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Effect of advancing maturity stages of corn for silage on chemical characterization, digestibility and production costs

Efeito do avanço do estádio de maturação do milho para silagem sobre a caracterização bromatológica, digestibilidade e custos de produção

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Highlights

The advance of the stages of the corn plants increases the production of dry biomass.
Lower costs at more advanced stages do not justify harvesting for silage production.
Grain-free plants at younger stages showed better ruminal disappearance of dry matter.

Abstract

The goal of the present study was to evaluate the biomass and grain yield, the morphological and chemical composition, production costs and the ruminal disappearance of the whole corn plant and grain-free corn plant harvested at different reproductive stages. The experimental design was completely randomized, consisting of six treatments, where each treatment corresponded to a stage of corn maturity. The advance of plant cycle promoted an increase in dry biomass and grain yields per unit area, reducing production costs. Higher participation of grains and lower participation of structural components promoted a reduction in NDF and ADF, with the lowest values in dough grain (R4) and dent grain (R5) stages. The advancement of stages promoted an increase in production and a reduction in costs, but significantly reduced the quality of

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grain-free plants, increasing the NDF, ADF and ADL; but R4 and R5 presented NDFd of 84.80 % and 82.79 %, respectively, showing to be a good quality fiber. R4 stage had the highest rumen disappearance values after 24 and 48 hours of incubation. Based on chemical data, ruminal disappearance, ruminal degradation kinetics of the whole corn plant and without grains, the R4 stage of the evaluated hybrid is the stage at which the plant had the best quality, representing the appropriate stage to harvest the material for making silage, aiming at the production of a silage with good chemical quality.
Key words: Chemical composition. NDF digestibility. Phenological cycle. Physical composition. Plant without grains.

Resumo

O objetivo do presente trabalho foi avaliar a produção de biomassa e de grãos, a composição morfo-bromatológica, os custos de produção e o desaparecimento ruminal da planta de milho inteira e sem grãos, colhidas em diferentes estádios reprodutivos. O delineamento experimental foi inteiramente casualizado, composto por seis tratamentos, onde cada tratamento correspondeu a um estádio de maturação do milho. A evolução do ciclo das plantas promoveu aumento na produção de biomassa seca e de grãos por unidade de área, proporcionando redução nos custos de produção. A maior participação de grãos e a menor de componentes estruturais promoveu redução nos teores de FDN e FDA, tendo os menores valores nos estádios de grão farináceo (R4) e grão duro (R5). O avanço dos estádios promoveu aumento na produção e redução nos custos, porém reduziu significativamente a qualidade da planta sem grãos, elevando os teores de FDN, FDA e LDA, porém R4 e R5 obtiveram FDNd de 84,80 % e 82,79 % respectivamente, mostrando ainda ser uma fibra de boa qualidade, o estádio R4 possuiu os maiores valores de desaparecimento ruminal em 24 e 48 horas de incubação. Embasado nos dados bromatológicos, nos custos de produção, desaparecimento ruminal, cinética da degradação ruminal da planta de milho inteira e sem grãos o estádio R4 do híbrido avaliado é o estádio em que a planta possuiu melhor qualidade, sendo este o momento adequado para realizar a colheita do material para confecção de silagem, visando a produção de uma silagem com boa qualidade bromatológica.
Palavras-chave: Ciclo fenológico. Composição física. Composição química. Digestibilidade da FDN. Planta sem grãos.

Introduction

Intensification of livestock production in Brazil has been experiencing vertical growth in recent years (L. B. Pereira et al., 2017). One of the pillars of this increase is the production of roughage of high quality, in this context, corn as silage is an excellent alternative.

Corn plant is considered a reference for silage production, due to its quantitative characteristics, ease of fermentation related to the adequate content of soluble carbohydrates, low buffering capacity, good acceptance by animals and high energy value (Zopollatto et al., 2009; C. O. Silva & Machado, 2014; Neumann, Poczynek, Leão, Figueira, & Souza, 2018). However, these characteristics can be modified and directly influence the final quality of the silage, with the advancement of maturity stages of plants (Zopollatto et al., 2009; Skonieski et al., 2014).

With the advance in reproductive phenological cycle in corn crop, there is an increase in biomass production per unit area, as well as increase in DM and non-fiber carbohydrate contents in the resulting silage, due to the deposition of starch in the ear, promoting dilution of the NDF content (Oba & Allen, 2000; Santos, Amaral, Carpejan, & Junges, 2014). In contrast, with advancing maturity, the tendency is for reductions in plant digestibility, given the unavailability of some constituents of the fiber fraction and an increase in others, such as lignin (Sena et al., 2014).

In this context, harvesting the plants at the right stage aims to achieve a balance between maximum productivity and good quality of the material (Oliveira et al., 2013).

The objective of the present study was to evaluate the biomass production, morphological composition, chemical composition, production costs, ruminal disappearance and the ruminal degradation kinetics of the whole corn plant and grain free corn plant harvested at different maturity stages for silage production.

Material and Methods

The experiment was conducted at the Núcleo de Produção Animal (NUPRAN) along with the Masters Course in Agronomy, Plant Production Area, Agrarian and Environmental Sciences Sector, Universidade Estadual do Centro-Oeste (UNICENTRO), located in Guarapuava, State of Paraná. The climate of the region is humid subtropical mesothermal (Cfb), without dry season, with cool summers and moderate winter. According to the Köppen classification, Guarapuava is at an altitude of approximately 1.100 m.

Figure 1 illustrates the mean maximum and minimum temperatures (ºC) and the monthly sum of rainfall, in mm, during the experimental period.

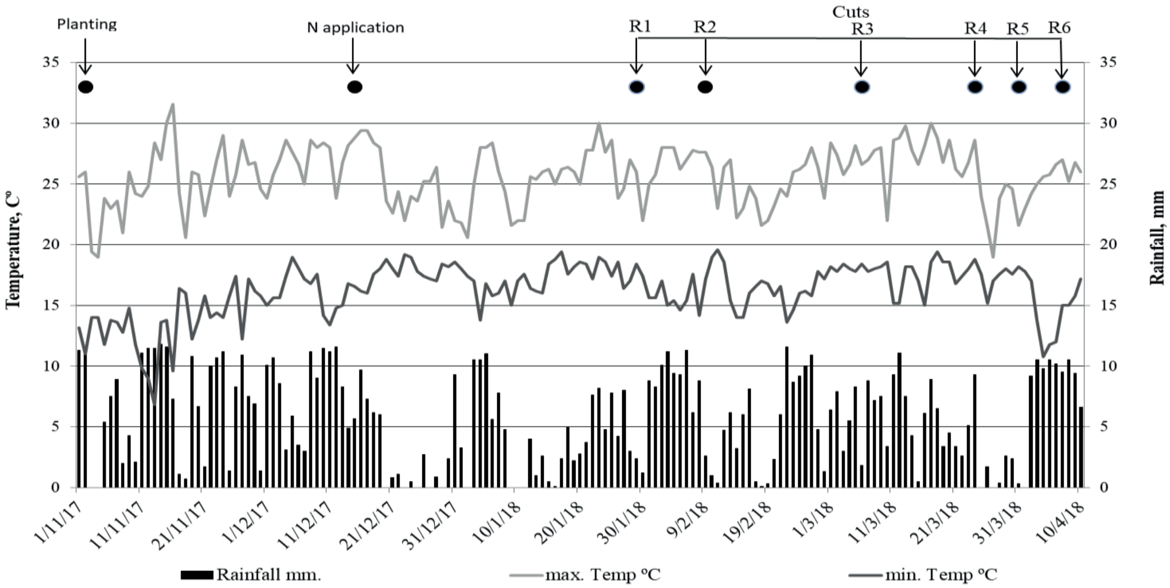

Figure 1. Mean maximum and minimum temperatures (ºC) and the monthly sum of rainfall, in mm, during the experimental period.

Soil in the experimental area is classified as Latossolo Bruno Típico. The area where corn was grown has been used in recent years with annual cycle pastures in the winter season, and corn crops in the summer season, receiving phosphorus and potassium fertilization, according to recommendations of Moreira (2017).

Crop was planted on November 2, 2017, with the early cycle hybrid Maximus Viptera 3 (Syngenta®), a hybrid for grain and silage production, with hard kernels. This hybrid is resistant to glyphosate and was grown under no-till system, using 0.80 m row spacing, 0.04 m sowing depth and distribution of five seeds per linear meter, aiming at a final population of 62,500 plants ha^{-1}.

The basal fertilization consisted of the application of 500 kg ha^{-1} 12-31-17 (N-P_2O_5-K_2O). Topdressing included 500 kg ha^{-1} commercial fertilizer Yara Bela Plus®, with formulation of 27 % N, 5 % Ca, 3.7 % S, at the vegetative stage V5. Management of the area before sowing was based on the preventive control of weeds and insects using glyphosate-based herbicide (commercial product Roundup WG®: 2 kg ha^{-1}) and Imidacloprid + Beta-cyfluthrin (commercial product). Connect®: 0.75 L ha^{-1} plus mineral oil (commercial product Nimbus®: 0.5 L ha^{-1}). Post-emergence control was carried out with Atrazine + Simazine (commercial product Primatop®: 3 L ha^{-1}) and Nicosulfuron (commercial product Nortox®: 0.7 L ha^{-1}) plus Alpha-cypermethrin (commercial product Immunit®: 0.18 L ha^{-1}), depending on the need of the crop, respectively.

The evaluated treatments consisted of harvesting corn plants at six distinct reproductive phases of corn plants, as determined by Ritchie, Hanway and Benson (2003): R1 - beginning of grain filling, 88 days after emergence (DAE); R2 - milky grain, 99 DAE; R3 - pasty grain, 124 DAE; R4 - dough grain, 142 DAE; R5 - hard grain, 149 DAE and R6 - grain at physiological maturity, 156 DAE, for evaluation of plant dry matter accumulation and participation of structural components in the physical composition of the plant. The experimental design was completely randomized with six treatments and five repetitions, where each repetition was represented by a plot of 6.4 m x 6 m (38.4 m^2 - 8 planting rows); the useful area of the plot was 4.8 m x 5 m (24 m^2 - 6 planting rows). In order to harvest the crop at the right stage, continuous monitoring was carried out at two-day intervals regarding the advance of the reproductive stages of corn.

In each evaluation, 20 whole plants were harvested in the useful area of each plot, manually cut at 20 cm from the ground, using the triple pairing technique, where the adoption of this practice allowed to determine, besides the content of dry matter, the percent physical composition of anatomical structures of the plant by separation into the components: stem, leaves, bracts plus cob and grains.

At the time of each evaluation, analyses were performed for plant height (m), first ear height (m), number of dry leaves, fresh and dry biomass yield and grain yield (kg ha^{-1}). Fresh biomass, dry biomass and grain yields were determined by relating individual weight of plants in each plot and the plant population per unit area.

Upon harvesting corn plots at different maturity stages, samples of whole plants and grain-free plants, which only had their grains manually removed, and samples of structural components (stem, leaf, bracts plus cob and grains) from each treatment were obtained in a homogeneous and representative manner, weighed and pre-dried in a forced air oven at 55 ºC. After drying for 72 hours, they were weighed again to determine the dry matter (DM) content, according to Association of Official Analytical Chemists [AOAC] (1995). Afterwards, samples were ground in a Wiley mill, with a 1 mm mesh screen.

In the pre-dried samples of whole plant and grain-free plants, determinations were made for neutral detergent fiber (NDF), according to Van Soest, Robertson and Lewis (1991), using thermostable α amylase (Termamyl 120L, Novozymes Latin America Ltda.), acid detergent fiber (ADF) according to Goering and Van Soest (1970) and acid detergent lignin (ADL), according to D. J. Silva and Queiroz (2009).

Contents of total digestible nutrients (TDN,%) were obtained using the equation [TDN,% = 87.84 - (0.70 x ADF)] suggested by Bolsen, Ashbell and Weinberg (1996). Concentrations of non-fiber carbohydrates plus ether extract (NFC + EE) were calculated according to the equation of Henriques, Silva, Detmann, Vasquez and Pereira (2007), [NFC + EE = 100 - (CP + MM + NDF)]. Digestible neutral detergent fiber was obtained through the equation [NDFd, % NDF = 100 - (((2.4 x LIG) ÷ NDF) x 100)] according to Neumann et al. (2017), the relative feed value (RFV) was calculated according to the equation RFV = ((DMD * DMIBW%) ÷ 1.29))], where DMD: dry matter digestibility and DMIBW%: dry matter intake expressed as a percentage of body weight (Bolsen et al., 1996).

The economic analysis was performed through the cost of planting and managing the crop (R\$ ha^{-1}) on the average dry matter production expressed in kg of DM ha^{-1}. For calculation, the fixed costs of the property were not considered. Costs of seeds already treated with insecticide, fertilizers, herbicides for pre-planting desiccation, selective post-emergence herbicide, insecticide and mineral oil were accounted at the time of purchase. Therefore, the costs related to machine hours and daily employee hours were obtained from data provided by the ABC foundation. These calculations were made after all the crop management. From the values obtained in the ruminal disappearance of dry matter of the whole plant incubated for 72 hours and the production costs, it was possible to determine the volume of digestible dry matter as well as the cost of kilogram of digestible DM.

The ruminal disappearance of dry matter (RDDM) and the ruminal degradability of dry matter of the whole corn plant without grains, were estimated by the in situ technique using nylon bags measuring 12 cm x 8 cm and with pores of 40 to 60 μm, containing approximately 5 g on a dry matter basis of each material, ground to 1 mm, for later incubation in the rumen (Nocek, 1988). For RDDM, incubation times were set at 24h; 48h and 72 hours, and for ruminal degradability of dry matter, the incubation times were 0h; 2h; 4h; 6h; 12h; 24h; 36h; 48h; 72h and 96 hours in reverse chronological order, always with care so that each animal received all samples of all treatments.

Samples were taken from the rumen, immersed in water with ice, in order to cease the activity of ruminal microorganisms, and subsequently properly washed, dried in a forced air oven at 55 °C for 72 hours for later weighing and determination of the amount of degraded material.

Results on ruminal degradability of dry matter at different incubation times were fit by non-linear regression using the Gauss-Newton method, with estimation of non-linear parameters “a”, “b” and “c”. As it is a first-order asymptotic growth model, which was repaired by subdividing the value of the asymptote in two fractions, “a” and “b”, the dry matter degradation rate was calculated using the equation proposed by Ørskov and McDonald (1979):

$$DegDM = a + b(1 - e^{-ct})$$

Where,

DegDM = Fraction degraded at time “t” (%);

a = Soluble fraction (%);

b = Potentially degradable fraction (%);

c = Rate of degradation of fraction “b” (% $hour^{-1}$);

t = Time (hours).

Effective degradability (ED) of dry matter in the rumen was calculated using the model suggested by Ørskov and McDonald (1979):

$$ED_{DM} = a + b \times [c/(c+k)]$$

Where,

k = Rate of ruminal passage, with 5 % corresponding to average intake;

The experimental procedures were previously submitted to the Committee for Ethics in Animal Experimentation (CEUA/UNICENTRO), and approved for execution under the number 022/2018 of August 3, 2018. The two cattle used had 60 months old, average body weight of 750 kg, with ruminal fistula.

Data were subjected to Shapiro-Wilk and Bartlett tests to check the assumptions of normality and homogeneity of variance, respectively. Once these assumptions were met, the F-test at 5% confidence probability was applied using the Analysis of Variance (ANOVA) followed by Tukey’s test for the comparison of multiple means at 5 % significance using the SAS software (Statistical Analysis System Institute [SAS], 1993).

The analysis of each variable followed the statistical model: $Y_{ij} = \mu + T_i + E_{ij}$; where: Y_{ij} = dependent variable; μ = Overall mean of all observations; T_i = effect of treatment of order “i”; and E_{ij} = Residual random effect.

Results and Discussion

Plant height and first ear height were not different (P>0.05) between plant maturity stages (Table 1). Oliveira et al. (2013) evaluated the corn plant at different maturity stages and also found no differences for these parameters. Similarity in plant height and first ear height during maturity stages is normal, since when the plant reaches these stages its growth is already stagnant (Ritchie et al., 2003).

Table 1
Productive agronomic characterization of corn plants harvested at different maturity stages

Parameters	Maturity stages						CV	*P*
	R1	R2	R3	R4	R5	R6	(%)	
Plant height, m	2.18	2.17	2.14	2.17	2.15	2.15	1.35	0.3649
Ear height, m	1.23	1.25	1.25	1.21	1.22	1.25	3.38	0.3318
Dry leaves, number	0 d	0 d	1 d	3 c	5 b	9 a	13.81	0.0001
Green leaves, number	15 a	14 b	14 b	11 c	9 d	5 e	4.04	0.0001
GP, kg ha^{-1}	29 d	503 d	7465 c	11987 b	12259 b	14740 a	10.26	0.0001
GBP, kg ha^{-1}	61514 c	80139 a	82847 a	67518 b	70545 b	66391 bc	3.54	0.0001
DBP, kg ha^{-1}	9261 e	13347 d	19548 c	21528 c	25953 b	30135 a	7.33	0.0001
DM Cost, R$	0.32 a	0.23 b	0.15 c	0.14 c	0.12 d	0.10 d	6.26	0.0001
DDBP, Kg ha^{-1}	4256 d	6854 c	11117 b	12710 b	16327 a	17792 a	7.47	0.0001
CDDM, R$	0.71 a	0.44 b	0.27 c	0.24 c	0.18 d	0.17 d	5.92	0.0001

Mean values followed by different lowercase letters, in the same row, are significantly different by Tukey's test, at 5%. m: meter; GP: Grain production; GBP: Green biomass production; DBP: Dry biomass production; DDBP: Digestible dry biomass production; CDDM: Cost digestible dry matter.

As the maturity stages progressed, the number of dried leaves gradually increased from 0 at R1 to 9 at R6, while green leaves reduced; but at R5, 64.28 % leaves were still green. Plants that have the characteristic of remaining green with the advance of maturity stages have a stronger stay-green, promoting a wider cutting window, besides favoring grain filling and maintaining greater stability in NDF digestion (Neumann et al., 2018).

Values for the production of green biomass, dry biomass, digestible biomass, grains and the costs of Kg of DM and digestible DM were significantly different ($P < 0.05$) between the maturity stages. The highest values of green biomass were found in the early stages (R2 with 80.139 kg ha^{-1} and R3 with 82.847 kg ha^{-1}), this behavior is due to the onset of grain filling (Magalhães & Drães, 2006).

For dry biomass production, the R6 stage had the highest average, with 30.135 kg ha^{-1}, whereas, for the production of digestible dry biomass, the stages R5 and R6 had the highest averages, with 16.327 and 17.792 kg ha^{-1} respectively. It is noteworthy that, with advancing maturity stages, the production of dry biomass and digestible biomass increased, as well as the production of grains, presenting the highest average at R6, with 14.740 kg ha^{-1}.

Similar behavior was reported by A. X. Souza et al. (2011), who evaluated the corn plant at R4, R5 and R6, presenting 19.978, 21.489 and 22.032 kg ha^{-1} dry biomass, respectively. According to J. L. A. R. Pereira, Von Pinho, Souza, Santos and Fonseca (2011) the progression of the plant cycle promotes increases in DM production.

According to Oliveira et al. (2013) and Marafon et al. (2015), corn plants destined for silage production should be harvested in more advanced maturity stages; in this way its potential for production of dry biomass and grains is exploited to the maximum.

Costs of production of dry biomass and digestible dry biomass tended to decline with advancing maturity stages (Table 1). When evaluating the dry biomass production of corn plants under different nitrogen doses, Neumann et al. (2019) obtained a production cost of 0.36 cents Kg DM^{-1} when producing 18.657 Kg DM ha^{-1}, however, when production increased to 19.561 Kg DM ha^{-1}, the cost reduced to 0.33 cents Kg DM^{-1}. L. A. Souza et al. (2020) analyzed the production of corn plants harvested at different heights, and reported that the increase in cutting height reduced the volume produced, implying an increase in production costs.

Artuzo, Foguesatto, Souza and Silva (2018) report that, the higher the production, the lower the costs, due to the dilution effect. This inference justifies the behavior of the costs mentioned above and those obtained in the present study (Table 1).

As maturity stages advanced, DM content of all structural components of the plant, the whole plant and the grain-free plant increased (Table 2). These results are in agreement with those presented by Oliveira et al. (2013), who evaluated corn plants between stages R1 and R5.

Table 2

Mean dry matter contents of the whole plant, grain-free plant and the structural components and percentage participation of the components in the structure of corn plant harvested at different maturity stages

Components	Maturity stages						CV (%)	*P*
	R1	R2	R3	R4	R5	R6		
				DM content, %				
Stem	17.27 d	17.57 d	19.30 c	20.28 b	20.87 a	21.26 a	1.11	0.0001
Leaves	18.40 f	21.04 e	22.95 d	26.02 c	29.26 b	36.09 a	2.84	0.0001
Bracts+Cob	13.85 f	16.75 e	28.35 d	32.51 c	38.18 b	43.72 a	1.87	0.0001
Grains	7.01 e	11.46 d	47.77 c	65.14 b	66.53 b	69.00 a	2.41	0.0001
Whole plant	15.06 e	16.65 e	23.60 d	31.84 c	36.81 b	45.44 a	7.31	0.0001
Grain-free plant	14.05 d	15.65 d	22.22 c	24.58 b	26.05 b	30.47 a	3.87	0.0001
				Physical composition of the plant, % DM				
Stem	38.55 a	35.92 b	20.36 c	16.07 d	15.31 de	13.84 e	3.64	0.0001
Leaves	41.38 a	34.71 b	19.10 c	16.81 d	16.80 d	15.20 d	3.73	0.0001
Bracts+Cob	19.68 b	25.28 a	24.49 a	18.31 bc	18.62 bc	16.96 c	5.10	0.0001
Grains	0.40 d	4.09 d	36.05 c	48.81 b	49.27 b	54.00 a	6.17	0.0001

Mean values followed by different lowercase letters, in the same row, are significantly different by Tukey's test, at 5%.

As in the present study, the same authors observed that the stem presented less variation in DM content, from 20.8% at R1 to 21.2% at R5, showing that this component has a high capacity to store water, which can help in the maintenance of plant hydration. For leaves, the DM increased from 23.5 % to 27.8 %, for bracts plus cob, from 13.8 % to 29.4%, for grains at R2, from 19.9 % to 49.6 % and for the whole plant, from 17.9 % to 31.6 %. These alterations in the DM contents of the plant components, along development described above, and those found in the present study, are the effect of changes occurring in the morphological composition, and the translocation of photoassimilates.

The participation of stem, leaf, bract plus cobs in the plant structure decreased from R1 to R6, so the participation of grains increased from 0.40 % at R1 to 54% at R6 (Table 2). Likewise, M. P. Souza et al. (2017) observed reductions for the stem, leaves, bracts plus cob and increase for the grains along the development of the plants. Factori, Costa, Meirelles, Silveira and Silva (2014) evaluated the corn plant at the milky, beginning of physiological maturity and physiological maturity stages and obtained grain participation of 42 %, 44 % and 46 %, respectively.

Dilution in the participation of stem and bracts in the plant structure when destined for silage production is advantageous, as these components have a high percentage of poorly degradable cell wall compounds (J. L. A. R. Pereira et al., 2012; Neumann, Mühlbach, Nörnberg, Restle, and Ost, 2007), so a leaf reduction as presented above is undesirable, as this component has low concentrations of fiber compounds and has high degradability (J. L. A. R. Pereira et al., 2012).

Nevertheless, the increase in grain participation obtained in the present study and reported by other authors is considered by Mendes, Gabriel, Faria, Rossi and Possatto (2015) as desirable, since they give higher energy value to the silage produced (Marafon et al., 2015), but it is noteworthy that one should not only consider this parameter to characterize the harvesting time as appropriate or not for silage production.

Table 3 lists the chemical composition of the whole plant and the grain-free plant harvested at different maturity stages. There was a difference ($P <0.05$) between the stages, but with different behaviors.

The NDF of the whole plant presented the highest values at R1 and R2 (72.29 % and 70.32 %), later these values decreased, whereas for grain-free plant, higher values occurred at R5 and R6 (80.69 % and 81.24 %). For ADF, the whole plant and the grain-free plant presented a reduction until the R4 and R3 stages, respectively, with a subsequent increase. Pôssas et al. (2015) evaluated corn plant at maturity stages R3, R4 and R5, and verified NDF values of 56.0 %, 53.59 % and 54.16 % and ADF of 30.75 %, 29.84 % and 27.62 % respectively.

Values of TDN presented a behavior opposite to that of ADF for the whole plant and grain-free plant; this because it is calculated based on ADF values as described by Bolsen et al. (1996), but in agreement with Mertens (1994), who infers that increasing fiber compounds reduces the concentration of digestible nutrients in food.

The behavior of fiber components of the whole plant (Table 3) is due to the increase in grain participation (Table 2). According to Buso, Machado, Ribeiro and Silva (2018), the higher grain participation provides increase in starch concentrations, causing dilutions in the NDF content of plants at advanced maturity stages.

Values of ADL were higher at R6, with 6.20 % for the whole plant and 7.27 % for grain-free plant. The advance of plant cycle promoted lignification of its structures, a behavior that requires special attention, since lignin is a determining component in forage quality, implying limitations in nutrient digestibility (Wolf, Coors, Albrecht, Undersander, & Carter, 1993).

Table 3
Chemical composition of whole corn plants and grain-free corn plants harvested at different maturity stages

Parameters	Maturity stages						CV (%)	P
	R1	R2	R3	R4	R5	R6		
NDF, % DM								
Whole plant	72.29 a	70.32 a	57.10 b	56.46 b	56.45 b	55.66 b	1.69	0.0001
Grain-free plant	74.21 c	70.90 d	75.60 b	76.20 b	80.69 a	81.24 a	0.59	0.0001
ADF, % DM								
Whole plant	47.16 a	46.01 b	36.51 c	31.98 f	32.93 e	33.69 d	0.92	0.0001
Grain-free plant	48.16 b	47.01 c	45.51 d	47.78 bc	49.22 a	50.04 a	1.01	0.0001
ADL, % DM								
Whole plant	3.04 d	3.35 d	3.49 d	4.62 c	5.55 b	6.20 a	5.94	0.0001
Grain-free plant	3.72 d	3.68 d	4.26 dc	4.83 c	5.79 b	7.27 a	6.21	0.0001
NDFd, % NDF								
Whole plant	89.89 a	88.55 a	85.34 b	80.36 c	76.40 d	73.25 e	1.33	0.0001
Grain-free plant	87.95 a	87.54 a	86.46 ab	84.80 b	82.79 c	78.51 d	1.16	0.0001
% TDN, DM								
Whole plant	54.83 f	55.64 e	62.28 d	65.46 a	64.79 b	64.26 c	0.40	0.0001
Grain-free plant	54.48 c	55.29 b	55.98 a	54.39 c	53.39 d	52.81 d	0.63	0.0001
NFC+EE, % DM								
Whole plant	16.20 b	17.20 b	30.69 a	31.69 a	30.23 a	31.48 a	3.82	0.0001
Grain-free plant	14.28 b	16.62 a	16.32 a	15.86 a	11.59 c	11.05 c	3.49	0.0001
RFV, index								
Whole plant	67 c	70 c	99 b	105 a	104 a	105 a	1.71	0.0001
Grain-free plant	65 b	69 a	66 b	63 c	58 d	57 e	0.76	0.0001

Mean values followed by different lowercase letters, in the same row, are significantly different by Tukey's test, at 5%.

The content of NDFd is closely related to ADL; it can be seen in Table 3 that the values of NDFd decreased with increasing ADL, but at maturity stages R5 and R6, values were still high, with 76.40 % and 73.25 % for whole plant and 82.79 % and 78.51 % for grain-free plant, respectively.

NDF digestibility is related to the degradation of the fiber portion of the food and its rate of passage, that is, when these values are high, the rate of passage is higher, promoting a reduction in physical fill of the rumen and increased intake (Oba & Allen, 2000), evidencing that if the harvesting of this material occurs at more advanced stages it will have a good use of its fiber.

Whole plant NFC + EE values were higher from R3, which did not differ (P> 0.05) from subsequent stages, while for grain-free plants, the highest values were concentrated at R2, R3 and R4 (16.62 %, 16.32 % and 15.86 %). For the whole plant RFV, higher values were obtained at R4, R5 and R6 stages, which did not differ (P> 0.05), whereas the grain-free plant presented a decreasing linear behavior with advancing maturity stages.

Marafon et al. (2015) attributed the increase in RFV at advanced maturity stages to higher concentration of grains. Buso et al. (2018) used the same argument to explain the increase in non-fiber carbohydrate concentration at these stages; according to these authors, grain is a starch-rich and low-fiber component.

Data in Table 3 also indicate that the plant without grains gradually lost its quality with the advance of maturity stages, which is a consequence of the thickening and lignification of the cell wall (Velásquez et al., 2010). However, even with these events, it is noted that the more advanced stages showed high contents of NDF and NFC + EE, giving this hybrid a good quality fiber.

Table 4 lists parameters of ruminal disappearance of the whole plant and the grain-free plant harvested at different maturity stages, which showed a difference (P <0.05) between the stages.

Table 4
Ruminal disappearance of whole corn plants and grain-free corn plants harvested at different maturity stages, and incubated for 24, 48 and 72 hours

Parameters	Maturity stages						CV (%)	*P*
	R1	R2	R3	R4	R5	R6		
Ruminal disappearance 24 hours^{-1}, % DM								
Whole plant	34.17 d	39.63 c	46.12 a	47.36 a	43.41 b	38.40 c	1.81	0.0001
Grain-free plant	31.17 c	32.76 b	36.63 a	28.22 d	26.26 e	21.80 f	2.05	0.0001
Ruminal disappearance 48 hours^{-1}, % DM								
Whole plant	43.16 d	44.88 d	55.67 bc	57.42 ab	58.08 a	54.81c	1.71	0.0001
Grain-free plant	40.15 b	38.41 c	41.88 a	42.01 a	34.48 d	32.60 e	1.76	0.0001
Ruminal disappearance 72 hours^{-1}, % DM								
Whole plant	45.96 e	51.36 d	56.87 c	59.04 b	62.91 a	59.04 b	1.40	0.0001
Grain-free plant	42.96 c	47.94 b	48.36 b	50.30 a	38.03 d	35.05 e	1.69	0.0001

Mean values followed by different lowercase letters, in the same row, are significantly different by Tukey's test, at 5%.

Within 24 hours of incubation, the whole plant and the grain-free plant had an increase in ruminal disappearance to the R3 stage (46.12 % and 36.63 %, respectively). With 48 hours of incubation, the whole plant harvested at stages R4 and R5 proved to be superior to the others, but did not differ from each other (57.42 % and 58.08 % respectively). The grain-free plant incubated for 48 hours, on the other hand, presented the highest averages in stages R3 and R4, which also did not differ from each other (41.88 % and 42.01 % respectively). In 72 hours of incubation, the stages R5 and R4 presented the highest values of ruminal disappearance of DM for whole plant and the grain-free plant, respectively (62.91 % and 50.30 %).

The behavior of ruminal disappearance of DM from the whole plant and grain-free plant in 24 hours of incubation until R3 is a reflection of the advance of maturity stages, which reduces the content of soluble carbohydrates and increases the levels of fiber compounds of low digestion (Bezerra et al., 2015).

Higher values of ruminal disappearance of DM from the whole plant, as well as from the grain-free plant between stages R4 and R5, are due to the lower participation of stem and bracts plus cob in the plant structure (Table 2), which is positive, due the high concentration of fiber compounds with low digestion in these components (J. L. A. R. Pereira et al., 2012), and the low content of LDA and high content of NDF (Table 3).

When analyzing Table 5, it is possible to notice differences (P <0.05) between maturity stages for the whole corn plant and grain-free plant in every analyzed variable.

Fractions A and B of the whole corn plant obtained higher and lower levels at R3 stage among the evaluated stages (33.18 % and 27.27 % respectively), and fraction C presented the highest amounts of $hour^{-1}$ degradation in stages R3, R4 and R6, which did not differ from each other (0.0294 %, 0.0287 % and 0.0289 % respectively). The potentially degradable fraction showed to be higher at stages R2 and R5 (76.53 % and 77.35 % respectively), but did not differ at stages R1 (65.47 %), R4 (69.57 %) and R6 (67.33 %), so that the indigestible portion presented an opposite effect, in which R2 and R5 showed the lowest values (23.47 % and 22.65 % respectively). Effective degradability, when considering 5 % of the passing $hour^{-1}$ rate, was higher att stage R3, with 43.27 %, followed by R4 and R5, with 40.11 % and 38.72%, respectively.

Table 5

Ruminal degradation kinetics of whole corn plants and grain-free plants harvested at different maturity stages

Parameters	Maturity stages						CV (%)	*P*
	R1	R2	R3	R4	R5	R6		
Whole plant								
a, %	23.37 c	27.88 b	33.18 a	23.18 c	24.53 c	19.46 d	3.05	0.0001
b, %	42.09 a	48.64 a	27.27 b	46.39 a	52.81 a	47.86 a	13.833	0.0020
c, % h^{-1}	0.0142 c	0.0096 d	0.0294 a	0.0287 a	0.0184 b	0.0289 a	5.96	0.0001
PD	65.47 ab	76.53 a	60.46 b	69.57 ab	77.35 a	67.33 ab	7.94	0.0137
U	34.53 ab	23.47 b	39.54 a	30.43 ab	22.65 b	32.67 ab	18.07	0.0137
ED, 5% h^{-1}	32.68 e	35.66 d	43.27 a	40.11 b	38.72 bc	36.98 bd	2.47	0.0001
Grain-free plant								
a, %	21.15 c	24.88 a	22.68 b	17.79 d	18.04 d	17.04 e	1.49	0.0001
b, %	36.08 c	48.64 b	28.63 c	69.08 a	32.19 c	31.98 c	3.94	0.0001
c, % h^{-1}	0.0134 ab	0.0096 bc	0.0168 a	0.0080 c	0.0135 bc	0.0091 c	13.89	0.0001
PD	57.23 c	73.53 b	51.31 c	86.88 a	50.22 c	49.02 c	6.46	0.0001
U	42.77 a	26.47 b	48.69 a	13.12 c	49.78 a	50.98 a	10.26	0.0001
ED, 5% h^{-1}	28.72 c	32.66 a	29.87 b	27.26 d	24.84 e	21.84 f	1.23	0.0001

Mean values followed by different lowercase letters, in the same row, are significantly different by Tukey's test, at 5%.

For grain-free plant, fraction A at the R2 stage was superior to the others (24.88 %), fractions B and potentially degradable presented higher mean levels at R4 (69.08 % and 86.88 % respectively), while the insoluble fraction was lower at R4 (13.12 %). Fraction C was greater at R3, with 0.0168 %, but not differing from R1, with 0.0134 %, and effective degradability was higher at R2, compared to the other stages, by 32.66 %.

Peyrat et al. (2014) evaluated corn plants, and found degradation of the soluble fraction (A), of the potential degradable (B), fraction C, and effective degradability of 37 %, 58 % and 0.026 % $hour^{-1}$ and 60 % respectively. Zou et al. (2016) found values for the fractions A, B and C, of 13.65 %, 58.50 % and 1.69 %, respectively.

Comparing the values of the abovementioned authors to those on Table 5, there is a discrepancy in the values, which is the effect of the stage at which plants were harvested. According to Garcez et al. (2016), degradation of each fraction is altered by the advance of the stages of the plant cycle, due to rising ADF, thickening of stems, and lignification of leaves.

For Sampaio, Pike and Owen (1995), forage quality should be interpreted by fractions A and C, because, according to the authors, forages with higher levels of fraction A are more digestible to the rumen, and forage with higher levels of fraction C take less time to reach the maximum degradation potential.

Still, stage R4 needs special attention, once whole corn plants presented a degradation kinetic rate close to the other stages and to grain-free plant, and even without presenting the highest levels of fractions A and C, it showed higher degradation potential (86.88 %), smaller indigestible portion among stages (13.12 %) and effective degradability of only 5.4 %, less than stage R2, which was the highest among evaluated stages. These results can be the reflex of its low ADL and high content of NDF (Table 3).

Conclusion

Considering the chemical quality, the ruminal disappearance of dry matter, the ruminal degradation kinetics of whole corn plants and grain-free corn plants, the harvested volume and production costs, the R4 stage of the evaluated hybrid showed the best plant quality at the time of harvest, however studies on how the material will ferment in the ensiling process need to be carried out.

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