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Differences between chemical analysis and portable near-infrared reflectance spectrometry in maize hybrids

Radko Loučka[1], *Václav Jambor*[2], *Jan Nedělník*[3], *Jaroslav Lang*[3], *Petr Homolka*[1,4], *Filip Jančík*[1]*, *Veronika Koukolová*[1], *Petra Kubelková*[1], *Yvona Tyrolová*[1], *Alena Výborná*[1]

[1]*Institute of Animal Science, Prague-Uhříněves, Czech Republic*
[2]*NutriVet, Ltd, Pohořelice, Czech Republic*
[3]*Agricultural Research, Ltd Troubsko, Czech Republic*
[4]*Deparment of Microbiology, Nutrition and Dietetics; Faculty of Agrobiology, Food and Natural Resources; Czech University of Life Sciences, Prague, Czech Republic*

**Corresponding author: jancik.filip@vuzv.cz*

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Abstract: The aim of this study is to compare the differences between four maize hybrids in terms of nutrient determination by portable near-infrared reflectance spectrometer (pNIRS) and chemical analysis; each of the hybrids was grown in the same locality from 2018 to 2020. The topic relates to the variability of the feed value of maize being an important feedstuff in livestock nutrition. The nutritional values determined by pNIRS in comparison with the chemical analysis were higher ($P < 0.001$) in starch and ash content but lower in dry matter, neutral detergent fibre and crude protein (CP) content. The digestibility levels of neutral detergent fibre and the net energy of lactation as well as the potential milk production per hectare in relation to each tonne of dry matter were also lower. According to this result, it would be necessary to calibrate all tested indicators for a given spectrometer. However, the pNIRS results are useful for evaluating nutrient variability; the standard deviation of the values found in pNIRS was mostly lower than that determined chemically. The pNIRS results are also useful for making practical adjustments to the total mixed rations when calculated from actual chemical analysis if the correlation between the two methods is used; the correlation between the pNIRS and chemical results was found to be significant ($P < 0.05$) in terms of all the indicators.

Keywords: forage species; product quality; ruminant nutrition; digestibility; potential milk production

Recently, spectroscopies have been completed increasingly more often on farms by utilising a portable near-infrared reflectance spectrometer (pNIRS) that measures the values of fresh plants (in the original matter). The results of research relating to this area were presented by Evangelista et al. (2021), who emphasised the benefits of using a pNIRS to evaluate the physicochemical composition of total mixed rations (TMR) on dairy farms. According to the authors, the use of a pNIRS with

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suitable calibrations in stables is a fast and accurate analytical technique that is potentially very beneficial. This was also confirmed in a study by Monteiro et al. (2021), which offered an overview of the use of precision livestock farming methods as part of precision agriculture (PA). Pierce and Nowak (1999) defined PA as 'a system that provides the tools to do the right thing, in the right place, at the right time'.

Maize (*Zea mays* L.) is the most important annual crop in the Czech Republic. Moreover, maize silage is an important part of TMR for cattle, and its consumption by biogas plants for biogas production has been growing rapidly in recent times. Therefore, there is an increasing need for higher production rates and for the maize to have a greater nutritional value, forcing farmers to grow, harvest, preserve and store an appropriate amount of maize every year; however, much depends on what hybrid is used. Many scientists, such as Barriere et al. (2003) and Gruber et al. (2018), have emphasised the importance of hybrid breeding strategies, especially for neutral detergent fibre digestibility (NDFD). For silage hybrids, it is important to know not only their nutrient and silage composition, but also their digestibility and performance levels.

However, conclusions can only be drawn after several years of growing hybrids because the above indicators are significantly affected by weather patterns during the growing season. Indeed, the substantial effect that the weather has had in some years on maize yield and nutritional value has been reported in many studies (Taube et al. 2020).

Models are used to estimate potential milk production (Oba and Allen 1999; Khan et al. 2007; Schonleben et al. 2020) because feeding tests to evaluate differences in animal performance are demanding and expensive (Bal et al. 2000). The most widely used program in the world today is Milk 2006 (Shaver 2006), which estimates milk production per hectare and per tonne of DM.

The aim of this study was to compare the differences between the four maize hybrids in terms of nutrient determination by pNIRS and chemical analysis; each of the crops was grown in the same locality from 2018 to 2020.

MATERIAL AND METHODS

Experimental material

Four hybrids (Table 1) were graded according to their Food and Agriculture Organization (FAO) numbers (the FAO number indicates earliness), which were between FAO 240 and FAO 270, and they were then tested. All four of the tested hybrids belong to the early hybrid group (two can also be categorised as early-medium). Moreover, each of them has a semi-flint grain type (two of them lean more towards the flint type). According to variations in the vitreous and floury portion of the maize kernel, hybrids are classified into flint maize, semi-flint maize and dent maize (Zhang and Xu 2019). The vitreous, hard (glassy) type of endosperm flint needs a longer time to soften (swell); thus, it has a lower degradability of starch in the rumen and the remaining starch is digested in the intestine. The secondary criteria were the properties and assumptions declared by the hybrid producer.

Agrotechnics of tested maize hybrids

The experiment took place on a farm in the central area of the Czech Republic (50°02'24.5''N 14°36'50.0''E) (280 m above sea level) and lasted three years (2018 to 2020). For the purpose of this study,

Table 1. Basic characteristics of tested hybrids

Items	Hybrid			
	DKC3872	DKC3450	DKC3568	DKC3575
FAO number	240	250	260	270
Maturity group	early	early	early-medium	early-medium
Endosperm	turn to flint	semi-flint	semi-flint	turn to flint
Properties	quality	performance	resistance	starch
Assumptions	higher in starch	better NDFD	better NDFD	higher in starch

FAO = Food and Agriculture Organization – indicates earliness; NDFD = neutral detergent fibre digestibility

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these years were appropriate because in the growing season 2018 there was little precipitation and the highest temperature, 2019 had an average rainfall and temperature, and 2020 had the highest rain amount and lower temperature in ten years (Table 2).

The experimental plots were organised in four replicates. Individual plots were 4.5 m wide and 50 m long. Four silage maize hybrids were seeded on 19th April 2018, 15th April 2019, 17th April 2020, using a Monosem sowing machine (Ribouleau Monosem, Largeasse, France). Conventional 75 cm wide and plant densities of 90 000 plants/ha were used. The preceding crop grown on the experimental plots was winter wheat (*Triticum aestivum*). The plots were ploughed in autumn (and the soil was prepared with a seedbed cultivator before sowing.

Additionally, the agrotechnics were almost the same for all three years. In autumn, the experimental plot (winter wheat crop) was fertilised with manure (40 t/ha) and ploughing was carried out. In spring, there was a seedbed preparation (compactor), and a urea fertilizer (AB Achema, Jonava, Lithuania) containing 46% of nitrogen was incorporated into the soil (200 kg/ha) before sowing. Weeds were removed by the pre-emergence application of the selective herbicide "Balaton" (Cheminova A/S, Lemwig, Denmark) (3 l/ha), which contains the active ingredients pethoxamid and terbuthylazine, the day after sowing. Pre-emergence treatment was with herbicides (Adengo 0.44 l/ha; Bayer AG, Leverkusen, Germany), post-emergence treatment with herbicides (MaisTer power 1.0 l/ha; Bayer AG, Leverkusen, Germany) and treatment with insecticide against corn borer (Coragen 20 SC 0.1 l/ha; Bayer AG, Leverkusen, Germany). Maize plants were manually collected on the 8th August 2018, 27th August 2019 and 3rd September 2020 (depending on the appropriate stage of ripeness for the harvest), at the beginning of the pasty stage of grains. All four hybrids were harvested on the same day. The central row (3rd) of each experimental plot was used as the evaluation of the yield of the area. Ten consecutive plants (located 10 m from the edge of the row) were cut about 10 cm from the ground level. The weights of the whole plants and their ears were recorded. Fresh representative samples of the whole plants, ears, and kernels from each plot were dried in a laboratory (Institute of Animal Science) at 55 °C to a constant weight, to determine their DM percentages. Whole plant and ear DM percentages were then used to calculate DM yield per ha. DM yield was not significant ($P < 0.05$) between the hybrids (22.5 t DM/ha for DKC3450; 21.7 t DM/ha for DKC3568; 22.7 t DM/ha for DKC3575; 24.1 t DM/ha for DKC3872). Chemical and pNIRS analyses were performed on identical samples obtained by sequentially harvesting each field with a Claas Jaguar 850 cutter (Claas Saulgau GmbH, Harsewinkel, Germany). So, samples from 3 × 10 plants were used only to determine DM yield.

Chemical, near-infrared spectroscopy and *in sacco* analyses

The samples (four from each hybrid) harvested by the cutter were then immediately transported to the laboratory (NutriVet, Ltd, Pohořelice, Czech Republic) and processed immediately. First, the laboratory measured (three times for each hybrid) baseline nutrient contents [DM, starch, neutral detergent fibre (NDF), crude protein (CP), ash] and NDFD (24 h) using pNIRS. The manufacturer of the Portable AgriNIR was Dinamica Generale

Table 2. Average temperatures (°C) and precipitation (mm) in the growing season in Prague (source: CHMI 2021)

Items	Year	Month					Average
		V.	VI.	VII.	VIII.	IX.	
Temperature	2018	16.9	18.2	20.8	21.5	15.3	18.5
	2019	11.4	21.5	19.8	19.5	14.1	17.3
	2020	11.7	17.0	18.7	19.6	14.8	16.4
	1981–2010	13.7	16.5	18.5	18.0	13.5	16.0
Precipitation	2018	54	69	27	33	49	46.4
	2019	72	47	52	72	46	57.8
	2020	64	120	40	99	64	77.4
	1981–2010	63	70	82	75	47	67.4

(www.dinamicagenerale.com); the supplier was AgriTechnika, s.r.o. (Veľký Meder, Slovakia).

Individual fresh cut samples were placed fresh in the pNIRS sample carrier and immediately measured. Measurements with the AgriNIR portable instrument were done in laboratory conditions, which can be considered stable. The device can supply 220 V and 12 V. The manufacturer declares the accuracy of individual calibration curves in the range of 2% to 3%.

For chemical analysis, the samples were dried at 60 °C and then ground on a 1 mm sieve in a laboratory grinder. Subsequently, according to the methods specified by the Association of Official Analytical Chemists (AOAC 2005), the following details were determined (three times for each hybrid): the DM (#934.01), starch (#920.40), NDF (#2002.04), CP (#976.05) and ash (#942.05) contents.

The digestibility of nutrients was determined by the *in sacco* method in the rumen of Holstein cows with cannula according to Orskov and McDonald (1979), expressed as a percentage of the nutrient ingested: 100 × (weight – residue)/weight. Cows (dry cows) were fed meadow hay (*ad libitum*) with 2 kg of supplemental mix. Samples were incubated for 24 h using nylon bags with external size 10 × 20 cm and mesh size 51 μm. The experimental protocol was approved by the institutional Animal Care and Use Committee (Institute of Animal Science, Prague, Czech Republic, Act No. 359/2012 Coll.). The NEL was calculated according to the Van Es (1978) method, adapted by Vencl et al. (1991), when this equation was used:

$$\mathrm{NEL} = [0.463 + \{0.24 \times (\mathrm{ME}/\mathrm{GE})\}] \times \mathrm{ME} \qquad (1)$$

where:

ME – [0.015 49 × (OMD × 10)];

GE – (0.005 88 × CP + 0.019 18 × OM).

The potential for milk production (t/ha and kg/t DM) was calculated using the Milk 2006 software (Shaver 2006). For calculation, NDFD was added to the software after incubation for 24 hours. Truly digested starch (IS-IV) was used.

Statistical analysis

Analysis of variance (ANOVA) with multivariate design was used (STATISTICA v10; StatSoft, Inc., Tulsa, OK, USA). The statistical model for the results was:

$$Y_{ijkl} = \mu + H_i + Y_j + M_k + HY_{ij} + HM_{ik} + YM_{jk} + HYM_{ijk} + e_{ijkl} \qquad (2)$$

where:

Y_{ijkl} – dependent variable;

μ – overall mean;

H_i – effect of hybrid (i = 1 to 4);

Y_j – effect of year (j = 1 to 4);

M_k – effect of method (k = 1 to 2);

HY_{ij} – interaction of hybrid with year;

HM_{ik} – interaction of hybrid with method;

YM_{jk} – interaction of year with method;

HYM_{ijk} – interaction of hybrid with year with method;

e_{ijkl} – error term.

Tukey HSD (honestly significant difference) test at a significance level of $P < 0.05$ was used to evaluate the results.

The associations for every item (DM, starch, NDF, CP, ash, NDFD, NEL, milk t/ha, milk kg/t DM) among factors (methods, years and hybrids) were evaluated using a bivariate correlation analysis (STATISTICA v10; StatSoft, Inc., Tulsa, OK, USA). The probability of correlation (P-value) was calculated and Pearson bivariate correlations (Puth et al. 2014) were considered significant at $P < 0.001$ and $P < 0.01$. The r coefficient values for correlation were interpreted according to Prion and Haerling (2014): very strong correlation (± 0.91 to ± 1.00); strong correlation (± 0.68 to ± 0.90); moderate correlation (± 0.36 to ± 0.67); weak correlation (± 0.21 to ± 0.35); and negligible correlation (0 to ± 0.20).

RESULTS AND DISCUSSION

General differences between pNIRS and chemical analysis

The first aim of this study was to compare the differences between pNIRS and chemical analysis. The results of testing maize hybrids according to both methods, pNIRS versus chemical, regardless of the year and of the hybrid of determination, are shown in Table 3. Statistical significance ($P < 0.001$) was found for all monitored indicators. According to this result, it would be necessary to calibrate all tested indicators for a given spectrometer.

Table 3. Results of testing maize hybrids (± standard deviation) according to methods (pNIRS versus chemical analysis) regardless of the year of determination

Items	Methods		SEM
	pNIRS (n = 48)	chemical (n = 48)	
DM (g/kg)	349 ± 19.8^{a}	364 ± 25.4^{b}	3.3
Starch (g/kg DM)	356 ± 18.4^{b}	291 ± 38.2^{a}	4.4
NDF (g/kg DM)	390 ± 26.0^{a}	457 ± 31.0^{b}	4.2
CP (g/kg DM)	67.0 ± 5.5^{a}	83.6 ± 8.9^{b}	1.1
Ash (g/kg DM)	39.0 ± 3.5^{b}	345 ± 2.9^{a}	0.5
NDFD (%)	45.2 ± 2.58^{a}	55.4 ± 4.47^{b}	0.54
NEL (MJ/kg DM)	6.30 ± 0.08^{a}	6.40 ± 0.13^{b}	0.02
Milk (t/ha)	29.1 ± 6.7^{a}	39.4 ± 7.5^{b}	1.35
Milk (kg/t DM)	1 987 ± 25.2^{a}	2 019 ± 40.4^{b}	4.91

CP = crude protein; DM = dry matter; NDF = neutral detergent fibre; NDFD = NDF digestibility; NEL = net energy of lactation; pNIRS = portable near-infrared reflectance spectrometer

^{a,b}Means with different superscripts differ significantly

In the case of DM, NDF, CP, NDFD, NEL and milk (both in kg/ha and in kg/t DM), the values determined by pNIRS were lower than those found by chemical analysis; in the case of starch and ash, the values determined by pNIRS were higher than those provided by chemical analysis. An important finding is that the standard deviations of pNIRS were generally lower than those determined chemically.

As the results of both pNIRS and chemical analysis can be affected (be in interaction) by several factors, the hybrid factor (Table 4) and the growing year factor (Table 5) were considered.

The second aim of this study was the influence of the climatic conditions (temperature and precipitation) of the year of planting hybrids and to compare the differences between hybrids (see other chapters).

According to the chemical composition, selected indicators of nutritional value and the potential amount of milk production, there were no statistically significant differences between the selected hybrids. However, noteworthy differences were

Table 4. Comparison of pNIRS (pN) and chemical analysis (Ch) of hybrids in individual years (interaction of methods and years)

Items	2018 (n = 32)		2019 (n = 32)		2020 (n = 32)		SEM
	pN	Ch	pN	Ch	pN	Ch	
DM (g/kg)	357^{ab}	385^{c}	338^{a}	364^{b}	354^{ab}	344^{a}	4.7
SD	16.9	22.7	12.3	20.0	23.8	12.8	
Starch (g/kg DM)	354^{cd}	253^{a}	339^{bc}	318^{ab}	374^{d}	301^{b}	5.1
SD	9.3	11.9	12.6	12.1	11.5	15.1	
NDF (g/kg DM)	405^{b}	481^{d}	413^{b}	449^{c}	352^{a}	440^{c}	4.4
SD	15.0	22.0	16.6	11.2	14.8	22.4	
CP (g/kg DM)	60.7^{a}	92.5^{d}	70.1^{b}	84.7^{c}	70.2^{b}	73.6^{b}	1.0
SD	3.74	6.15	2.98	2.96	2.85	3.47	
Ash (g/kg DM)	35.3^{bc}	36.9^{c}	39.1^{d}	34.5^{b}	42.6^{e}	32.2^{a}	0.5
SD	2.23	2.44	3.42	2.66	1.84	1.37	
NDFD (%)	43.6^{a}	43.7^{a}	48.3^{b}	56.5^{c}	56.3^{c}	53.2^{c}	0.79
SD	1.44	4.03	0.92	3.14	1.46	4.48	
NEL (MJ/kg DM)	6.26^{a}	6.36^{b}	6.24^{a}	6.47^{c}	6.40^{bc}	6.37^{b}	0.02
SD	0.05	0.16	0.03	0.07	0.03	0.12	
Milk (t/ha)	32.3^{b}	32.1^{b}	38.9^{c}	41.3^{cd}	16.2^{a}	45.0^{d}	1.23
SD	3.92	3.36	6.83	7.09	1.93	4.35	
Milk (kg/t DM)	1 974^{a}	2 007^{b}	1 968^{a}	2 040^{c}	2 018^{bc}	2 010^{b}	7.10
SD	16.7	20.0	8.7	22.8	8.6	17.3	

CP = crude protein; DM = dry matter; NDF = neutral detergent fibre; NDFD = NDF digestibility; NEL = net energy of lactation; pNIRS = portable near-infrared reflectance spectrometer; SD = standard deviation

$^{a–d}$Means with different superscripts differ significantly

Table 5. Comparison of pNIRS (pN) and chemical analysis (Ch) of DKC hybrids over an average of three years (interaction of methods and hybrids) (for each hybrid $n = 24$)

Items	DKC3872		DKC3450		DKC3568		DKC3575		SEM
	pN	Ch	pN	Ch	pN	Ch	pN	Ch	
DM (g/kg)	358^{ab}	360^{ab}	343^{a}	362^{ab}	344^{ab}	364^{ab}	352^{ab}	372^{b}	6.6
SD	23.8	28.1	18.8	25.2	13.4	25.6	20.3	23.9	
Starch (g/kg DM)	360^{b}	292^{a}	353^{b}	284^{a}	351^{b}	283^{a}	359^{b}	304^{a}	8.7
SD	18.0	19.9	21.9	25.3	15.5	23.7	18.0	24.7	
NDF (g/kg DM)	382^{a}	458^{b}	394^{a}	466^{b}	395^{a}	456^{b}	389^{a}	446^{b}	8.3
SD	26.8	16.2	35.5	29.5	26.4	33.0	36.4	21.3	
CP (g/kg DM)	66.7^{a}	82.6^{b}	69.0^{a}	83.9^{b}	65.8^{a}	84.0^{b}	66.4^{a}	84.0^{b}	2.2
SD	5.93	7.38	5.09	7.66	5.02	7.27	6.06	8.69	
Ash (g/kg DM)	38.5^{bc}	35.9^{abc}	39.6^{c}	32.7^{a}	39.6^{c}	35.4^{ab}	38.3^{bc}	34.1^{a}	0.9
SD	4.32	2.28	3.49	2.35	3.38	2.21	2.87	3.74	
NDFD (%)	44.3^{a}	55.5^{b}	45.6^{a}	55.5^{b}	45.2^{a}	54.6^{b}	45.6^{a}	55.8^{b}	1.08
SD	2.78	5.06	2.85	3.83	2.76	4.58	1.92	4.81	
NEL (MJ/kg DM)	6.30^{ab}	6.41^{ab}	6.28^{a}	6.41^{ab}	6.28^{a}	6.35^{ab}	6.32^{ab}	6.43^{b}	0.03
SD	0.08	0.09	0.09	0.14	0.07	0.17	0.09	0.09	
Milk (t/ha)	32.1^{abc}	41.7^{c}	28.4^{ab}	38.9^{abc}	27.6^{a}	37.3^{abc}	28.5^{ab}	39.9^{bc}	2.71
SD	9.87	9.31	6.72	6.51	5.25	5.87	8.44	8.04	
Milk (kg/t DM)	$1\,988^{ab}$	$2\,023^{ab}$	$1\,983^{a}$	$2\,023^{ab}$	$1\,983^{a}$	$2\,004^{ab}$	$1\,993^{ab}$	$2\,028^{b}$	9.83
SD	24.2	29.5	23.8	24.6	22.9	23.8	27.6	29.5	

CP = crude protein; DM = dry matter; NDF = neutral detergent fibre; NDFD = NDF digestibility; NEL = net energy of lactation; pNIRS = portable near-infrared reflectance spectrometer; SD = standard deviation

$^{a–c}$Means with different superscripts differ significantly

found both between the methods of determination (pNIRS versus chemical analysis) and between the individual years of hybrid cultivation. In line with the above findings, especially with regard to the results of pNIRS and chemical analysis, it follows that the pNIRS must be calibrated as soon as possible, so that the values measured by it approach the values that were uncovered during chemical analysis in the laboratory. Until the pNIRS results can be reconciled with the findings from the chemical examinations, it is not recommended for use when calculating the nutritional value for compound feeding purposes (TMR) or to estimate the milk production per hectare or tonne of DM based on the values obtained with pNIRS. However, the pNIRS results are useful for evaluating nutrient variability; the standard deviation of the values found in pNIRS was mostly lower than the variability determined chemically. The pNIRS results are also useful for making practical adjustments to the TMR when calculated from the actual chemical analysis if the correlation between the two methods is used; the correlation between the pNIRS and chemical results was found to be significant ($P < 0.05$) in terms of all the indicators, especially for starch, CP, NDF and NDFD.

The analysis of the maize plant immediately after harvesting is essential in order to check the composition and maturity of the plant to optimise the silage quality. For the past few years, examinations of fodder, including maize silage, were performed routinely by laboratories with pNIRS; this is a predictive technique based on the relationship between the absorbance/reflectance properties of a sample and its organic nutrient content. With regard to maize, Marchesini et al. (2018) used two versions of a pNIRS and a laboratory-based instrument, Foss NIRSystems 5000, for comparison with the chemical analysis approach. They concluded that, considering the great diversity between the instruments and the strong inhomogeneity of the sliced maize plant, the calibration transmission obtained was considered satisfactory for most parameters, with the exception of starch and total sugars. This is in line with our results: the nutritional values determined by pNIRS were also higher when starch content measurements were performed (sugars present in maize were not determined in our study).

Errors in the results, both in the chemical analysis and in the measurement using pNIRS, can be caused by the ratio of grain to plant residue in the sample. The difference is mainly in the starch content in the dry matter. Therefore, some authors recommend processing the grain part and the rest part of the plant separately from the whole plant (Barriere et al. 2004; Zhang and Xu 2019). The result would then be calculated by the weighted average of the two different samples. In our experiments, we did not use this method to evaluate two different samples. From the results shown in Tables 3–6, it can be seen that the starch content in DM was significantly higher in pNIRS than in the chemical analysis, while the result from the chemical analysis is more in line with reality.

Influence of the year of planting hybrids

Table 4 shows a comparison of pNIRS and chemical analysis interacting for each of the years 2018, 2019 and 2020. A significant difference can be seen between the determinations in relation to both approaches. Nevertheless, exceptions were found in 2018 for ash, NDFD and milk yield potential per ha, where the disparities were not significant; this was also the case in 2019 (in DM, NDF, CP, ash, NEL and milk yield potential in tonnes per ha) and in 2020 (in DM, CP, NDFD and milk yield potential in kg per tonne DM). According to the Czech Hydrometeorological Institute (CHMI 2021), in 2018 there was little precipitation in the growing season, 2019 had an average amount and 2020 had the highest amount in ten years (Table 2). During the growing seasons 2018 and 2019, it rained less than the average amount between 1981 and 2010. In contrast, except in July, it rained more in 2020 than in the other monitored years, 2018 and 2019, and there was an even greater amount of precipitation than the average amount from 1981 to 2010. The findings were similar in terms of temperatures, as 2018 was the warmest and 2020 was the coldest. Except for May 2019 and 2020, the temperatures were above the normative average from 1981 to 2010 in all the months.

Table 6. Correlations between nutrient determination methods (2), hybrids (4) and years (3) of experiment for individual items ($n = 96$)

Items	Methods	Hybrids	Years
DM (%)	0.32*	0.13	–0.39*
Starch (% DM)	–0.74*	0.10	0.32*
NDF (% DM)	0.76*	–0.10	–0.44*
CP (% DM)	0.75*	–0.05	–0.17
Ash (% DM)	–0.57*	0.05	0.13
NDFD (%)	0.81*	–0.02	0.05
NEL (MJ/kg DM)	0.44*	0.07	0.26*
Milk (t/ha)	0.49*	0.12	–0.06
Milk (kg/t DM)	0.44*	0.07	0.26*

CP = crude protein; DM = dry matter; NDF = neutral detergent fibre; NDFD = NDF digestibility; NEL = net energy of lactation

*Significant at $P < 0.05$

Differences between hybrids

Table 5 shows a comparison of pNIRS and chemical analysis interactions with hybrids. We chose such hybrids for the experiment that were expected to be grown throughout the experiment, which are commonly used in practice, which have different early periods and different properties, but the difference between them is small. Significant differences between pNIRS and chemical analysis were found for all hybrids in starch, NDF, CP, ash content (except DKC3872) and NDFD. However, if the individual hybrids were evaluated separately, according to one of the assay methods, then there were no differences between the hybrids. So, as can be seen in Table 5, there were no statistically significant differences between the tested maize hybrids in terms of their chemical composition, selected nutritional values or their milk production potential (the relevant data are given regardless of the method used and year). The disparities between the crops with regard to the differences in the earliness of hybrids FAO 240 to FAO 270 (Table 1) were not therefore reflected in the results in terms of the DM content, nutrient content in DM, NDFD, NEL energy values, or the potential milk production per hectare/per tonne of DM.

Barriere et al. (2004) recorded a significant effect of genotype variation in respect to NDF and NDFD regardless of whether they compared 477 or only 27 genotypes. A similar result regarding the significant effect of hybrid and site variations was previously obtained from an experiment with *in vivo* crude fibre digestibility in 14 sites with 241 genotypes (Argillier et al. 1997). Kruse et al. (2008) reported only marginal differences in fibre content within the involved maturity groups (eight hybrids, one site, three years). Differences in quality between hybrids were more apparent in studies with a large genotype pool; however, a significant effect of maize hybrid on forage quality is often reported in single-site experiments with a lower number of hybrids (Boon et al. 2012; Lynch et al. 2012). These results support the idea that other factors, such as variation of site and/or weather conditions, could be partly responsible for differences between maize hybrids. Kruse et al. (2008) further pointed out that differences in some studies can be connected with various DM content.

Correlation according to methods of analysis, characteristics of hybrids and year of their cultivation

According to Table 6, the correlations between pNIRS and chemical analysis were significant for all indicators ($P \leq 0.05$), however the aim is to get even closer to the values found via chemical analysis. The results relating to starch are negatively strong correlated; the results relating to NDF, CP and NDFD are positively strong correlated. Whereas starch and NDF are the principal nutrients in maize silages, their contents, expressed as a proportion in dry matter content, are linked to each other in chemical and pNIRS analyses. So, if the higher content of starch had been analysed, the lower content of NDF was found subsequently. That is the reason why the content of starch, analysed by the pNIRS method, is overvalued close to contemporary devaluation of NDF content. This trend was manifested also in 2018, when we observed the low content of starch in maize silages. The calibration of pNIRS is not prepared for so low values of starch, because the common content of starch in maize silages is higher. So, it is necessary to improve the number of samples with different quality, analysed on pNIRS, to improve the accuracy of this method. The results relating to ash are negatively moderately correlated; the results relating to NEL and potential milk production are positively moderately correlated. Correlations between the four hybrids (DKC3450, DKC3568, DKC3575 and DKC3872), and also between the three years of testing (2018 versus 2019 versus 2020) were weak, except DM and NDF, which were negatively moderately correlated.

CONCLUSION

Among the many types of precision livestock farming technologies, the use of the pNIRS to aid dairy cow feeding management is undoubtedly one of the most promising. The employment of pNIRS to evaluate the physicochemical composition of TMR represents a recently introduced technology, yet the reviewed literature already shows that its use in barns with the appropriate calibrations is a rapid and accurate analytical technique. As has been widely discussed, the potential benefits are enormous (Schwab et al. 2003). Moreover, the issue of using a pNIRS in agriculture is not only a very current and much debated topic as part of the field of PA, but these moveable devices can be quickly used during agricultural practices on farms. However, the accuracy of such devices in terms of nutrient determination is still far from perfect, and chemical analysis of nutrient values is still necessary for control; the results of this research prove that. Indeed, there is a long way to go before perfection can be achieved. The originality of this paper mainly lies in its evaluation of the influence of both methods (pNIRS and chemical analysis) when determining the chemical composition of maize hybrids in terms of nutritional values and milk production potential.

Conflict of interest

The authors declare no conflict of interest.

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