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# Bromatological characteristics and ruminal digestibility of grain corn hybrids with different vitreousness in silage maturity

**Evandrei Santos Rossi[1*], Marcos Ventura Faria[2], Marcelo Cruz Mendes[2], Mikael Neumann[2], Andre Gabriel[2] and Murilo Viotto Del Conte[3]**

*[1]Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Universidade Estadual do Centro-Oeste, Guarapuava, Paraná, Brazil. [3]Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil. *Author for correspondence. E-mail: rossi.es@hotmail.com*

**ABSTRACT.** The aim of this research was to evaluate vitreousness in commercial corn hybrids with flint and dent grains and to study the effect of this characteristic on agronomic behavior, nutritional value, and ruminal degradability of grains harvested in silage maturity. Twelve commercial corn hybrids were evaluated. They were divided in two groups (six with flint grains and six with dent grains). The experiments were conducted in two municipalities represented by Guarapuava and Laranjeiras do Sul, both in Paraná State. The harvest for the grain quality analysis was performed at ¾ of the milk line stage in the grain. The following characteristics were evaluated: grain yield, grain yield in silage maturity, vitreousness, ruminal digestibility of grain, neutral detergent fiber, acid detergent fiber and crude protein. The grains in the group of dent hybrids exhibited better degradability associated with lower vitreousness than the group of flint hybrids. The group of dent hybrids exhibited better ruminal digestibility of the grains associated with lower vitreousness versus the group of flint hybrids. There is a negative correlation between vitreousness and the digestibility of the grain; thus, vitreousness can be a criterion for selecting genotypes for forage production.

**Keywords:** endosperm, protein matrix, degradability, grain texture, *Zea mays* L.

## Características bromatológicas e digestibilidade de grãos de híbridos de milho com diferentes vitreosidades no ponto de silagem

**RESUMO.** O objetivo desta pesquisa foi avaliar a vitreosidade em híbridos comerciais de milho com grãos duros e dentados, e estudar o efeito desta característica no comportamento agronômico, valor nutricional e na degradabilidade ruminal dos grãos colhidos no ponto de silagem. Foram avaliados 12 híbridos comerciais de milho. Estes híbridos foram divididos em dois grupos (seis com grãos duros e seis com grãos dentados). Os experimentos foram conduzidos em dois municípios representados por Guarapuava e Laranjeiras do Sul, no Paraná. A colheita para análise da qualidade dos grãos foi feita no estádio de ¾ da linha do leite no grão. Foram avaliadas as seguintes características: produtividade de grão secos, produtividade de grãos no ponto de ensilagem, vitreosidade, digestibilidade ruminal de grãos, fibra em detergente neutro, fibra em detergente ácido e proteína bruta. Há uma melhor digestibilidade ruminal dos grãos no grupo de híbridos dentados, associada a menor vitreosidade quando comparada ao grupo de híbridos duros. Existe correlação negativa entre a vitreosidade e a digestibilidade dos grãos e podem ser um critério para selecionar genótipos destinados à produção de forragem.

**Palavras-chave:** endosperma, matriz proteica, degradabilidade, textura do grão, *Zea mays* L.

## Introduction

One of the most important sources of energy for animal feed is the corn harvested for silage or grain because the grains have on average 65 - 70% of starch (Zsubori, Pinter, Spitko, Hegyi, & Marton, 2013) and represent more than 40% of the dry mass produced per area Mendes, Gabriel, Faria, Rossi, & Júnior, 2015. It is important to consider the different environments of cultivation because the genotype x environment interaction alters the expression of some characteristics, such as the proportion of plant components (Mendes et al., 2015). This can certainly affect the quantity and quality of grain. Furthermore, few studies have investigated vitreousness and the bromatological qualities of corn grain for silage in more than one environment.

For whole plant silage or grain production, important studies have shown that the type of endosperm in the grain assumes an important role in the quality and in the final use of the food (Corona, Owens, & Zinn, 2006; Majee, Shaver, Coors, Sapienza, & Lauer, 2008; Vieira, Moro, Farinacio, Martin, & Menezes, 2011; Zsubori et al., 2013; Giuberti et al., 2014). Traditional corn hybrids have an endosperm comprising two parts with different textures represented by the farinaceous and vitreous regions. Cells containing starch and proteins are basically the components of these two parts, and they are directly related to the hardness of the endosperm (Gaytán-Martínez et al., 2006). The vitreous grain region has higher hardness due to the presence of a compact and well-developed protein matrix. The opposite is true for the farinaceous region with lower hardness, which is characterized by a discontinuous protein matrix with reduced protein bodies (Gaytán-Martínez et al., 2006).

When present in the endosperm, these proteins form a hydrophobic barrier encapsulating starch granules in a protein matrix (Momany et al., 2006), damaging the enzymatic starch attack; thus, they are undesirable from a nutritional perspective. Hybrids are classified by the variations in the vitreous and farinaceous portions, which are related to the flintiness of the endosperm. Among the grain types, dent grains have a higher proportion of farinaceous endosperm and are preferred as feed over hybrids with flint endosperm (Piovesan, Oliveira, & Gewehr, 2011; Zilic, Milasinovic, Terzic, Barac, & Ignjatovic-Micic, 2011).

It is important to know that few studies have determined vitreousness by manual dissection of the vitreous and farinaceous endosperm in corn hybrids, a methodology which enables the confident assignment of the real vitreousness pattern of a genotype (Davide, Ramalho, Figueiredo, & Souza, 2011; Osorio-Díaz et al., 2011) versus analyzing only the visual appearance of the grain.

In this context, international studies have reported optimal performance in animals fed with the silage of corn hybrids with dent grains (Majee et al., 2008; Zilic et al., 2011), and recently in Brazil it has also been proposed in the animal feed (Piovesan et al., 2011; Pereira et al., 2012). These studies reinforce the importance of better characterization of the grain participation in silage maturity, either through the vitreousness of the endosperm or grain digestibility because this component represents a large proportion of the silage produced and the energy provision of this food (Ramos et al., 2009).

In this way, the aim of this study was to evaluate the vitreousness of flint and dent endosperms in grain corn hybrids and to study the effect of this feature on the agronomic behavior, nutritional value and ruminal digestibility of the grain harvested in silage maturity.

## Material and methods

Two experiments were performed in the Center-South region of Paraná State. One was in Guarapuava City, located in the experimental field of the Agronomy Department, *Campus* Cedeteg of the Universidade Estadual do Centro Oeste (altitude 1100 m, latitude 25º21'S and longitude 51º30'W) with an average temperature of 19ºC from October to March (Instituto Nacional de Pesquisas Espaciais [INPE], 2015). The second experiment was conducted in Laranjeiras do Sul City, on Rio Almoço farm (700 m above sea level, latitude 25° 33'S and longitude 52° 24'W), which experiences an average temperature of 21ºC from October to March (INPE, 2015).

Twelve commercial corn hybrids were evaluated: six with semi-dent and dent grains (grouped in dent endosperm) and six with semi-flint (grouped in flint endosperm) grains according to the breeders' classification (Table 1). These hybrids were selected because they are cultivated in a large area of maize in the Center-South region of Paraná State, and they were also contained in the recommendations for making plant silage. The hybrids differ in genetic basis, grain types and maturation cycles, thus affecting the cut window and starch accumulation rate in the grains.

**Table 1.** Characteristics of the 12 corn commercial hybrids used to evaluate grain quality in two locations in the Center-South region of Paraná State, Brazil, in the 2012/2013 crop year.

| Hybrid | Genetic | Grain | Company | Grain Color | Cycle |
|---|---|---|---|---|---|
| 2B688Hx | HT | Semi Flint | Dow Agroscience | AM/AL | P |
| AG 8025PRO | HS | Semi Flint | Agroceres/Monsanto | AM/AL | P |
| DKB 245PRO | HS | Semi Flint | Dekalb/Monsanto | AL | P |
| 32R48H | HS | Semi Flint | Pioneer/Dupont | AL | SP |
| 30R50H | HS | Semi Flint | Pioneer/Dupont | AL | P |
| SW3949 TL | HS | Semi Flint | Syngenta | - | HP |
| DKB 240PRO | HS | Dent | Dekalb/Monsanto | AM | P |
| AG 8041PRO | HS | Semi Dent | Agroceres/Monsanto | AM/AL | SP |
| P1630H | HS | Semi Dent | Pioneer/Dupont | AM/AL | HP |
| AS 1572PRO | HS | Dent | Agroeste/Monsanto | AM | P |
| 32R22H | HS | Dent | Pioneer/Dupont | AM | SP |
| 2B587Hx | HS | Semi Dent | Dow Agroscience | AM/AL | P |

HS = single hybrid; HT = triple hybrid; P = early; SP = super early; HP = early hyper; AM = yellow; AL = orange.

The experiments were installed on 2012/10/12 and 2012/10/20 in Guarapuava and Laranjeiras do Sul City, respectively. A stabilized no-till system was used in both areas were conducted. The experimental design was a randomized block with four replications. The plots comprised four rows of five meters each spaced 0.8 m and with a final density of 65,000 plants $ha^{-1}$.

All of the data were obtained from the two central rows of the plot. One line was used for evaluating the grain yield in silage maturity (GYS), ruminal grain digestibility (DEG), neutral insoluble detergent fiber (NDF), acid insoluble detergent fiber (ADF) and crude protein content (CB). To evaluate these characteristics, the plants were harvested when the grains were at the ¾ milk line stage. In the other line all of the plants were harvested to evaluate the productivity of dry grains (PG) with 13% humidity and vitreousness (VIT)

To evaluate the GYS, DEG, NDF, ADF and CP the grains of all plants in silage maturity of one plot row were removed. Afterward grain samples were homogeneously removed and dried in a forced-air oven at 55°C until constant weight. Then, a part of each grain sample was ground in a Wiley mill with a 1 mm sieve. The dry grain yield (GY) was obtained by hand-picking the plant ears in one of the centerlines after physiological maturity and threshing with the aid of a mechanical mixer. Then, the samples were weighed with the humidity corrected to 13%. At the end of this stage a homogeneous sample of dried grains from each experimental plot was also removed to perform the vitreousness analysis.

The vitreousness analysis (VIT) was performed manually according to the methodology described by Dombrink-Kurtzman and Bietz (1993). For this analysis, dry grains harvested after physiological maturity were used. To reduce the effect of the grain position in the cobs, 100 grains from each plot were selected randomly and divided into 10 groups homogeneous in size and shape such that each group contained 10 grains. In each group, a grain was removed at random for the vitreousness analysis. Then, the selected grains were immersed in distilled water for 5 minutes and dried on paper towels. The grains were dissected with a scalpel to remove the pericarp (tubular cells, crossed and epidermal cells), germ and pedicel (seed point); the remaining endosperm was weighed and then divided with a scalpel into farinaceous and vitreous portions. The vitreousness was expressed by the ratio between the vitreous endosperm portion and the total endosperm with the result as a percentage.

The in situ grain ruminal digestibility (DEG) harvested in silage maturity was performed according to the methodology proposed by Pereira et al. (2015). A composite sample was used by the junction of four field replicates of each treatment with a duplicate in each animal. For ruminal incubation 10 x 15 cm nylon 'polyester' bags were used. Each bag received six grams of dried grains at 55°C. The grains were sectioned into four parts to simulate the silage process as described by Pereira et al. (2015).

In the in situ ruminal digestibility evaluations, two lactating Holstein cows were fistulized in the rumen. Each animal received 48 packs: a duplicate sample for each of 12 hybrids for each of the two sites. The animals were adapted for two weeks prior to the analysis with a standard diet of 20% concentrate (18% protein, 72% digestible total nutrients) and 80% corn silage.

The samples were incubated for 24 hours to estimate the grain dry matter digestibility. All bags containing the samples were sealed with an elastic containing a metal ring through which a current was passed to fix all of the bags. A 0.5 kg weight was added at the lower extremity of the current to prevent the movement of the bags in the rumen. After 24 hours of incubation, all bags were removed at the same time and dipped in cold water. Then, they were washed in running water until the water was clear. The bags were dried in a forced-air oven at 55°C until constant weight and then weighed. Then, the ruminal digestibility of dry matter after 24 hours of incubation was determined, and the results were expressed as percentages referring to the initial dry weight.

The insoluble fiber in neutral detergent (NDF) and the insoluble fiber in acid detergent (ADF) of the grains in silage maturity were obtained according to the method described by Van Soest, Robertson, & Lewis (1991). However, the procedure proposed by Souza, Nogueira, Sumi, & Batista (1999) was followed, such that the analysis was performed in test tubes with filtering in a filter crucible with a porous plate. To obtain the NDF, each sample was prepared with 10 mL of urea at 8 mol $L^{-1}$ and 0.2 mL of thermostable alpha amylase with the tubes submerged in a water bath for five minutes at 80 – 90°C.

The protein concentration n in the grains (CP) was determined according to the methodology described by Silva and Queiroz (2006).

The treatment data for all variables analyzed were submitted to homoscedasticity test of the variances by Hartley test at 5%. Then, the averages were submitted to individual variance analyses for each location. The residual variances of each experiment were submitted to the Hartley test at 5%, and after the homoscedasticity was found, a joint variance analysis at 5% probability involving the two locations was performed according to the randomized blocks design using the statistical software GENES (Cruz, 2013).

A comparison between the averages of the flint grain hybrids and the dent grain hybrids was performed (Table 1). This analysis was performed using the statistical software Sisvar at 5% probability by an F test (Ferreira, 2011).

To determine the rate association between the measured traits, the partial correlation coefficient in each characteristic pair was estimated at 5% significance by a t test with the aid of the statistical software GENES (Cruz, 2013).

## Results and discussion

There was a significant effect for 'local', 'hybrid' and 'hybrid x location' for all traits except for crude protein in grains (CP), which was not influenced by the local and even not expressed interaction with the environment (Table 2). Thus, it was evident that the agronomic and bromatological characteristics of the grain corn hybrids are influenced by the cultivation environment, depending on the genetic basis of the genotypes, and exhibit different behavior when submitted to different environmental conditions. Similar results were observed by Domingues et al. (2013), Zsubori et al. (2013) and Mendes et al. (2015), who evaluated corn hybrids of different grain textures in distinct environments, noting differences between sites in term of the expression pattern of agronomic and bromatological characteristics of corn grains. Corona et al. (2006) claimed that the agronomic and nutritional performance of grains is dependent on the genetic background used, which was in accordance with the results obtained in this study.

The aforementioned studies show that the quality of maize grain for animal feed is greatly related to the grain texture and can markedly influence the available energy use. Hence, to study the performance in dent and flint hybrids, a comparison to evaluate grain characteristics was performed, and the results are shown in Table 3. The negative estimates associated with the statistical significance indicate the superiority of the dent hybrids, while positive estimates indicate superiority of the flint hybrids (Table 3).

Compared with PG, involving the groups of hybrids in Guarapuava was significant, with superiority of the flint group (273.94 kg $ha^{-1}$) against the dent group. In Laranjeiras do Sul, the dent group was higher (-421.72 kg $ha^{-1}$) against the flint group when the grain yield was compared (Table 3). It is important to know that the contrasting estimate was low of magnitude for both locations. For PGS there was no significant difference in average between the flint and dent group of grain hybrids for both sites (Table 3), indicating that the grain participation of the different hybrids groups in silage was similar. This fact was also not considered responsible for differences in the dry mass quality in the corn hybrids of different endosperm textures evaluated by Pereira et al. (2012), who harvested samples at the ¾ milk line stage.

The differences related to PG and PGS demonstrate that the dent grain hybrids showed a yield potential similar to the flint grain hybrids. These results are similar to the results obtained by Mendes, Von Pinho, Pereira, Faria Filho, & Souza Filho (2008), who evaluated flint, dent and semi-dent grain hybrid groups and verified a similar average performance between them in terms of yield grain with green mass and dry mass differing in bromatological characteristics. Pereira et al. (2012) compared the grain yield of dent and flint hybrids and found no significant difference between the groups for one evaluation location.

**Table 2.** Analysis of variance for grain yield (GY), grain yield in silage maturity (GYS), vitreousness (VIT), ruminal digestibility of grain (DEG), neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP). 2012/2013 crop year.

| | | Mean Squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Effect | DF | GY | GYS | VIT | DEG | NDF | ADF | CP |
| Block/L | 6 | 284760.54 | 352827.5 | 38.07 | 5.06 | 1.21 | 0.104 | 0.348 |
| Locals (L) | 1 | 50873237.1** | 25971505.6** | 53.97* | 200.94* | 17.61** | 3.04** | 0.358 |
| Hybrids (H) | 11 | 814069.67** | 1524407.9* | 285.95** | 116.19** | 7.22** | 0.921** | 1.26** |
| Dent (D) | 5 | 909851.2** | 1772369.4 | 254.9** | 190.8** | 137.5** | 0.6420** | 1.84** |
| Flint (F) | 5 | 886757.6** | 1572205.9** | 75.33** | 27.6** | 48.43** | 1.35** | 0.893** |
| D *vs.* F | 1 | 148940.6 | 45610.8 | 1494.3** | 185.53** | 17.3* | 0.132 | 0.2118 |
| H x L | 11 | 4174844.1** | 3499263.5** | 37.21** | 25.78** | 4.04** | 0.696** | 0.356 |
| D x L | 5 | 2308442.7** | 3830134.1** | 60.97** | 16.02 | 19.26 | 0.2830 | 0.4358 |
| F x L | 5 | 6301625.7** | 3855412.5** | 16.78 | 38.9** | 7746** | 1.17** | 0.02982 |
| (D *vs.* F)xL | 1 | 2985891.2* | 64165.3 | 20.55* | 28.64* | 0.42 | 0.379 | 1.58 |
| Error | 66 | 343819.9 | 644994.7 | 9.81 | 6.98 | 0.65 | 0.144 | 0.241 |
| General Mean | | 12865 | 10322 | 65.90 | 53.65 | 11.31 | 3.48 | 7.56 |
| Mean D | | 12881 | 10268 | 61.90 | 55.60 | 11.35 | 3.50 | 7.61 |
| Mean F | | 12847 | 10377 | 69.80 | 51.65 | 11.26 | 3.44 | 7.52 |
| CV% | | 4.56 | 7.72 | 4.75 | 4.93 | 7.13 | 10.92 | 6.5 |

** and*: significant at 1% and 5% de probability, respectively by F test.

**Table 3.** Estimates and significance of the contrast between groups of dent and flint corn hybrids, for grain yield (GY), grain yield in silage maturity (GYS), vitreousness (VIT), ruminal digestibility (DEG), neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP). 2012/2013 crop year.

| Variable | Guarapuava | | Laranjeiras do Sul | | Joint Analysis | |
|---|---|---|---|---|---|---|
| | Flint *vs* Dent | *P* contrast | Flint *vs* Dent | *P* contrast | Flint *vs* Dent | *P* contrast |
| | ---kg ha$^{-1}$--- | | ----kg ha$^{-1}$---- | | | |
| GY | 273.94 | 0.02 | -421.72 | 0.00 | - | - |
| GYS | -8.11 | 0.97 | 95.3 | 0.68 | - | - |
| | ---- % ---- | | ----- % ----- | | ---- % ---- | ----- % ----- |
| VIT | 6.97 | 0.00 | 8.82 | 0.00 | - | - |
| DEG | -4.78 | 0.01 | -3.09 | 0.00 | - | - |
| NDF | -1.08 | 0.00 | 0.76 | 0.00 | - | - |
| ADF | -0.20 | 0.07 | 0.05 | 0.63 | - | - |
| CP | - | - | - | - | -0.09 | 0.87 |

($p < 0.05$) contrast significant by F test at 5% probability.

The contrasts between the average vitreousness of flint and dent grain hybrids were significant for the two sites, with higher vitreousness for the group of flint grains, for which the estimate was of high magnitude (Table 3). Other research findings also attribute a higher percentage of vitreous endosperm to flint grain hybrids (Cantarelli et al., 2007; Corona et al., 2006; Majee et al., 2008; Piovesan et al., 2011).

For vitreousness, few techniques can precisely determine as by manual dissection and evaluate the internal grain aspect, accurately quantifying the vitreous and farinaceous endosperm. Evaluating vitreousness using visual scoring is a methodology used often in many

3studies and by many seed companies to classify corn genotypes in relation to the vitreousness standard, but it should be used with reservation because it evaluates only the external grain appearance, which may not be correlated in all cases with reality (Davide et al., 2011).

The contrast between the DEG averages was significant in both locations, and the dent grain hybrid groups were superior to the flint grains group (Table 3), which indicates that hybrids carrying dent grains have better characteristics to make silage with better use of starch, as evidenced by the best digestibility. The results also indicate that the DEG undergoes reduction with increasing vitreousness, thus, farinaceous endosperm hybrids are preferred for making silage.

The higher DEG is very interesting in animal feed as the grain component rich in starch with approximate levels of 65 - 70% (Zsubori et al., 2013). It is the component responsible for adjusting the energy value for the silage, which reduces the necessity of the use of concentrates to balance the animal's diet (Mendes et al., 2008; Piovesan et al., 2011).

Several studies have shown that hybrids with dent grains have lower vitreousness compared with flint grain hybrids (Cantarelli, Fialho, Sousa, Freitas, & Lima, 2007; Piovesan et al., 2011; Zilic et al., 2011; Giuberti et al., 2014). In addition, Ramos, Champion, Poncet, Mizubuti, & Nozière (2009) reported that higher vitreousness reduces the digestibility of dry matter and starch, which is in accordance with our results.

In a study conducted in the United States, Majee et al. (2008) evaluated 33 maize germplasm sources and found a negative correlation between the vitreousness of the grains and the digestibility of dry matter. These authors attributed the results to the negative relationships exerted by the vitreousness on starch digestibility, which is possibly hindered by the proteins present in the vitreous portion of the grain.

Majee et al. (2008) also found a greater reduction in digestibility in genotypes with higher vitreousness associated with late harvest. The reduction in dry matter grain digestibility was also more pronounced in the genotypes with higher vitreousness in a study by Corona et al. (2006), where they were harvested late in comparison with dent grain genotypes. These authors regard this as an undesirable feature for genotypes intended for silage because large areas for silage are currently cultivated, and it is not possible to harvest them all at once. Hence, we may infer that the dent grain hybrids tend to exhibit a more flexible harvest window than flint hybrids.

Studies show that the lower digestibility of flint grains when compared with dent can be attributed to lower enzymatic attack on the starch granules that are surrounded by the dense protein matrix in the vitreous endosperm (Piovesan et al., 2011; Ramos et al., 2009), corroborating the results obtained in this study .

Grain corn is a component that comprises approximately 40% of the dry matter of the silage (Pereira et al., 2012; Domingues et al., 2013; Mendes et al., 2015); thus, variations on the digestibility of this portion will certainly affect the final product digestibility, a factor required for obtaining good results.

The NDF contrast was significant to both locations; however, in Guarapuava, the dent group had a higher average in contrast with Laranjeiras do Sul, where the flint group showed a higher average (Table 3) This demonstrates a difference in behavior when submitted to environmental variations. However, it is worth noting that the estimate of contrast was of low magnitude.

The result of the contrast between the flint and dent grain hybrid groups in terms of ADF content was not significant for both sites evaluated (Table 3). Similar to the results found in this study, Piovesan et al. (2011) observed that semi-dent and flint grain hybrids did not differ in NDF and ADF rates in the grain.

Regarding the fiber content in the corn grains obtained in this study, it can be inferred that it is not a factor that markedly differs in flint and dent grains hybrids. Thus, the fiber levels may not impact the digestibility of the grain.

Similarly, for the CP content the contrast was also not significant (Table 3). Similar to these results, Piovesan et al. (2011) evaluated the flint and semi-dent CP content and found no significant difference between the hybrid groups. These authors suggest that it is not the protein content of the grain that largely affects the digestibility but rather the way in which these proteins are arranged with starch granules.

To measure the degree of association between the characteristics, the partial correlation coefficient was estimated (Table 4). It provides more precise information about the degree of the relationship because it removes the effect of other variables on the association studied.

There was a positive correlation between the dry grain yield (GY) and the grains yield in silage maturity (GYS) (0.57) (Table 4), showing that corn hybrids with high grain yield tend to also exhibit high grain participation in the silage.

**Table 4.** Estimates of the partial correlation between grain yield (GY), grain yield in the silage maturity (GYS), vitreousness (VIT), ruminal digestibility of grain (DEG), neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP). 2012/2013 crop year.

| | GYS | VIT | DEG | NDF | ADF | CP |
|---|---|---|---|---|---|---|
| GY | 0.57* | $0.30^{NS}$ | 0.53★ | $-0.34^{NS}$ | 0.45* | -0.26 |
| GYS | - | $-0.20^{NS}$ | $-0.28^{NS}$ | $-0.02^{NS}$ | $-0.20^{NS}$ | $-0.16^{NS}$ |
| VIT | - | - | -0.46★ | $-0.08^{NS}$ | $0.03^{NS}$ | 0.40★ |
| DEG | - | - | - | $-0.04^{NS}$ | $-0.31^{NS}$ | $0.17^{NS}$ |
| NDF | - | - | - | - | 0.69★ | $-0.33^{NS}$ |
| ADF | - | - | - | - | - | $0.30^{NS}$ |

★: significant at 5% de probability by *t* test; $^{NS}$: Not significant.

The vitreousness correlated positively with the CP content (Table 4), demonstrating that a higher CP content may have a linear relationship with the vitreous endosperm proportion; however, the index correlation was of a low magnitude (0.40). This behavior can be related to the definition of vitreousness, which expresses the vitreous grain proportion and is characterized by having dense protein matrix surrounding the starch granules; thus, if there is an increase in vitreousness, an increase in protein content can occur (Majee et al., 2008; Piovesan et al., 2011).

Negative correlations of vitreousness with DEG (Table 4) allow us to infer that hybrid grains with lower vitreousness will result in a forage with better digestibility, making the production process more efficient. Thus, the vitreousness can support and be used as a digestibility indicator of the silage genotypes. Zilic et al. (2011) and Majee et al. (2008) also had negative correlation coefficients between vitreousness grain and grain digestibility. Majee et al. (2008) attributed these results to a lower starch digestibility in high-vitreousness situations.

Davide et al. (2011) evaluated the vitreousness through visual grain scoring and found no significant correlation between vitreousness and the degradability of grain corn hybrids with different grain textures. The authors attributed these results to the inaccuracy of evaluating vitreousness by the visual appearance of the grain, reinforcing the importance of determining vitreousness manually and providing results close to reality.

Zillic et al. (2011) found a positive correlation between zein and vitreousness amount, which justifies the cause of the lower digestibility of the vitreous portion of the grains. These results show that for the protein matrix, a component which complicates the ruminal starch digestion, hybrids with dent endosperm must be chosen to make silage because they have a lower vitreous proportion in the grain. Vitreousness is highlighted as an important parameter to be considered from the inferences of Szasz et al. (2007), who claimed that corn hybrids differ minimally in starch content in the grains while there are large differences in vitreousness.

Corona et al. (2006) and Cantarelli et al. (2007) verified the higher digestibility coefficient of grain dry matter in dent genotypes compared with flint grains in corn hybrids. These reports are valuable for breeding programs, where the focus is the production of high quality hybrids for silage, and also to farmers who use directly the raw material.

From the evidence of other previously described research and from the consistent results in this study where the group of dent hybrids exhibited better feed performance, it is clear that the studies are driving a change in the use of hybrids; however, currently in the Brazil Paraná State market, only 9.0% of the offered hybrids

(Vieira et al., 2011) have dent grains. Therefore, further studies to produce hybrids with such features by the breeders and also regionalized assessments are necessary.

There was no significant correlation between the NDF and ADF levels with other important agronomic characteristics or grain quality (Table 4), demonstrating that the grain fiber content was not responsible for major changes in grain quality in this situation, and the changes were more related to vitreousness. The low correlation of the fiber content in corn grain yield characteristics and quality of maize grain demonstrate the importance of using grain digestibility and vitreousness to select hybrids for utilization in animal feed.

## Conclusion

The effect of the cultivation environment can be characterized by hybrid x location interaction under the production characteristics and quality of corn grain hybrids for forage production.

The group of dent hybrids exhibited better ruminal digestibility of the grains associated with lower vitreousness versus the group of flint hybrids.

A negative correlation exists between vitreousness and the ruminal digestibility of grain, and the vitreousness can be a criterion for selecting genotypes for forage production.

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