (Table 6). Likewise, the significant impact of the year on the nutritive quality of maize (DM, CP, starch, NDF; $P < 0.001$) was confirmed by Lehtilä et al. (2023). By analyzing changes in nutrient content for individual years, the highest DM content (39.30%) was found in silage from 2018 and the second highest (36.71%) in silages from 2016, whilst the lowest DM content (31.60%) was in samples from 2013. The maize silages from 2018 had significantly ($P < 0.05$) the highest DM content in comparison with samples from other years. The difference between min. and max. the CP content was 0.85 absolute percentage points in individual years. The lowest CP content in maize silage was recorded in the years with the highest rainfall (the years 2011 and 2016). Reduced protein concentration and yield are caused by excessive rainfall during early vegetative growth, most likely as a result of nitrogen leaching or denitrification (Butts-Wilmsmeyer et al., 2019). The silages with the lowest dry matter content (31.60%, produced in 2013) characteristically had the highest CF, CA, NDF, and ADF content and simultaneously the lowest NFE, starch, EE, and OM contents. According to Ferraretto et al. (2018), the earlier harvest of maize (low DM content) is associated with lower starch concentration, and a high increase in the concentration of NDF, CP, EE, and CA, which is largely consistent with the results of this study. Average year's precipitation lower than 62.00 mm (in 2012, 2013, 2015) was in relationship with lower starch content in maize silage because of reduced photosynthesis as a result of drought and heat stress leading to less grain starch deposition (Butts-Wilmsmeyer et al., 2019). The opposite trend of changes in nutrient content was recorded in silages with the second-highest dry matter content (36.71%, produced in 2016). The highest NFE, starch, EE, and OM contents, and the lowest CF, CA, NDF, and ADF contents were found in the silage samples from 2016. These results confirm the previous findings of Loučka et al. (2013), that an increase in DM of maize silage significantly increases starch content while decreasing NDF, and ADF content. The development of the kernels and the accumulation of starch in the kernels during the grain-filling stage are related to the increase in starch content (Khan et al., 2015).

The effect of rainfall and temperatures on the nutritive value of maize silage is shown in Table 7. Temperature, precipitation, and sunshine hours are climatic factors that have a considerable impact on the growth and development of silage maize (Liu et al., 2013; Maitah et al., 2021). Earlier studies found that irrigation has a higher effect on maize yield than seasonal temperature fluctuations (Carter et al, 2016; Butts-Wilmsmeyer et al., 2019). Increasing irrigation water (0–480 mm) increased dry matter yield in maize silage but negatively affected its nutritive value by increasing NDF and decreasing CP and WSC (Islam et al., 2012). Precipitation variability impacts maize silage production by affecting yield, crude protein content, and soil water content, with no-tillage and cover crop mulching helping mitigate these risks (Niu et al., 2023).

Table 6. Annual differences in nutrient content of maize silage from Slovakia

Nutrients in % DM		2011	2012	2013	2014	2015	2016	2017	2018	2019	*P* - value
DM	Mean	35.00^{ade}	32.48^{bc}	31.60^{b}	32.63^{abc}	35.75^{de}	36.71^{e}	34.41^{acde}	39.30^{f}	34.15^{acd}	0.000
	SEM	0.56	0.61	0.46	0.35	0.39	0.61	0.42	0.50	0.36	
CP	Mean	7.47^{a}	8.10^{bc}	8.10^{bc}	8.00^{bc}	7.85^{bd}	7.59^{ad}	7.77^{abd}	7.85^{bd}	8.32^{c}	0.000
	SEM	0.12	0.14	0.07	0.06	0.07	0.08	0.07	0.03	0.04	
CF	Mean	20.38^{a}	22.39^{b}	24.17^{c}	19.71^{ad}	19.99^{ad}	18.22^{e}	19.34^{ade}	20.25^{a}	18.84^{de}	0.000
	SEM	0.33	0.39	0.29	0.21	0.22	0.25	0.26	0.21	0.22	
EE	Mean	2.81^{ab}	2.48^{bc}	2.40^{c}	3.00^{ad}	2.75^{abc}	3.19^{d}	2.89^{ad}	3.02^{ad}	2.80^{ad}	0.000
	SEM	0.04	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.20	
CA	Mean	4.27^{ac}	4.19^{ab}	4.46^{c}	4.21^{a}	3.97^{ab}	3.75^{b}	3.95^{ab}	4.04^{ab}	3.91^{ab}	0.000
	SEM	0.19	0.08	0.17	0.05	0.05	0.05	0.05	0.06	0.05	
NFE	Mean	65.08^{a}	62.88^{b}	60.91^{c}	65.14^{a}	65.47^{a}	67.25^{d}	66.06^{ad}	64.76^{a}	66.08^{ad}	0.000
	SEM	0.45	0.44	0.35	0.26	0.25	0.31	0.31	0.24	0.30	
OM	Mean	95.73	95.84	95.34	95.80	95.96	96.25	96.05	95.97	96.10	0.451
	SEM	0.19	0.08	0.17	0.05	0.05	0.05	0.05	0.06	0.05	
ADF	Mean	23.06^{a}	24.86^{b}	27.01^{c}	22.07^{ad}	22.36^{a}	20.45^{e}	21.69^{ade}	22.70^{a}	20.95^{de}	0.000
	SEM	0.35	0.42	0.33	0.23	0.27	0.26	0.27	0.22	0.22	
NDF	Mean	41.57^{ae}	45.98^{b}	50.22^{c}	40.25^{ad}	41.65^{ae}	38.37^{d}	40.84^{ae}	42.81^{e}	39.71^{ad}	0.000
	SEM	0.67	0.83	0.59	0.47	0.50	0.53	0.50	0.41	0.42	
Starch	Mean	31.95^{ac}	26.20^{b}	23.78^{b}	33.29^{ac}	30.55^{a}	36.46^{d}	34.34^{cd}	34.16^{cd}	34.31^{cd}	0.000
	SEM	0.78	0.99	0.69	0.44	0.50	0.56	0.57	0.39	0.47	

C1-Bratislava, C2-Trnava, C3-Nitra, C4-Trenčín, C5-Žilina, C6-Banská Bystrica, C7-Prešov, C8-Košice; DM-dry matter, CP-crude protein, CF-crude fiber, EE-ether extract, CA-crude ash, NFE- nitrogen-free extract, OM-organic matter, ADF-acid detergent fiber, NDF-neutral detergent fiber, data are presented as mean value and SEM (standard error of the mean); $^{a-d}$ - means within a row with different superscripts are significant at $P < 0.05$.

The results of this study corroborated the same impact on the nutrient content of maize silage. In general, the strongest effect of precipitation on the nutritive value of silage during April and July was found. The effect of precipitation on DM content was weak but significantly negative in April, May, and August. Similarly, a weak effect of rainfall on the CP content was found, but statistically non-significant. A mostly negative effect on the CF was observed with statistically significant correlations in April, June, and July in the present study. The effect of rainfall on CA during the growing season was variable. Similarly, a variable effect on the NFE content was observed. On the contrary, a statistically significant effect on the starch content was determined in April and July. The same pattern in the ADF and NDF concentrations affected by precipitation in April, June and July was found. Water-stressed plants store more energy in the form of fiber fractions (Islam and Obour, 2014). It is confirmed by results in all months except June. Otherwise, Nilahyane et al. (2020) detected no effect of irrigation on the nutritive value of maize, NDF and ADF content d only tended to increase with water stress. The mostly positive significant relationship between the rainfall and EE concentrations was observed. On the other side, the effect on OM during the growing season was variable.

Table 7. Correlations relationship between the microclimatic conditions during the growing season of maize on the nutritive value of the silage in Slovakia

	Precipitation					Temperature				
	April	May	June	July	August	April	May	June	July	August
DM	-0.212*	-0.293**	0.084	-0.104	-0.235*	0.375**	0.329**	0.254**	0.172	0.356**
CP	0.073	0.194	0.089	-0.029	0.039	-0.138	-0.198*	-0.128	-0.153	-0.188
CF	-0.284**	-0.026	0.272*	-0.306**	-0.153	0.016	0.025	-0.244*	0.066	0.109
EE	0.303**	0.136	-0.063	0.454**	0.413**	-0.099	-0.067	-0.216*	-0.372**	-0.496**
CA	-0.212*	0.151	0.306**	-0.192	0.060	-0.042	-0.115	-0.289**	-0.173	-0.133
NFE	0.234*	-0.063	-0.315**	0.253*	0.057	0.030	0.046	0.326**	0.056	0.035
OM	0.234*	-0.057	-0.055	0.041	0.028	-0.107	0.040	0.075	-0.057	0.018
ADF	-0.278**	-0.038	0.297**	-0.297**	-0.174	-0.012	0.013	-0.284**	0.048	0.092
NDF	-0.303**	-0.011	0.273*	-0.364**	-0.198	-0.016	0.020	-0.221*	0.044	0.145
Starch	0.315**	0.045	-0.073	0.290**	0.173	0.050	0.015	0.180	-0.140	-0.115

DM - dry matter, CP - crude protein, CF - crude fiber, EE - ether extract, CA - crude ash, NFE - nitrogen-free extract, OM - organic matter; ADF - acid detergent fiber, NDF - neutral detergent fiber; **Pearson Correlation is significant at the 0.01 level; *Pearson Correlation is significant at the 0.05 level.

In general, the strongest effect of temperature on the nutritive value of silage during June was observed. The most positively affected nutrient in maize silage by temperature was DM (significant effect in April, May, June, and August). On the other side, the effect of temperature on the starch and OM content was non-significant and very weak. However, a negative significant effect on the CF and fiber fractions (ADF, NDF) in June was observed. The trend of decreasing CF content with increasing mean annual temperature is consistent with the results of Zhao et al. (2022), and differently, CA, NDF, and ADF contents were not significantly affected by climatic conditions. Then, the effect of temperature on the CP was weakly negative and significant only in May. Also, the content of CA was affected by temperature weakly, but only in June was significant. On the contrary, the effect of temperature on NFE content was positive and statistically significant in June. The trend of increasing NFE content with increasing mean annual temperature is in accordance with the results of Zhao et al. (2022). The study by Gąsiorowska et al. (2019) confirmed a significant effect of weather conditions on the sugar content in maize. Finally, the negative weak to moderate relationship between the EE and temperature in June, July and August was found.

CONCLUSIONS

The nutritional value of maize silage from Slovakia in monitored years 2011-2019 was influenced by the year, county, and region. Overall, on average, maize silage had a target dry matter content (35.00%) with an NDF content of 42.46%, and a high starch content (31.90%), which is one of the important factors affecting the energy value of silages. The dry matter content significantly affects the nutritional value of maize silages, while as the dry matter increases, the NFE, EE, starch content increases, and CA, CP, fiber, and its fractions content decreases. In individual years, dry matter ranged from 31.60% (2013) to 39.30% (2018), with higher starch by 30.4% and lower NDF content by 14.8% in favor of silages with a higher dry matter content. Whereas silages from 2016 (DM 36.71%) had the highest nutritional value regarding the starch and NDF content (with values 36.46% and 38.37% respectively), in the year with the second highest average precipitation (79.77 mm) and the third lowest average temperature (16.33 °C) during the growing season. The results confirmed a greater influence of precipitation on the nutritional value of maize silage compared to temperature. The precipitation in April and July had the greatest influence on the nutritional value of silage. By increasing the rainfall, starch content increased, and neutral detergent fiber content decreased. In June, there was the greatest temperature impact on the nutritional value of silage. Increasing the June temperature caused a significant increase in dry matter, and NFE content and a significant decrease in crude fiber and fiber fractions, crude ash, and ether extract content.

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