DIGESTIBILITY OF ENSILED MAIZE HYBRIDS DIFFERING BY MATURITY AND ENDOSPERM TYPE*

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Selected maize hybrids were analyzed according to the *in vivo* digestibility of the silage. Eight tested hybrids were grown, harvested, and ensiled under identical conditions. The effect of earliness (early maturity group FAO 230–260 vs moderately early maturity group FAO 290–340) significantly ($P < 0.05$) affected the chemical composition, fermentation quality, and digestibility of neutral and acid detergent fibre. Type of kernel endosperm (dent vs flint) differed by digestibility of nutrients. Digestibility of dry matter, organic matter, and neutral detergent fibre was the highest for silage of the dent hybrid FAO 250 (73.7, 75.7, and 67.6%, respectively) and these digestibility values were significantly ($P < 0.05$) lower for silage of the dent hybrid FAO 320 (61.1, 63.4, and 51.4%, respectively). It was concluded that the digestibility differs mainly in dent-type hybrids. All correlation coefficients between the digestibility values were significantly ($P < 0.05$) high.

silage, ripening, milk line, grain, correlation

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INTRODUCTION

Maize (*Zea mays* L.) is a high-quality forage crop for ruminants, but its proper use in feeding requires accurate information regarding the chemical composition and nutrients digestibility not only of the fresh plant material but also of the silage. Improving the digestibility of forage maize through plant breeding is important for optimizing the efficiency of ruminant rations. This can be achieved in part by improving the digestibility of stem tissue, a genetically complex and diverse trait that changes during the growing season (Boon et al., 2012). Maize can be classified according to the maturity group (FAO index) or the type of kernel endosperm (flint, dent, intermediate flint, or intermediate dent). The kernel type is defined by the ratio of hard (vitreous flint) and soft (floury dent) endosperm (Cone et al., 2008).

The aim of the present study was to analyze maize hybrids of the early maturity group FAO 230–260 and the moderately early maturity group FAO 290–340, while comparing also the influence of endosperm type (dent or flint kernel and intermediate values for these), according to the chemical composition, ensilability, and especially *in vivo* digestibility of silage. Another goal was to harvest the hybrids at the same level of ripeness at 2/3 milk line (ML) and with non-significantly differing dry matter (DM) content in order to eliminate the effect of DM content on the chemical composition, fermentation profile, and digestibility.

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MATERIAL AND METHODS

Eight maize hybrids (H1–H8) were used in the experiment. The silages made from early maturing (E) hybrids of FAO 230–260 (H1–H4) were compared to those from moderately early maturing (M) hybrids of FAO 290–340 (H5–H8). The flint (F) type hybrids (H1, H5) were compared to the intermediate flint (IF) type (H2, H6), the intermediate dent (ID) type (H3, H7), and the dent (D) type (H4, H8).

Hybrids were grown on a single farm located at the village of Cervenka (GPS 49.7187908 N, 17.0837022 E) in the Olomouc Region of the Czech Republic, situated at approximately 230 m a.s.l., and with mean annual temperature of 9.9°C and rainfall of 591 mm. All hybrids were planted in the same field in randomised blocks with three replicates per hybrid with the crop density 95 000 plants per ha with row distance 0.75 m. The forecrops, method of tillage, dressing, and plant protection were identical. The silage ripeness was monitored continuously on the base of the grain milkline and the measurement of the DM content. Experimental plots were harvested at the moment when the DM content in whole plants of a given hybrid was approximately 320 g kg^{-1}. All hybrids were harvested by the same cutter (Jaguar 690; Harsewinkel, Germany) with a corncracker and chopped to a theoretical length of cut (TLC) of 12 mm when grain was at 2/3 ML. Average DM yield was 20.3 t ha^{-1}. No biological or chemical additives were used in the ensiling process. The silages were stored in large plastic containers each with a volume of 1.2 m^3 and sealed with a black and white 250 µm thick foil. The methodology of filling, compressing, and sealing was the same for all variants.

After complete fermentation (90 days), the silages were opened and used for an *in vivo* experiment. Three samples of approximately 2 kg each, taken from each container of the final silages, were used for chemical analyses. Fresh silage samples were analyzed for fermentation quality (pH plus concentrations of lactic, acetic, and propionic acids) using an IONOSEP 2001 analyser (RECMAN – laboratorni technika, Ostrava, Czech Republic). DM was obtained by drying chopped fresh material and correcting for volatile components. The dried material was subsequently milled to pass through a 1 mm sieve for laboratory analyses. DM, raw ash, crude protein (CP), starch, amylase-treated neutral detergent fibre (aNDF), and acid detergent fibre (ADF) were determined as described by A O A C (2005). Organic matter (OM) was calculated as DM minus raw ash. Four *in vivo* digestion trials were performed with eight silages made from eight maize hybrids. Six sheep (wethers of the Romanov breed, live weight 83 ± 9 kg) were used in each trial. The sheep were kept individually in adaptation boxes and subsequently in balance cages and fed at the rate of 1.2 kg DM per animal per day. Prior to the first trial, the animals were fed maize silage for three weeks. The first trial was conducted with a two-week adaptation period (animals were provided experimental silages), followed by a six-day collection period. During the collection period, the fodder intake and amounts of residual feedstuff and faeces were measured on a daily basis. The daily feed ration was offered twice daily in equal portions at 8 a.m. and 6 p.m. Silages were offered to the sheep at a body-maintenance feeding level. The animals had free access to drinking water.

Samples of silages, residuals, and faeces were dried and analyzed for DM, ash, CP, aNDF and ADF as describe above. The *in vivo* digestibility coefficients were calculated as follows:

Nutrient digestibility (%) = ((nutrient consumed (g day^{-1}) – nutrient excreted in faeces (g day^{-1}))/nutrient consumed (g day^{-1})) × 100.

Statistical values were processed using the software package STATISTICA 10 (StatSoft, Tulsa, USA) while utilizing the methods for calculating ANOVA and the modules for analyzing multi-factorial designs and repeated measures designs. The mean differences were separated using Tukey's range test. In these analyses, P values lower than 0.05 were regarded as indicating significance. The correlation coefficients were calculated using STATISTICA 10 (StatSoft, Tulsa, USA).

RESULTS

The chemical composition and fermentation quality of the tested silages are presented in Tables 1–2; in Table 1 individually by hybrids and in Table 2 by hybrids group.

The differences in DM between hybrids were not significant ($P > 0.05$).

The effect of earliness (early maturity group FAO 230–260 vs moderately early maturity group FAO 290–340) and type of kernel endosperm (dent vs flint vs intermediate dent or flint) significantly ($P < 0.05$) affected the chemical composition and fermentation quality of maize silages. Moderately early maturity group silages had significantly ($P > 0.01$) higher content of starch and lactic acid, but lower aNDF, ADF, and pH than early maturity group silages. Flint type of endosperm silages had significantly ($P > 0.01$) higher content of starch and the ratio between lactic acid and voluntary fatty acids, but lower aNDF, ADF, acetic acid, and pH than dent type of endosperm silages.

The *in vivo* digestibility of the tested silages is presented in Tables 3–4; in Table 3 individually by hybrids and in Table 4 by hybrids group. The effect of earliness significantly ($P < 0.05$) affected the digestibility of aNDF (aNDFD) and ADF (ADFD), but not the digestibility of DM (DMD) and organic matter (OMD). By contrast, the effect of kernel endosperm type (dent vs flint vs intermediates) was significant ($P < 0.05$) for the digestibility of all nutrients. Digestibility of DM, OM, and aNDF were the highest ($P < 0.05$) for

Table 1. Chemical composition and fermentation quality of maize silages by hybrids (H)

Silage (hybrid)	H1	H2	H3	H4	H5	H6	H7	H8	SEM
FAO index	230	245	250	260	290	320	340	320	
Index	E F	E IF	E ID	E D	M F	M IF	M ID	M D	
DM ($g\ kg^{-1}$)	316	311	318	316	298	303	303	301	4.95
aNDF ($g\ kg^{-1}$ DM)	443^{bc}	485^{d}	436^{b}	512^{d}	357^{a}	376^{a}	479^{cd}	429^{b}	7.89
ADF ($g\ kg^{-1}$ DM)	258^{b}	242^{b}	236^{b}	272^{b}	172^{a}	193^{a}	261^{b}	237^{b}	8.74
Starch ($g\ kg^{-1}$ DM)	336^{d}	257^{a}	268^{ab}	248^{a}	309^{cd}	293^{bc}	305^{c}	294^{bc}	6.25
NEL (MJ/kg^{-1} DM)	6.27^{b}	6.20^{b}	6.55^{cd}	5.64^{a}	6.58^{cd}	6.58^{cd}	6.73^{d}	6.43^{bc}	0.05
LA ($g\ kg^{-1}$ DM)	61.7^{ab}	57.2^{a}	55.6^{a}	57.0^{a}	70.9^{bc}	64.0^{ab}	77.1^{c}	71.3^{bc}	2.20
AA ($g\ kg^{-1}$ DM)	12.0^{a}	13.5^{a}	24.0^{b}	22.5^{b}	13.7^{a}	12.5^{a}	25.1^{b}	25.0^{b}	0.64
LA/VFA	4.33^{cd}	3.63^{bc}	2.24^{a}	2.29^{a}	5.05^{d}	4.97^{d}	2.97^{ab}	2.76^{ab}	0.20
pH	3.72^{ab}	3.67^{a}	4.19^{c}	4.07^{c}	3.80^{b}	3.70^{ab}	3.72^{ab}	3.78^{ab}	0.03

FAO = maturity index, E = early maturity group (FAO 230–260), M = moderately early maturity group (FAO 290–340), F = flint, D = dent, IF = intermediate F, ID = intermediate D, DM = dry matter, aNDF = amylase-treated neutral detergent fibre, ADF = acid detergent fibre, NEL = net energy of lactation, LA = lactic acid, AA = acetic acid, VFA = volatile fatty acids

$^{a–e}$within a row means with different superscripts differ ($P < 0.05$)

Table 2. Chemical composition and fermentation quality of maize silages by hybrids group (G, T)

Index	FAO maturity group (G)			Type of endosperm (T)					Effect	
	E	M	SEM	F	IF	ID	D	SEM	G	T
DM ($g\ kg^{-1}$)	315^{B}	301^{A}	2.5	307	307	309	311	3.0	0.001	0.878
aNDF ($g\ kg^{-1}$ DM)	469^{B}	410^{A}	3.9	400^{a}	430^{b}	457^{c}	470^{c}	5.6	< 0.001	< 0.001
ADF ($g\ kg^{-1}$ DM)	252^{B}	215^{A}	4.4	215^{a}	217^{a}	248^{b}	254^{b}	6.2	< 0.001	< 0.001
Starch ($g\ kg^{-1}$ DM)	277^{A}	300^{B}	3.1	322^{b}	275^{a}	286^{a}	271^{a}	4.4	< 0.001	< 0.001
NEL ($MJ\ kg^{-1}$ DM)	6.17^{A}	6.58^{B}	0.02	6.43^{b}	6.39^{b}	6.64^{c}	6.04^{a}	0.03	< 0.001	< 0.001
LA ($g\ kg^{-1}$ DM)	57.9^{A}	70.8^{B}	1.1	66.3	60.6	66.4	64.2	1.6	< 0.001	< 0.001
AA ($g\ kg^{-1}$ DM)	18.0^{A}	19.1^{B}	0.3	12.9^{a}	13.0^{a}	24.6^{b}	23.8^{b}	0.6	0.030	< 0.001
LA/VFA	3.12^{A}	3.94^{B}	0.1	4.69^{b}	4.30^{b}	2.60^{a}	2.52^{a}	0.1	< 0.001	< 0.001
pH	3.91^{B}	3.76^{A}	0.01	3.76^{a}	3.70^{a}	3.96^{b}	3.9^{b}	0.02	< 0.001	< 0.001

FAO = maturity index, E = early maturity group (FAO 230–260), M = moderately early maturity group (FAO 290–340), F = flint, D = dent, IF = intermediate F, ID = intermediate D, DM = dry matter, aNDF = amylase-treated neutral detergent fibre, ADF = acid detergent fibre, NEL = net energy of lactation, LA = lactic acid, AA = acetic acid, VFA = volatile fatty acids

$^{A–B,\ a–c}$within a row means with different superscripts differ ($P < 0.05$) for G and T, respectively

silage of the dent hybrid FAO 250 and these digestibility values were significantly ($P < 0.05$) lower for silage of the dent hybrid FAO 320.

The correlation coefficients between digestibility values are in Table 5, between chemical composition and digestibility in Table 6. All correlation coefficients between the digestibility values were significantly ($P < 0.05$) high.

DISCUSSION

Our current research builds on previous work (L o u c k a et al., 2015a, b) in which we evaluated the nutritional values of hybrids depending upon their FAO maturity group, type of ripening (stay-green vs normal), and type of kernel endosperm (flint vs dent). The innovative idea of our new manuscript is

Table 3. Digestibility (Dig) of maize silages by hybrids (H)

H	H1	H2	H3	H4	H5	H6	H7	H8	SEM
FAO group	E	E	E	E	M	M	M	M	
Dig (%)	F	IF	ID	D	F	IF	ID	D	
DMD	67.3^{b}	66.9^{b}	71.8^{bc}	73.7^{c}	71.5^{bc}	70.9^{bc}	71.5^{bc}	61.1^{a}	1.28
OMD	69.4^{b}	68.7^{ab}	74.0^{bc}	75.7^{c}	73.3^{bc}	73.3^{bc}	73.3^{bc}	63.4^{a}	1.30
aNDFD	50.3^{a}	53.4^{a}	57.9^{ab}	67.6^{b}	49.7^{a}	53.0^{a}	58.4^{ab}	51.4^{a}	2.51
ADFD	47.9^{ab}	45.6^{ab}	54.1^{bc}	63.5^{c}	39.1^{a}	47.4^{ab}	55.2^{bc}	47.6^{ab}	2.91

FAO = maturity index, E = early maturity group (FAO 230–260), M = moderately early maturity group (FAO 290–340), F = flint, D = dent, IF = intermediate F, ID = intermediate D, DMD = dry matter digestibility, OMD = organic matter digestibility, aNDFD = amylase-treated neutral detergent fibre digestibility, ADFD = acid detergent fibre digestibility

$^{a-d}$within a row means with different superscripts differ ($P < 0.05$)

Table 4. Digestibility (Dig) of maize silages by hybrids group (G, T)

Dig (%)	FAO maturity group (G)			Type of endosperm (T)					Effect	
	E	M	SEM	F	IF	ID	D	SEM	G	T
DMD	69.9	68.8	0.6	69.4^{ab}	68.9^{ab}	67.4^{b}	71.7^{a}	0.9	0.205	0.018
OMD	71.9	70.8	0.7	71.3^{ab}	71.0^{ab}	69.6^{b}	73.7^{a}	0.9	0.239	0.027
aNDFD	57.7^{B}	53.1^{A}	1.3	48.8^{a}	53.2^{ab}	59.5^{b}	58.2^{b}	1.8	0.049	< 0.001
ADFD	55.1^{B}	47.3^{A}	1.5	44.7^{a}	46.5^{a}	57.5^{b}	56.2^{b}	2.1	< 0.001	< 0.001

FAO = maturity index, E = early maturity group (FAO 230–260), M = moderately early maturity group (FAO 290–340), F = flint, D = dent, IF = intermediate F, ID = intermediate D, DMD = dry matter digestibility, OMD = organic matter digestibility, aNDFD = amylase-treated neutral detergent fibre digestibility, ADFD = acid detergent fibre digestibility

$^{A-B,\ a-b}$within a row means with different superscripts differ ($P < 0.05$) for G and T, respectively

to work with silages, not only fresh maize hybrids, and to give a higher focus on digestibility instead of chemical analysis. One of the aims of our new study is to eliminate the effects of DM content on their nutritional parameters. The experiment was organized in such a way that plants were harvested at very similar stages of maturity at 2/3 ML at similar DM content (311 ± 12.1 g kg^{-1}; $P > 0.05$), and thus the influence of DM content was eliminated (Table 1). That was the case, too, in our previous work (Loucka et al., 2015b). In the literature, this effect was described e.g. Der Bedrosian et al. (2012), Hetta et al. (2012), Lynch et al. (2012) or Rabelo et al. (2015).

All silages had good fermentation quality, as indicated by pH 3.83 ± 0.15 and ratio of lactic acid/volatile fatty acids of 3.42 ± 1.06.

Conducting *in vivo* experiments with sheep over a period of 34 years, Barriere et al. (2004) found that the digestibility of aNDF of silages made using different maize hybrids within the range FAO 170–350 varied from 35.9 to 60.4%. It is very important that the specified values are comparable to those found by Barriere et al. (2004). In our study, the values of aNDF ranged from 357 to 512 g kg^{-1} DM, OMD from 63.4 to 75.7%, and aNDFD from 49.7 to 67.6%. Although the ranges are somewhat narrower, these values are similar to those reported by Ferret et al. (1997). They confirmed mainly a wide range of OMD and aNDFD.

Di Marco et al. (2002) confirmed that *in vivo* DMD of silage remained constant with maturity because the depression in aNDFD could be compensated by starch accumulation in the grain.

The objective of earlier research by Moreno-Gonzalez et al. (2000) was to determine the potential performance and heterosis when using flint and dent populations as base germplasm for developing silage maize hybrids. Although their results suggested that forage maize hybrids should be developed from a flint × dent heterotic pattern, they observed no significant heterosis for OMD and ADFD. In our study, the relevant differences ($P > 0.05$) between intermediate and specialized types of hybrids were not observed.

The highest DMD, OMD, and aNDFD values were determined for silage of the dent hybrid FAO 250 (73.7, 75.7, and 67.6%, respectively; Table 3). Meanwhile, the silage from dent hybrid FAO 320 had significantly

Table 5. Correlation coefficients between digestibility values ($P < 0.0001$)

Index	OMD	aNDFD	ADFD
DMD	0.98	0.72	0.60
OMD		0.73	0.61
aNDFD			0.88

DMD = dry matter digestibility, OMD = organic matter digestibility, aNDFD = amylase-treated neutral detergent fibre digestibility, ADFD = acid detergent fibre digestibility

Table 6. Correlation coefficients between chemical composition and digestibility ($P > 0.05$)

Index	DMD	OMD	aNDFD	ADFD
DM	0.22	–0.22	0.10	0.25
aNDF	–0.45	–0.44	0.20	0.31
ADF	–0.14	–0.14	0.35	0.39
Starch	0.48	0.47	0.09	0.33

DM = dry matter, DMD = DM digestibility, OMD = organic matter digestibility, aNDF = amylase-treated neutral detergent fibre, aNDFD = aNDF digestibility, ADF = acid detergent fibre, ADFD = ADF digestibility

($P < 0.05$) lower DMD, OMD, and aNDFD (at 61.1, 63.4, and 51.4%, respectively). It was concluded that the digestibilities differ mainly in dent-type hybrids. This may be related to the way in which the dent-type kernel's flour and whole the plant mature.

The data presented in Tables 5 and 6 confirm that all correlation coefficients between the digestibility values were high ($P < 0.0001$). Nevertheless, the correlation coefficients between the digestibility of nutrients and chemical composition of silages were not statistically significant ($P > 0.05$) except in the case of CP ($r = 0.85$). This is consistent with Andrae et al. (2001) who found that the aNDF content of maize silage was poorly correlated to the aNDFD and OMD. Furthermore, they illustrated that the starch content of maize silage was not a good predictor of either aNDFD or OMD.

CONCLUSION

Our study illustrated some differences in individual chemical compositions and *in vivo* digestibility of maize silage produced from different hybrids. The principal original contribution of this paper lies in its comparison of maize hybrids of the early maturity group FAO 230–260 versus those of the moderately early group FAO 290–340 while examining also the kernel endosperm type dent vs flint. The second original aspect of this paper consists in examining *in vivo* digestibility using sheep, which is a very precise and demanding method of determination. Also original is that hybrids were harvested gradually within the same maturity range at 2/3 ML, and therefore the influence of FAO index on the nutritional parameters was eliminated. A final point of originality stems from the fact that we compared all correlation coefficients of digestibility among themselves.

The main consequence of the article is practical inasmuch as we confirm the hypothesis that the digestibility of silage from the dent-type hybrids depends upon their earliness. This statement confirms the difference between H4 and H8. According to our results, growing of dent hybrids with high FAO index (340) should not be recommended in this relatively northern region of Moravia, situated approximately 230 m a.s.l., because aNDFD is very low at the otherwise ideal time for harvesting to ensile. Any later harvesting time, however, would be risky in this region due to the probability of bad weather.

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