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Evaluation of changes in dry matter and nutrient content during the growth dynamics of silage maize

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Abstract: The aim of this study was to identify and quantify the relationships between the nutrient content and the DM (dry matter) content of various maize hybrids (*Zea mays* L.) in the dynamics of vegetative maturity and various soil-climatic growing conditions. Over the course of 7 growing seasons (years), a set of 1 972 samples of whole silage maize plants consisting of 206 different hybrids grown in two contrasting regions (lowland and foothill areas) was analysed. The focus was on DM content and the content of key energy nutrients (WSC – water soluble carbohydrates, starch, NDF – neutral detergent fibre) and their interactions. Results show that the transformation of WSC into starch has four key points: (*i*) it begins at a DM content of 150 g/kg; (*ii*) it peaks at a DM content of approximately 235 g/kg; (*iii*) it begins to decrease significantly from a DM content of 300 g/kg; and (*iv*) it practically stops rapidly after exceeding a DM content of 350 g/kg. In the dynamics of vegetative development of maize plants, the DM content is very closely related to the WSC content (R^2 = 0.728) and the starch content (R^2 = 0.873). With the gradual increase in vegetative maturity and DM content in maize plants, the transformation of WSC into starch dynamically increases. These characteristics, with small deviations, were also confirmed at different levels of evaluation (all analyses, regions, seasons and individual hybrids). These results show that a DM content of 300 g/kg to 350 g/kg can be considered the optimal harvesting window for maize ensiling and the optimal phase of silage maturity for whole maize plants, because once the DM content exceeds 350 g/kg; the transformation of WSC into starch stops and the drying phase of plants begins.

Keywords: carbohydrate transformation; hybrid; maize; silage maturity; vegetative development

Maize (*Zea mays* L.) is one of the basic sources of fibre and energy for dairy and meat cattle. The silage maturity of maize is most often characterised by dry matter content, which is determined by harvest date and the suitability of the climate for harvesting, as well as seasonal influences. Dry matter content, nutrient composition and nutrient digestibility change dynamically during the vegetative development of silage maize crops (Ferraretto et al. 2018; Horst et al. 2020). The nutritional value and production efficiency of maize for silage are closely related to the nutrient content in dry matter

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(Ferraretto and Shaver 2012), therefore dry matter (DM) content is considered a basic nutritional and technological evaluation parameter of maize silages maturity at harvest. With the entire plant having DM content of 300 g/kg, the DM content of the grain reaches 500 g/kg (Daynard and Hunter 1975). As the DM content increases, both starch and NDF digestibility decrease (Di Marco et al. 2002; Mertens 2010). The DM content of different types of hybrids (early to late) in the same conditions and at the same stage of vegetative development (milk-wax maturity) is not the same and reached a relatively wide range (Biro et al. 2008). The highest level of milk production was achieved at a DM content in maize silages of 280–320 g/kg (Ferraretto and Shaver 2012). The DM content is related to the calendar day and represents a characteristic property for a given hybrid (Mitrik and Mitrik 2022).

The DM content of maize silages from farms analysed during the evaluation period in Slovakia averaged 334 g/kg; however, only 50% of the samples reached a DM content of 303 g/kg to 368 g/kg (Table 1).

This is the result of the simultaneous action of several factors: the genetic potential of the hybrids used, the weather and soil-climatic conditions, the availability of harvesting equipment, and other minor (subjective) factors. The highest DM content in silage maize between years 2011 and 2019 was observed in 2018 (Rajsky et al. 2024). Despite extensive research on maize silage maturity, most studies are limited by small sample sizes (typically <300 samples) and narrow geographic or hybrid ranges. Consequently, universally applicable predictive models for nutrient dynamics across diverse hybrids and environments are lacking, limiting practical decision-making for optimal harvest timing.

Therefore, the objectives of this study were to: (*i*) quantify the relationships between DM content and key energy nutrients (WSC, starch, NDF) across 206 maize hybrids over 7 growing seasons; (*ii*) develop predictive equations for estimating WSC and starch content based on DM; (*iii*) identify critical transition points in WSC to starch transformation during plant maturation; (*iv*) validate the consistency of these relationships across contrasting soil-climatic regions (foothill vs lowland).

We hypothesised that despite genetic and environmental variability, the fundamental physiological relationships between DM and nutrient content would be sufficiently consistent to enable robust, universally applicable predictive models.

MATERIAL AND METHODS

Experimental design. The study was designed as a comprehensive survey combining: (*i*) Small-plot hybrid trials with multiple hybrids at 3–5 locations per region, and (*ii*) on-farm monitoring of commercial maize crops at 8–12 farms per region. Hybrids were selected to represent a wide range of maturity groups (FAO 120–600) commonly grown in each region. Sampling locations within each region were selected to represent typical soil conditions and farm management practices.

Over the course of seven growing seasons (2015–2021), group experiments as well as individual monitoring of the nutrient composition of selected crops in two different production regions were conducted:

- FOOTHILLS (hereinafter referred to as the F region): a colder and higher region above 500 m above sea level (a.s.l.) in 3 locations: (*i*) 543 m

Table 1. DM content (g/kg) of maize silages in Slovakia during the experimental period (unpublished results)

Year	*N*	Average	SD	Minimum	Maximum	10th centile	25th centile	75th centile	90th centile
2015	342	333	51	182	713	273	299	360	388
2016	339	339	50	179	485	281	306	372	407
2017	258	307	80	148	469	170	252	370	398
2018	339	348	49	239	505	290	315	376	412
2019	238	346	54	174	489	285	313	378	416
2020	230	332	58	170	656	266	301	358	390
2021	283	327	53	170	513	272	296	358	391
Total	2 029	334	58	148	713	269	303	368	403

DM = dry matter

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a.s.l., N 49.059°, E 20.325°; (*ii*) 710 m a.s.l., N 49.276°, E 20.684°; (*iii*) 545 m a.s.l., N 48.961°, E 20.503°. Total number of samples: 1 320.

- LOWLAND (hereinafter referred to as the L region): a warmer and lower region up to 200 m above sea level bounded by the following points: (*i*) 168 m a.s.l., N 48.426°, E 17.934°; (*ii*) 207 m a.s.l., N 48.615°, E 17.631°; (*iii*) 182 m a.s.l., N 48.371°, E 20.163°. Total number of samples: 652.

Experimental locations were selected in agreement with seed suppliers. Fertilisation and plant protection followed the standard management practices of the individual farms. Hybrids were sown at optimal agrotechnical dates on cooperating farms using their routine sowing procedures. Each hybrid was sown in 4 to 8 rows at a planting density of 75 000–95 000 plants/ha. Sampling began at the onset of milk ripeness and was repeated at 5–10 day intervals (whenever possible depending on rainfall conditions) until the grain reached full ripeness. Samples were taken from crops consisting of 5–10 whole plants from the two central rows cut approximately 25 cm above the ground or 3–4 kg of chopped material cut during the ensiling period. For longer transport, the samples were packed: whole plants were packed into PE sacks and the chopped material into PE bags. The entire samples were chopped into chaff with an average particle size of approximately 15 mm and thoroughly homogenised by mixing. Samples weighing 500–750 g were dried in MEMMERT UFE 500 and UFE 700 dryers at a temperature of up to 60 °C for 16–24 hours. The dried samples were ground in SM-100 (RETCH) mills with a 2 mm sieve and then ground again in a TWISTER (RETCH) mill with a 1 mm sieve or in an SM-100 (RETCH) mill with a 1 mm sieve. The DM content and nutrients (crude protein, ether extract, water-soluble sugars, starch and NDF) in laboratory-dried samples were determined using an NIRS Antaris II FT-NIR Analyser (Thermo Fisher Scientific, Waltham, MS, USA) and by applying our own validated calibration models (Table 2).

Wet analysis methods. WSC – UV VIS spectrophotometry at 315 nm with a standard 50/50 glucose and fructose solution (Albalasmeh et al. 2013); starch – method according to AOAC 996.11 (AOAC 2005); NDF: ANKOM bag method.

The total DM content was evaluated based on gravimetric determination of laboratory dry matter corrected for DM content in dried samples. A total of 206 different silage maize hybrids were tested, covering a wide range of FAO groups from 120 to 600 (F region: FAO from 120 to 400; L region: FAO from 240 to 600).

Statistical evaluations were carried out using NCSS Statistical Software (NCSS 2024) and by applying the following methods: ANOVA with Tukeys HSD post-hoc test for pairwise comparisons, linear and nonlinear polynomial regression.

RESULTS AND DISCUSSION

The strongest correlations between dry matter content and nutrient fractions were observed for starch (r = 0.883), WSC (r = −0.807), and NDF (r = −0.788). Correlations with EE (r = 0.626) and CP (r = −0.527) were weaker, suggesting that variations in dry matter content are more closely associated with changes in WSC, starch, and NDF. The dry matter, starch and NDF content was measured in 1 972 samples, and the WSC content in 1 824 samples. 66.94% of samples came from the F region and 33.06% of samples came from the L region. The DM content of each sample was rounded to the nearest 50 ± 25 g/kg, resulting in 9 sequential clusters (Table 3).

Table 2. Calibration and validation parameters of models for NIRS (near-infrared spectroscopy)

Nutrient	RMSEC	R^2	RMSEP	R^2
Dry matter (DM; g/kg)	5.64	1.00	5.54	0.99
Crude protein (g/kg DM)	3.06	0.98	2.76	0.98
Ether extract (g/kg DM)	3.58	0.95	2.15	0.95
Starch (g/kg DM)	20.30	0.98	23.10	0.97
WSC (g/kg DM)	7.35	1.00	5.98	1.00
NDF (g/kg DM)	19.10	0.93	19.70	0.93

NDF = neutral detergent fibre; RMSEC = calibration; RMSEP = prediction; WSC = water soluble carbohydrates

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Table 3. WSC, starch and NDF content (g/kg DM)

DM	Parameter	*n*	Average	SD	Minimum	Maximum
	WSC	131	225.82[a]	33.90	168.00	319.53
150	starch	131	32.58[a]	22.69	1.00	99.00
	NDF	131	546.23[a]	42.06	449.00	680.24
	WSC	512	251.53[b]	35.87	140.40	356.05
200	starch	541	62.70[b]	49.96	1.09	274.33
	NDF	541	501.73[b]	40.46	408.00	614.81
	WSC	494	194.24[c]	43.89	80.00	332.00
250	starch	533	193.18[c]	57.42	43.00	325.85
	NDF	533	445.01[ci]	33.09	347.00	583.67
	WSC	399	141.46[d]	35.80	45.28	245.00
300	starch	440	278.45[dhi]	40.79	147.39	388.00
	NDF	440	411.45[di]	33.85	321.00	510.28
	WSC	158	102.44[efhi]	25.20	51.39	189.92
350	starch	188	325.93[efghi]	40.82	210.53	409.53
	NDF	188	388.26[efghi]	31.83	320.00	488.14
	WSC	81	89.34[efghi]	22.69	46.00	180.16
400	starch	89	339.88[efghi]	43.45	237.71	454.00
	NDF	89	378.17[efhi]	31.65	315.82	454.76
	WSC	40	75.88[fhig]	21.80	47.86	137.65
450	starch	41	347.72[efghi]	38.62	274.02	422.00
	NDF	41	373.30[efghi]	32.17	302.90	423.70
	WSC	7	62.48[efghi]	16.42	43.72	90.26
500	starch	7	340.21[efghi]	37.23	294.55	400.82
	NDF	7	360.77[efhi]	49.04	273.05	432.71
	WSC	2	44.77[efghi]	7.42	39.52	50.01
550	starch	2	336.67[efghi]	13.20	327.33	346.00
	NDF	2	406.38[cdefghi]	58.26	365.18	447.57
	WSC	1 824	185.17	66.86	39.52	356.05
262 ± 68	starch	1 972	188.90	116.17	1.00	454.00
	NDF	1 972	449.55	61.02	273.05	680.24

[a–i]Values with different superscript letters within a parameter are significantly different ($P < 0.05$, Tukey's HSD test)
DM = dry matter; NDF = neutral detergent fibre; SD = standard deviation; WSC = water soluble carbohydrates

Table 3 shows the dynamic changes in nutrient composition during maize maturation. WSC peaked at 200 g/kg DM (252 g/kg) before declining progressively, while starch increased most rapidly between 200–300 g/kg DM, then plateaued above 350 g/kg DM. NDF decreased from 546 g/kg at 150 g/kg DM to 378 g/kg at 400 g/kg DM.

The content of WSC, starch and NDF changes dynamically with increasing dry matter content. The measured data provides a very comprehensive view of the development of the nutrient composition of silage maize during its vegetative development from the earliest stages to full grain maturity (Table 3).

The contents of WSC, starch and NDF are significantly different from a statistical point of view, especially in a cluster with a DM content of up to 350 g/kg, which indicates that a DM content of 300 g/kg represents a turning point in the conversion of WSC to starch.

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Table 4. Nutrient composition of whole maize plants

Nutrients	Unit	*n*	Average	SD	Minimum	Maximum
Dry matter (DM)	g/kg	1 972	262	68	134	555
Starch	g/kg DM	1 972	189	116	1	454
WSC	g/kg DM	1 824	185	67	40	356
NDF	g/kg DM	1 972	450	61	273	680
Andrieu et al. (1993) – comparison						
Dry matter	g/kg	234	291	61	183	531
Starch	g/kg DM	234	236	80	29	404
WSC	g/kg DM	234	119	40	36	226
NDF	g/kg DM	234	473	33	389	575

NDF = neutral detergent fibre; SD = standard deviation; WSC = water soluble carbohydrates

The average nutrient contents (dry matter, WSC, starch, and NDF) as well as their minimum and maximum values (Table 4) are in a similar range to those found by Andrieu et al. (1993), although our sample set was approximately 8.5 times larger and the dry matter contents in our first samples was lower (134 g/kg vs 183 g/kg), because sampling began earlier (205th calendar day).

Water-soluble sugars. WSC measurements were performed on 1 874 samples (F: 1 320; L: 504). To express the relationship between DM content and WSC content, we used a second-degree polynomial function. The general relationship between DM content and WSC content is consistent (n = 1 824; R^2 = 0.728) and WSC concentration peaks in the DM content range of 180 g/kg to 200 g/kg (Figure 1).

The prediction of WSC content based on DM content [Equation (1)] confirms that, after exceeding a DM content of 350 g/kg, WSC content falls below 100 g/kg and continues to decline very slightly.

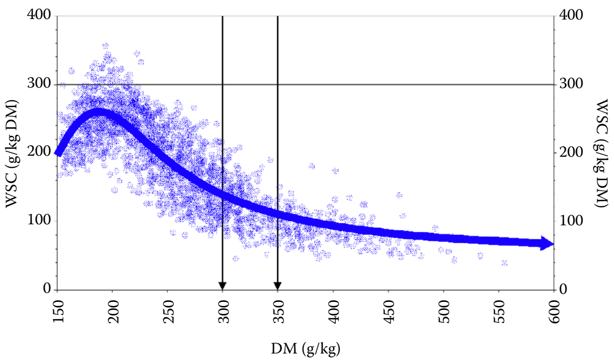

Figure 1. Dynamics of WSC in relation to DM content (seasons 2016 to 2021)

DM = dry matter; WSC = water soluble carbohydrates

$$\text{WSC} = (49.79 + 3\,565\,577.91X - 1\,000\,000\,000X^2)/(1 - 43\,289.93X + 1\,000\,000\,000X^2) \quad (1)$$

R^2 = 0.728; n = 1 824

where:

WSC – water soluble carbohydrates (g/kg DM);

X – 1/DM^2 (g/kg);

DM – dry matter.

The maximum cumulative WSC content, as well as the minimum values at the end of vegetation development, are similar to the measurements of other authors (Andrieu et al. 1993; Kruse et al. 2004). Kruse et al. (2004) compared two hybrids over two seasons and found a difference of approximately 20 days in the peak WSC content.

The relationships between WSC content and DM content at the level of evaluation by individual years are relatively very consistent (combined R^2 = 0.784 with individual annual values ranging from 0.611 to 0.878). The seasonal effect was mainly evident during the period of WSC peak content, which occurs at a DM content of around 200 g/kg, whereas in a DM content range of 300 g/kg to 350 g/kg the trends are very similar to the general model.

A limitation of this study is the absence of detailed meteorological data for individual growing seasons. However, the consistency of relationships across 7 years (R^2 > 0.72) suggests that the fundamental physiological patterns are robust despite annual weather variations.

At the level of individual hybrids, the most frequently tested hybrid was SEVERUS from the company KWS Semena: 6 seasons and 3 differ-

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ent locations in the F region. The relationship between the WSC content and the dry matter content (Figure 2A) is also very consistent (R^2 = 0.793), which suggests that such a relationship can be generalised and used in the characterisation of hybrids not only during their pre-market testing, but also during their commercial cultivation. At the level of individual hybrids, the main focus was on hybrids with 20 or more measurements, which means that they were tested over at least 4 seasons or in 4 combinations (season and test site). Also at this level, the relationship between WSC content and DM content was very similar (Figure 2B) to the evaluation.

The peak of WSC content and its decline trends are very similar at all levels of assessment. The relationship between the DM content of the whole maize plant and the WSC content is consistent across different levels of access and assessment and appears to be a nutritional characteristic of the vegetative development of whole silage corn plants.

Starch. Starch measurements were performed in 1 972 samples (F: 1 320; L: 652). To express the relationship between the DM content and the starch content, we used the logistic function (Figure 3):

$$Y = A/\{1 + B[\exp(-CX)]\} \text{ with transformation } X = 1/x \quad (2)$$

where:
Y – starch content (g/kg DM);
x – DM content (g/kg);
X – 1/DM (g/kg);
A, B, C – fitted constants.

Water-soluble carbohydrates (WSC; glucose, fructose, and sucrose) are synthesised in the phloem tissue of leaves via photosynthesis. Maize kernel development is supported by sucrose transported to the endosperm and embryo, where it is enzymatically converted into starch. These processes are tightly regulated as describe Rolletschek et al. (2005).

The relationship between the DM content and the starch content is very consistent (R^2 = 0.873), and is expressed by the equation [shown in Equation (3)]. The formation course and dynamics are fully consistent with the published results of the work of Khan et al. (2015), who analysed the results of studies from 1992 to 2013.

$$\text{Starch} = 360.808\,293\,402\,07/\{1 + 0.000\,720\,835\,630\,513\,963 \times [\text{EXP}(-(-1\,769.166\,214\,437\,39 \times X)]\} \quad (3)$$

$R^2 = 0.873$, n = 1 972

where:
starch – starch content (g/kg dm);
X – 1/DM (g/kg);
DM – dry matter.

Extensive database of results from observations of starch content in silage corn in Wisconsin were statistically processed where starch content ranging from 271.47 g/kg to 287.35 g/kg of dry matter was measured in individual years at a DM content of 300 g/kg, with an average of 274.71 g/kg of dry matter. These results are consistent with our findings (Figure 3). The relatively lower determination values in Wisconsin may be due to the geographical extent of the distribution of experimental units. Our measurements describe a geographically much more compact and less variable environment.

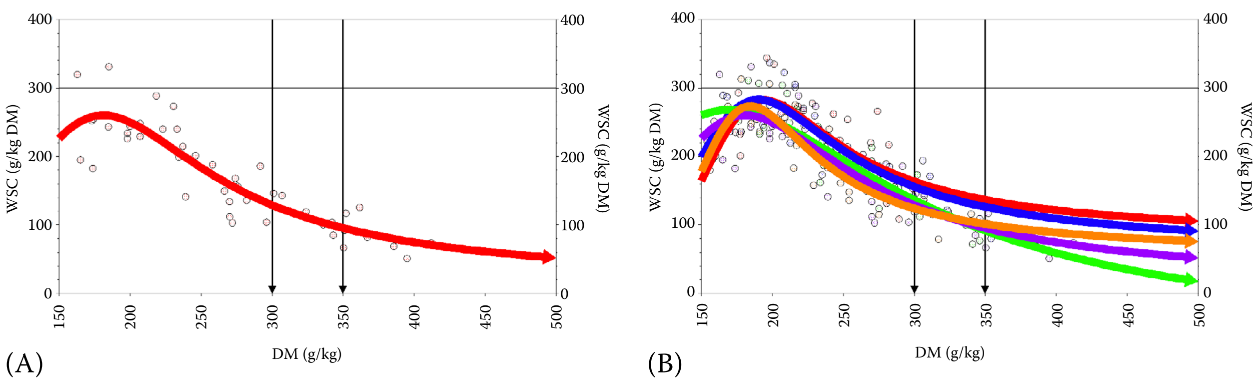

Figure 2. WSC and DM content of the most frequently analysed hybrid (A) (44 measurements, 6 seasons, 3 locations) and the group of hybrids with more than 25 measurements (B)
DM = dry matter; WSC = water soluble carbohydrates

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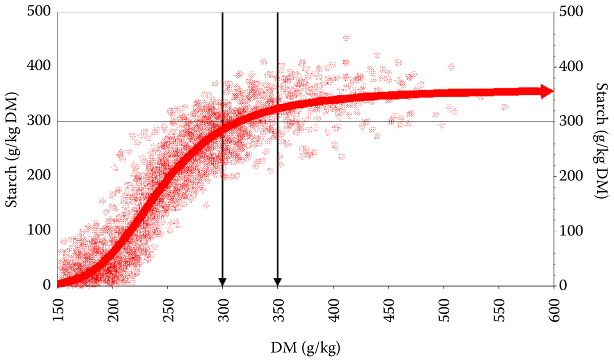

Figure 3. Dynamics of starch content in relation to DM content (seasons 2015 to 2021)
DM = dry matter

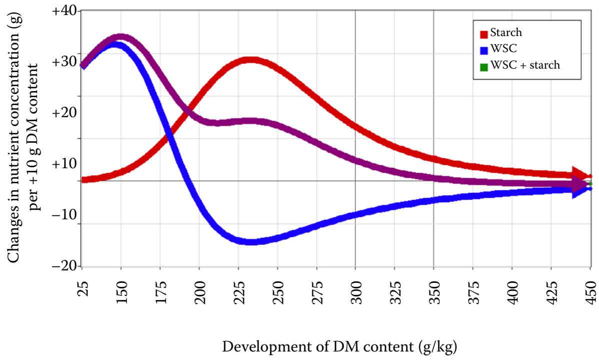

Figure 4. Dynamics of WSC and starch content in relation to DM content
DM = dry matter; WSC = water soluble carbohydrates

The increase in starch content is most intense in a dry matter range of 200 g/kg to 300 g/kg, where the starch content increases dynamically and then the increase falls below +15 g. From a DM content of 350 g/kg, the increase is already very low, falling below +5 g, and the total increase of WSC and starch reaches a negative balance (Figure 4).

The relationship between the starch content and the DM content remains very consistent even when evaluated at the level of individual regions and up to a DM content of 350 g/kg it is practically identical (Figure 5). In the harvest window (DM content 300 g/kg to 350 g/kg), maize achieves the optimal WSC concentration, creating optimal conditions for successful silage fermentation.

From these results, we can assume that this relationship is not dependent on the region or locality but is a characteristic of maize silage hybrids.

The trend in the development of starch content in relation to dry matter content, assessed at the annual level, indicates that seasonal influence is manifested by a shift in the onset of starch formation (DM content of 140 g/kg to 200 g/kg), with a transition to a significantly lower intensity of starch increase at a DM content of 300 g/kg to 350 g/kg (Table 5).

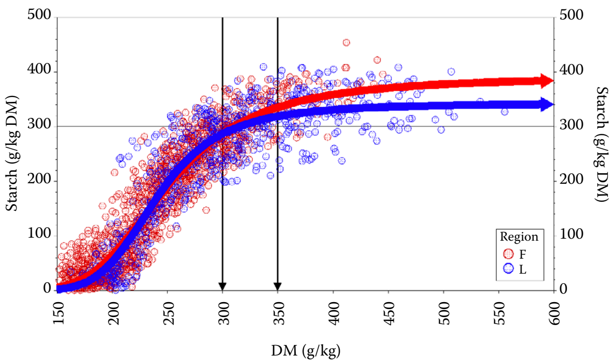

Figure 5. Starch and DM content by regions (F – R^2 = 0.881; L – R^2 = 0.828)
DM = dry matter

While many differences between DM clusters were statistically significant (Table 3), their practical significance for animal nutrition requires consideration. For instance, the NDF difference between 350 g/kg and 400 g/kg DM (10 g/kg DM) is statistically significant but likely negligible for dairy cow performance. In contrast, the starch increase from 250 g/kg to 300 g/kg DM (85 g/kg DM) would substantially affect energy concentration and milk production potential. These distinctions underscore that the 300–350 g/kg DM harvest window represents not only statistical but also biologically meaningful optimisation.

The lowest values of the variation coefficient (7%) between seasons were found at dry matter contents of 300 g/kg to 400 g/kg and the average deviation ranged from 19 g/kg to 25 g/kg.

Starch and WSC interactions. A decrease in WSC content is closely linked to an increase in starch content (201 hybrids; 1 824 measurements; Figure 6A) and is relatively uniform.

A look at the trends for hybrids with 10 or more measurements (63 hybrids; 1 047 measurements; Figure 6B) shows that the variation in values around the general trend is caused by the specific characteristics of individual hybrids and the differences between them.

The analysis and comparison of 89 different hybrids shows that a DM content of 300 g/kg was achieved on average on the 241st calendar day and a DM content of 350 g/kg was achieved on aver-

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Table 5. Starch content (g/kg DM) at different dry matter contents by years

DM (g/kg)	Year											
	2015	2016	2017	2018	2019	2020	2021	Average	SD	Minimum	Maximum	CV (%)
200	113	60	128	84	48	62	56	79	31	48	128	40
250	236	189	240	219	160	182	190	202	30	160	240	15
300	286	279	300	309	251	283	300	287	19	251	309	7
350	301	315	327	348	292	334	347	323	22	292	348	7
400	307	328	339	364	308	357	366	338	25	307	366	7

CV = coefficient of variation; DM = dry matter; SD = standard deviation

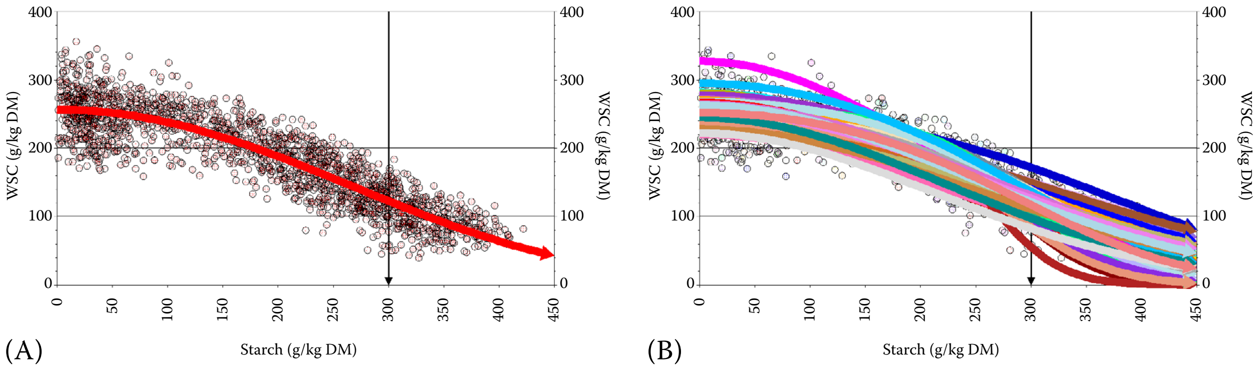

Figure 6. WSC content and starch content all measurements (A) and hybrids with 10 or more measurements (B)
WSC = water soluble carbohydrates

age on the 249th calendar day (Table 6) in a wide range of 52 or 53 calendar day periods. The increase in DM content from 300 g/kg to 350 g/kg took an average of 8 days, but again during a relatively wide range of 13 days.

The relationship between WSC and starch content (4) is similar to that found by other authors (Andrieu et al. 1993) (5):

$$\text{Starch} = 470 - 1.544\,9 \times \text{WSC} \; (\pm 7.48) \quad (4)$$

$R^2 = 0.881$; $n = 1\,824$

$$\text{Starch} = 450 - 1.798\,6 \times \text{WSC} \; (\pm 40.00) \quad (5)$$

$R^2 = 0.873$; $n = 234$

where:
WSC – water soluble carbohydrates (g/kg DM).

These parameters represent a realistic basis for characterising and describing the properties of hybrids, while the currently used systems, such as FAO groups, do not deal with these characteristics at all (Jugenheimer 1976).

Table 6. Time dynamics involved in achieving a DM content of 250, 300, 350 and 400 g/kg

Parameter	Number of days/DM content range (g/kg)			Calendar day	
	250–300	300–350	350–400	DM 300	DM 350
Average	11	8	7	241	249
Minimum	3	3	3	216	222
Maximum	20	15	14	268	274
Range	17	13	13	53	52
Dry matter content changes (g/kg/day)	+4.66	+5.92	+7.21	–	

89 hybrids (at least 4 measurements in the range of 200–280th calendar day)
DM = dry matter (g/kg)

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The average daily dry matter increase in experiments with a single silage hybrid in subtropical conditions at vegetation stages starting from a ½ milk line stage on the grain reached values of 4.18 ± 1.07 g/kg/day (Saylor et al. 2021) and 4.88 ± 1.74 g/kg/day (Rabelo et al. 2015), which is consistent with our results obtained under continental conditions with a dry matter range of 250 g/kg to 300 g/kg (Table 6).

PRACTICAL IMPLICATIONS

The optimal harvest window for silage maize is at a dry matter content of 300–350 g/kg, as this range ensures:

- optimal accumulation of WSC and starch;
- sufficient WSC (>100 g/kg DM) content to support efficient silage fermentation;
- minimisation of effluent losses;
- maintenance of starch and NDF digestibility;
- high overall silage production efficiency.

Therefore, repeated dynamic and frequent monitoring of hybrid nutrient composition (dry matter, WSC, starch, and NDF) under specific seasonal and climatic conditions is recommended in practice. Such monitoring provides a robust information base for detailed characterisation of hybrids in terms of nutrient composition. This recommendation is further supported by the wide variation in the duration of the optimal harvest window (3–15 days) within the dry matter range of 300–350 g/kg, with an average of 8 days.

Harvesting maize at dry matter contents exceeding 350 g/kg increases the risk of (*i*) insufficient compaction of the silage mass, (*ii*) inadequate WSC content for fermentation (<100 g/kg DM), and (*iii*) excessively hard and poorly breakable grain.

The proposed approach also includes the use of estimation equations describing the development of dry matter, starch, WSC, and NDF for individual hybrids within defined geographical regions of Central Europe with comparable climatic conditions. Based on time-series measurements, the rate of dry matter and nutrient development can be derived at standardised reference levels (25, 30, and 35% DM).

These data allow determination of the pre-harvest period (25–30% DM) and the silage harvest window (30–35% DM), which represent practical hybrid-specific characteristics relevant for farm management.

Systematic long-term monitoring of hybrids across diverse environments enables the gradual development of a comprehensive practical database, effectively serving as "hybrid birth certificates," which can be used to design targeted and optimised strategies for maize silage harvesting and production.

LIMITATIONS

We acknowledge that this study has several limitations, primarily in the following aspects:

- Geographic scope: the study was limited to Slovakia.
- NIRS methodology: NIRS is a comparative method, and the calibration models were based on wet-chemistry analyses of fresh samples originating from the Slovak Republic.
- Missing contextual factors: soil characteristics, agronomic practices, and pest and disease pressure were not systematically recorded.
- Fermentation outcomes: hybrid composition was evaluated at the plant level prior to ensiling, and no direct measurements of ensiling performance or fermentation success were conducted.
- Climate change implications: future climatic conditions may alter WSC–starch dynamics.

A limitation of this study is the absence of detailed meteorological data for individual growing seasons. However, the consistency of relationships across 7 years ($R^2 > 0.72$) suggests that the fundamental physiological patterns are robust despite annual weather variations. Despite these limitations, the large sample size and high consistency ($R^2 = 0.73–0.87$) provide confidence in findings for similar production environments.

CONCLUSION

This comprehensive study of 1 972 maize samples across 206 hybrids and 7 growing seasons has established clear, quantifiable guidelines for optimal silage maize harvest timing.

Key findings:

- WSC-to-starch transformation follows a predictable pattern with four critical thresholds: ini-

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tiation at 150 g/kg DM, peak at 235 g/kg DM, deceleration at 300 g/kg DM, and cessation at 350 g/kg DM.
- Predictive equations (R^2 = 0.73–0.87) enable accurate estimation of WSC and starch content from simple DM measurements.
- The optimal harvest window of 300–350 g/kg DM balances maximum starch accumulation (≈300 g/kg DM) with adequate WSC for fermentation (>100 g/kg DM)

The WSC content (R^2 = –0.728) as well as the starch content (R^2 = 0.873) are related and very closely linked to the dry matter content. As the WSC is gradually transformed into starch, which is stored in the grain, the DM content increases dynamically. These characteristics, with minor deviations, have been confirmed at all levels: all measurements, regions, seasons, and hybrids. Except for extremely dry conditions, DM content reflects the metabolic transformation of non-fibrous carbohydrates. The temporal dynamics of dry matter increase are specific to each hybrid, and we have found a high degree of repeatability of this relationship across seasons and locations in many hybrids. The observed relationships provide the basis for developing a comprehensive database for hybrid characterisation and for refining the determination of the silage maturity stage. Continued monitoring and targeted experiments are essential to further elucidate the dynamics of silage maturity under varying environmental and management conditions.

Farmers should prioritise harvest within the 300–350 g/kg DM window and avoid delays beyond 350 g/kg DM, as nutrient accumulation ceases and quality risks increase. The predictive tools developed here enable precise harvest timing without costly nutrient analyses, supporting economically and nutritionally optimised silage production.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Albalasmeh AA, Berhe AA, Ghezzehei TA. A new method for rapid determination of carbohydrate and total carbon concentrations using UV spectrophotometry. Carbohydr Polym. 2013 Sep 12;97(2):253-61.

Andrieu J, Demarquilly C, Dardenne P, Barriere Y, Lila M, Maupetit P, Riviere F, Femenias N. Composition and nutritive value of whole maize plants fed fresh to sheep. I. Factors of variation. Ann Zootech. 1993;42(3):221-49.

AOAC. Official methods of analysis. 18th ed. Gaithersburg, MD: Association of Official Analytical Chemists; 2005.

Biro D, Galik B, Juracek M, Simko M, Michalkova J, Gyongyova E, Taska M. Fermentation process characteristics of different maize silage hybrids. J Cent Eur Agric. 2008 Dec;9(3):463-8.

Daynard TB, Hunter RB. Relationships among whole-plant moisture, grain moisture, dry matter yield, and quality of whole-plant corn silage. Can J Plant Sci. 1975;55:77-84.

Di Marco ON, Aello MS, Nomdedeu M, Van Houtte S. Effect of maize crop maturity on silage chemical composition and digestibility (in vivo, in situ and in vitro). Anim Feed Sci Technol. 2002 Aug 30;99(1-4):37-43.

Ferraretto LF, Shaver RD, Luck BD. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J Dairy Sci. 2018 May; 101(5):3937-51.

Ferraretto LF, Shaver RD. Meta-analysis: Effect of corn silage harvest practices on intake, digestion, and milk production by dairy cows. Prof Anim Sci. 2012 Apr;28(2): 141-9.

Horst EH, Lopez S, Neumann M, Giraldez FJ, Bumbieris Junior VH. Effects of hybrid and grain maturity stage on the ruminal degradation and the nutritive value of maize forage for silage. Agriculture. 2020 Jul 1;10(7):251.

Jugenheimer RW. Corn: Improvement, seed production and uses. New York: Wiley-Interscience, John Wiley & Sons Inc.; 1976. 670 p.

Khan NA, Yu P, Ali M, Cone JW, Hendriks WH. Nutritive value of maize silage in relation to dairy cow performance and milk quality. J Sci Food Agric. 2015 Jan;95(2):238-52.

Kruse S, Hermann A, Komher A, Taube F. Modelling of water-soluble carbohydrates in forage maize. In: Luscher A, Jeangros B, Huguenin O, Lobsiger M, Millar N, Suter D, editors. Land use systems in grassland dominated regions. Proceedings of the 20th General Meeting of the European Grassland Federation; 2004 Jun 21–24; Luzern, Switzerland. Grassl Sci Eur. 2004;9:963-5.

Mertens DR. Particle size, fragmentation index and effective fiber: Tools for evaluating the physical attributes of corn silages. Madison, WI: USDA Agricultural Research Service, US Dairy Forage Research Center; 2010.

Mitrik T, Mitrik A. Silage maturity of maize in a foothill area with NIRS method support. Acta Phytotechn Zootechn. 2022 Dec;25(4):259-68.

https://doi.org/10.17221/172/2025-CJAS

NCSS. Number Cruncher Statistical System (NCSS) statistical software. Kaysville, UT: NCSS, LLC; 2024.

Rabelo CHS, De Rezende AV, Rabelo FHS, Basso FC, Harter CJ, Reis RA. Chemical composition, digestibility and aerobic stability of corn silages harvested at different maturity stages. Rev Caatinga. 2015 Jan;28(2):107-16.

Rajsky M, Mlynekova Z, Formelova Z, Hanusovsky O, Juracek M. 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. J Cent Eur Agric. 2024;25(4):966-77.

Rolletschek H, Koch K, Wobus U, Borisjuk L. Positional cues for the starch/lipid balance in maize kernels and resource partitioning to the embryo. Plant J. 2005 Apr;42(1):69-83.

Saylor BA, McCary CL, Diepersloot EC, Heinzen C Jr, Pupo MR, Gusmao JO, Ghizzi LG, Sultana H, Ferraretto LF. Effect of forage processor roll gap width and storage length on fermentation profile, nutrient composition, kernel processing score, and starch disappearance of whole-plant maize silage harvested at three different maturities. Agriculture. 2021 Jul 23;11:574.

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