Ciências Agrárias
SEMINA

DOI: 10.5433/1679-0359.2025v46n3p943

Biomass production and chemical composition of corn for silage in different reproductive stages

Produção de biomassa e bromatologia do milho para silagem em diferentes fases reprodutivas

Everton Luiz Carneiro Pereira[1]*; Ellen Baldissera[2]; Valeria Kalinovski[2]; João Antonio de Arruda Giacomet[3]; Arno Passarin Filho[1]; Luísa da Costa Venancio[4]; Paulo Victor Pinheiro Cesar[4]; Leandro Rampim[5]; Mikael Neumann[6]; Valter Harry Bumbieris Junior[7]

Highlights

The optimal harvest time of corn for silage depends on various dry matter content.
The dry matter content of the plant's other components alters its composition.
Each reproductive stage has different agronomic and chemical characteristics.
The combination of characteristics determines the optimal harvest time.

Abstract

The ongoing professionalization of corn silage production is related to the specific productive and qualitative agronomic characteristics of the different hybrids available on the market, which define the dynamics of the appropriate moment for harvesting and making silage. This experiment evaluated the morphological and chemical composition, dry biomass production, and rumen degradation of plants from different corn hybrids, harvested at various reproductive stages. The experimental design was randomized blocks, in a 3 x 21 and/or 8 factorial arrangements, with three corn hybrids (B2401PWU, B2782PWU, and B2801PWU) associated with 21 and/or 8 harvest times, to evaluate productive and

[1] M.e in Plant Production, Universidade Estadual do Centro-Oeste, UNICENTRO, Guarapuava, PR, Brazil. E-mail: everton.lcp@gmail.com; arnopassarin@gmail.com
[2] Veterinarian, UNICENTRO, Guarapuava, PR, Brazil. E-mail: ellen_baldissera@outlook.com; kalinovskivaleria@gmail.com
[3] Undergraduate in Veterinary Medicine, UNICENTRO, Guarapuava, PR, Brazil. E-mail: joaogiacomet3@gmail.com
[4] M.e in Veterinary Sciences, UNICENTRO, Guarapuava, PR, Brazil. E-mail: luisacosta23@outlook.com; paulo_victor147@hotmail.com
[5] Prof. Dr., Graduate Agronomy Program in the field of Plant Production, UNICENTRO, Guarapuava, PR, Brazil. E-mail: rampimleandro@hotmail.com
[6] Prof. Dr., Graduate Agronomy Program in the field of Plant Production and Veterinary Sciences and the area of Health and Sustainable Animal Production, UNICENTRO, Guarapuava, PR, Brazil. E-mail: neumann.mikael@hotmail.com
[7] Prof. Dr., Graduate Program in Animal Science, Department of Animal Science, Universidade Estadual de Londrina, UEL, Londrina, PR, Brazil. E-mail: jrbumbieris@uel.br
* Author for correspondence

Received: Nov. 25, 2024 Approved: June 10, 2025

chemical parameters, respectively, at regular intervals, between the R1 and R6 reproductive stages, with four repetitions each. Changes in the reproductive cycle increased the production of dry biomass of forage and grains up to R5, reaching 26,536 and 10,142 kg.ha^{-1}, respectively. This resulted in reduced average costs, reaching values of 0.51 R$ kg.DM^{-1}. As the reproductive cycle advanced, there was a greater participation of grains and a dilution of structural components, resulting in reductions in NDF (44.44%) and ADF (27.66%) at R5. At this stage, the plant showed an average DM of 30%, while the grains had a DM of 56%. *In situ* degradability values were higher at the R4-R5 transition stage, while other chemical parameters were higher at R5 and/or before reaching physiological maturity at R6. In addition to the reproductive stages described in the literature, the transition stages are also relevant due to the physiological changes in the plant that affect the productivity and chemical quality of corn plants used for silage production.
Key words: Grain filling. Harvest time. Desirable nutritional value.

Resumo

A constante profissionalização na produção de silagem de milho relaciona-se às características agronômicas produtivas e qualitativas específicas de diferentes híbridos disponíveis no mercado, que acabam definindo a dinâmica do momento apropriado de colheita e confecção da silagem. O experimento teve por objetivo avaliar as composições morfológicas e bromatológicas, produção de biomassa seca e a degradação ruminal da planta de diferentes híbridos de milho, colhidos em distintos estádios reprodutivos. O delineamento experimental foi o de blocos ao acaso, num esquema fatorial 3 x 21 e/ou 8, sendo três híbridos de milho (B2401PWU, B2782PWU e B2801PWU) associado a 21 e/ou a 8 momentos de colheita, para avaliação de parâmetros produtivos e bromatológicos, respectivamente, em intervalos regulares, entre as fases reprodutivas de R1 a R6, com quatro repetições cada. A evolução do ciclo reprodutivo das plantas promoveu aumento na produção de biomassa seca de forragem e de grãos até R5, chegando a 26,536 e 10,142 kg.ha^{-1}, respectivamente, proporcionando redução no custo médio, atingindo valores de 0.51 R$ kg.MS^{-1}. A maior participação de grãos e a diluição dos componentes estruturais, conforme avanço do ciclo reprodutivo promoveu redução nos teores de FDN (44.44%) e FDA (27.66%) em R5, estádio este que teve MS médio da planta de 30% e MS de grãos a 56%. A degradabilidade apresentou-se com melhores valores no estádio de transição, R4-R5, porém os demais parâmetros bromatológicos foram melhores em R5 e/ou antes de atingirem a maturidade fisiológica em R6. Além dos estádios reprodutivos descritos na literatura, os períodos de transição também são relevantes devido as mudanças fisiológicas da planta e estas interferem na qualidade produtiva e bromatológica para produção de silagem.
Palavras-chave: Enchimento de grãos. Momento de colheita. Valor nutricional desejável.

Introduction

In Brazil, corn is one of the most widely grown forage crops for silage production, which is the basis of cattle nutrition and is implemented by nutritionists on most properties (Silvestre & Millen, 2021) because it has excellent biomass production capacity and high nutritional value (Neumann et al., 2018). Its chemical characteristics provide a suitable environment for ruminal fermentation (Rabelo et al., 2018).

In general, most hybrids in the market are designed for grain production, with limited information available on forage quality. This lack of information makes the selection of the best hybrid for silage production challenging (Melo et al., 2017). Improving silage hybrids requires consideration of their adaptability to different regions and balancing energy and fiber content. This means that as the forage accumulates starch, the fiber portion also maintains its quality (Horst et al., 2021). These factors directly affect the chemical characteristics of the resulting silage and determine productivity per unit area (Neumann et al., 2020).

Despite this fiber and grain ratio, corn plants for silage making are monitored according to the reproductive stage of the grains because the nutritional value of the grains is linked to the hardness of their endosperm (Daniel et al., 2019). In addition, the DM content of the whole plant must be measured to determine the optimal harvest time based on the water activity required for proper fermentation (Horst et al., 2021).

Therefore, the objective of this study was to evaluate the production of dry biomass, morphological and chemical composition, and ruminal degradation of different corn hybrids harvested at different reproductive stages.

Material and Methods

All experimental procedures were previously submitted to the Animal Experimentation Ethics Committee (CEUA) and approved according to the protocol (Official Letter 016/2023).

The experiment was conducted in Guarapuava, state of Paraná, Brazil (25°23'36" S, 51°27'19" W; 1,100 m above sea level). The climate of the region is humid mesothermal subtropical (Cfb), with no dry season, cool summers, and moderate winters, according to the Köppen classification. The minimum and maximum temperatures, as well as the rainfall during the experimental period (from April 4th, 2022, to March 5th, 2023) are presented in Figure 1.

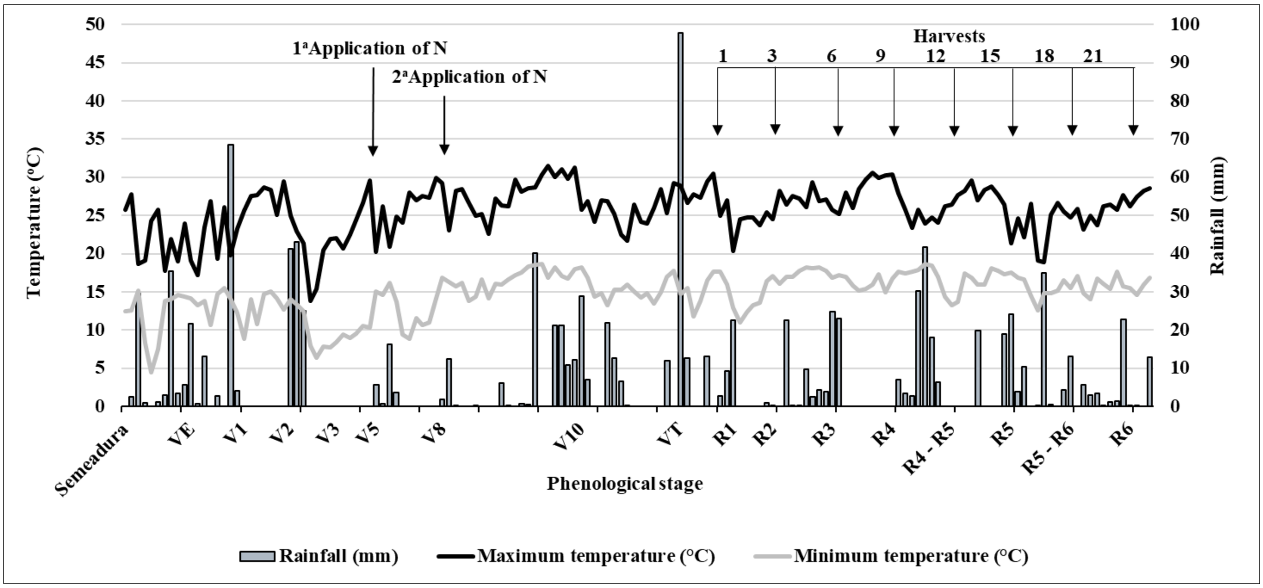

Figure 1. Maximum and minimum temperatures (ºC) and rainfall (mm) during the experimental period (April 4th, 2022, to March 5th, 2023).

The soil in the experimental area is a Typical Bruno Latosol (Michalovicz et al., 2019). The area was previously cultivated with annual cycle pastures in the winter season, receiving phosphorus and potassium fertilization according to the Fertilization and Liming Recommendations for the state of Paraná (Sociedade Brasileira de Ciência do Solo, Núcleo Estadual Paraná [SBCS/NEPAR], 2017).

Upon sowing, the chemical properties of the soil (0 to 20 cm) were pH $CaCl_2$ 0.01M: 5.98; Phosphorus: 15.30 mg dm^{-3}; K^+: 0.43 $cmol_c$ dm^{-3}; OM: 23.73%; Al^{3+}: 0.21 $cmol_c$ dm^{-3}; H+Al: 6.42 $cmol_c$ dm^{-3}; Ca^{2++}: 6.33 $cmol_c$ dm^{-3}; Mg^{2+}: 1.67 $cmol_c$ dm^{-3}, and base saturation: 56.75%.

The experimental plots were planted on October 4, 2022, using a row spacing of 0.45 m, a sowing depth of 0.05 m, and seed distribution targeting a final population of 78,000 $plants.ha^{-1}$. The hybrids evaluated were from Corteva Agriscience® (Indianapolis, USA): B2401PWU, with a super-early cycle, B2782PWU, and B2801PWU with an early cycle. All hybrids were designed for grain and silage production, as well as PowerCore® ULTRA (PWU) biotechnology, defined as broad-spectrum protection against caterpillars, in addition to tolerance to herbicides based on glyphosate and glufosinate-ammonium.

Basal fertilization consisted of 500 $kg.ha^{-1}$ of 12-31-17 (NPK) fertilizer (60 $kg.ha^{-1}$ N, 155 $kg.ha^{-1}$ of P_2O_5, and 85 $kg.ha^{-1}$ of K_2O). As a topdressing, 500 $kg.ha^{-1}$ of urea (230 $kg.ha^{-1}$ N) was applied, split into two applications, at the V5 and V8 vegetative stages. The management of the area before sowing was based on the preventive control of weeds and insects using the chemical method, with herbicides based on glyphosate (commercial product Shadow®, at a dose of 4 $L.ha^{-1}$) and Cletodim (commercial product Select® 240 EC, at a dose of 0.8 $L.ha^{-1}$). For post-emergence control, Atrazine (commercial product Atrazina®, at a dose of 5 $L.ha^{-1}$) and Glyphosate (commercial product Shadow®, at a dose of 4 $L.ha^{-1}$) were used.

Six applications of insecticide were carried out using two chemical products combined every seven days. The products used were Imidacloprid + Beta-cyfluthrin (Expedition®, dose of 0.3 $L.ha^{-1}$) and Methomyl (Brilhante®, dose of 1 $L.ha^{-1}$) in the first three applications, and Imidacloprid + Beta-cyfluthrin (Connect®, dose of 0.8 $L.ha^{-1}$) and Espinetoram (Exalt®, dose of 0.2 $L.ha^{-1}$) in the last three applications. One fungicide application was made with the chemical product Picoxystrobin + Cyproconazole (Aproach Power®, at a dose of 0.8 $L.ha^{-1}$).

The treatments evaluated consisted of harvesting plants of three corn hybrids on 21 different dates every three days to evaluate the accumulation of dry matter in the plant and the participation of its structural components in the physical composition of the plant. The scale of reproductive stages was monitored as determined by Ritchie et al. (2003), where the first harvest began at stage R1 - beginning of grain filling, until stage R6 - grain at physiological maturity, which comprised the period from 92 to 152 days after sowing. Of the 21 plant samples collected between stages R1 and R6, eight samples corresponding to the full stages of R1, R2, R3, R4, R4-R5, R5, R5-R6, and R6 were selected for chemical analysis.

The experimental design was a randomized block design, 3 x 21 and/or 8, with three corn hybrids (B2401PWU, B2782PWU, and B2801PWU) associated with 21 and/or 8 harvest times, to evaluate productive and chemical parameters, respectively, at regular intervals between the reproductive phases from R1 to R6, with four repetitions each.

The total area of the experiment was 1,080 m^2, separated into four blocks of 270 m2. Each block had a 90 m^2 area (useful area of 51.3 m2) for each hybrid, with plots of 2.5 m^2, containing 63 evaluation plots in each block.

For each evaluation, seven whole plants in the useful area of each plot were manually cut at a height of 30 cm from the ground. The triple pairing method was used, which allowed us to determine, in addition to the dry matter content, the percentage physical composition of the anatomical structures of the plant by separating the components: stem, leaves, bracts plus cobs, and grains.

Homogeneous and representative samples were taken from each treatment, weighed, and pre-dried in a forced-air oven at 55 °C. After 72 hours, the samples were weighed again to determine the dry matter (DM) content, according to AOAC (930.15) (Association of Official Analytical Chemists [AOAC], 1995), and ground in a Wiley mill with a 1 mm mesh sieve.

In whole plant samples, neutral detergent fiber (NDF) content was determined according to Van Soest (1994) using thermostable α-amylase (Termamyl 120 L, Novozymes Latin América Ltda.), acid detergent fiber (ADF) according to Goering and Van Soest (1970), and acid detergent lignin (ADL) and non-fiber carbohydrates plus ether extract (NFC+EE), according to Silva and Queiroz (2009). The concentration of total digestible nutrients (TDN, %) was determined according to the methodology suggested by Bolsen et al. (1996).

Rumen dry matter degradation (RDMD) was estimated by the *in situ* technique, using TNT (non-woven fabric) bags measuring 10 cm × 5 cm with 50 μm pores, containing approximately 0.5 g on a dry matter basis of each material, for subsequent incubation in the rumen (Nocek, 1988). For RDMD, the incubation times used were 24, 48, 72, and 168 hours, in reverse chronological order, ensuring that each animal received all samples from all treatments.

Economic analysis was obtained by the relationship between the cost of establishing and managing crops and the average production of digestible biomass expressed in kg.ha^{-1} of DM. The investment in implementing crops considers the costs of seeds, fertilizers, herbicides, insecticides, and fungicides, as well as the costs of machine hours for sowing, spraying, and topdressing, based on the agricultural mechanization cost spreadsheet provided by the ABC Foundation in 2023.

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

The analysis of each variable followed the statistical model: Yijkl = μ + Hi + ECj + Bk + (HiECj)l + Eijkl, where: Yijkl = dependent variable, μ = overall mean of all treatments, Hi = corn hybrid effect, ECj = harvest season effect, Bk = block effect, (HiECj)l = interaction effect between hybrid and harvest season, and Eijkl = random error associated with each observation Yijkl.

Data were also subjected to polynomial regression analysis, considering the variable days of evaluation, using the "proc reg" procedure of the SAS software (1993).

Results

Effect of the progression of reproductive stages of corn plants on productive agronomic parameters

The productive and chemical parameters showed significant interactions (P<0.05) between hybrids and reproductive stages, except for the plant height and ear height parameters, which did not differ (P>0.05) between the hybrids evaluated during the progression of the reproductive stages (Figure 2).

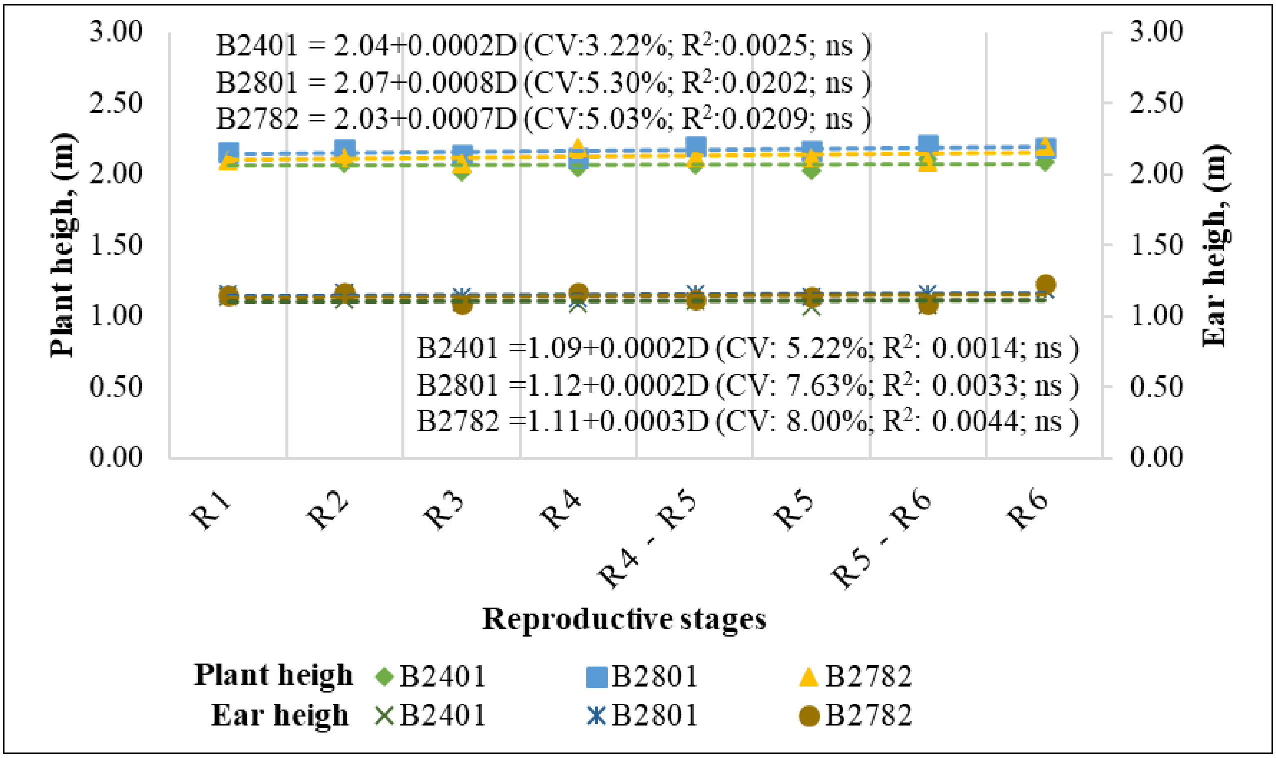

Figure 2. Plant and ear height of different corn hybrids harvested at different reproductive stages for silage making.

R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

The dry matter of the whole plant (Figure 3) is important for agronomic and chemical evaluation. This was one of the main points studied to determine the best harvest date for silage production. For each day of progression of the reproductive stage, B2401PWU showed an increase of 0.45%, and B2801PWU and B2782PWU showed 0.39 and 0.37%, respectively.

The participation of dry leaves per plant^{-1} (Figure 4), a parameter that indicates the stay-green of the plants, showed an average linear growth of 0.3 leaves per day^{-1} for the three hybrids evaluated. With this increase, only at R5 - R6, the plant population reached more than one dry leaf per plant^{-1}, showing the excellent potential to stay green during the reproductive stage of corn until the time of harvest for silage production.

The calculation of the cost of digestible biomass (Figure 5), on average for the three hybrids, showed a linear decrease of R\$0.02 day^{-1}, being inversely proportional to production, whose parameter increased linearly by 264.32 kg.day^{-1} as the reproductive stage of the corn plant progressed.

The production of natural biomass showed quadratic behavior (Figure 6), whereas the production of dry biomass and dry grains showed an average linear increase of 356 and 272 kg.day^{-1}, respectively, as the reproductive stage of the corn plant advanced.

The DM content in each fraction of the plant (Figure 7) showed an increasing linear trend, with variations in the fiber portions of 0.09% for the stem, 0.14% for the leaves, and 0.45% for the bracts plus cobs. The DM content of the grains showed a greater increase throughout the reproductive stage, with an average increase of 1.13% day^{-1}.

The participation of the plant components, represented by leaves, stems, bracts plus cobs and grains (Figure 8), showed that the fiber portion was diluted with the progression of the reproductive stages owing to the linear accumulation of the energy portion (starch deposition in grains) in the order of 0.9% day^{-1}.

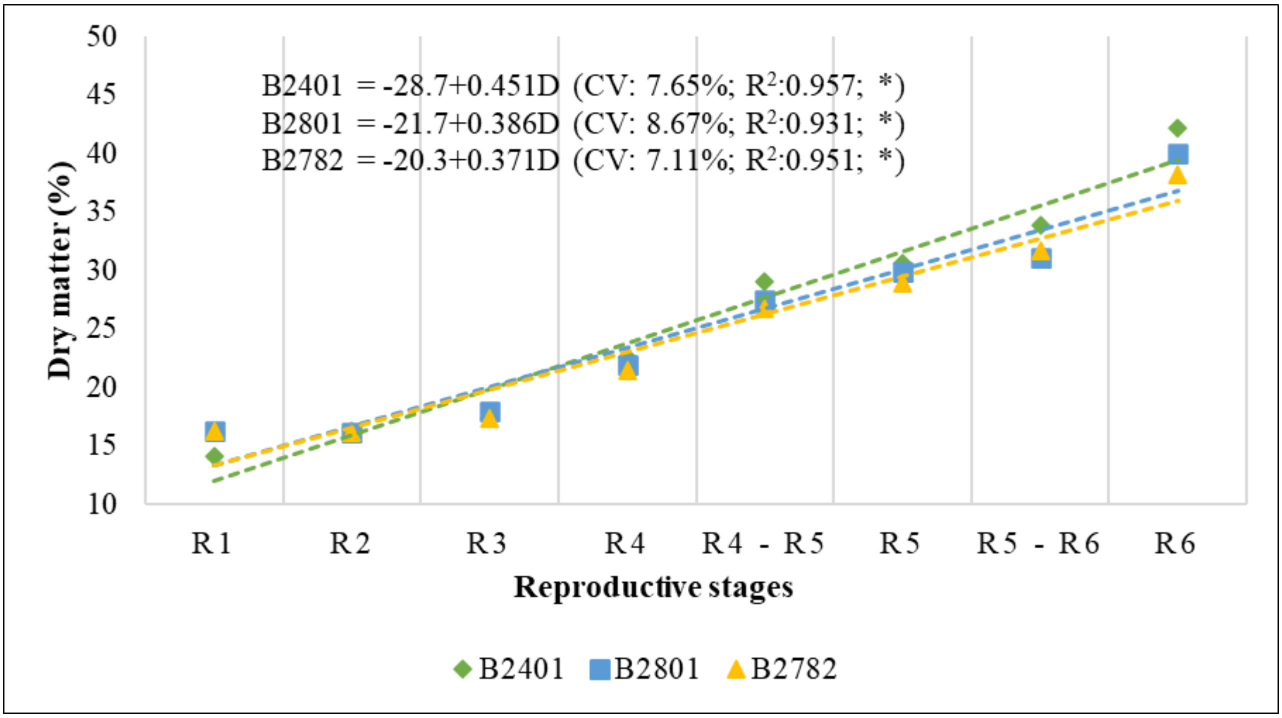

Figure 3. Whole plant dry matter (%) of different corn hybrids harvested at different reproductive stages for silage making.
R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

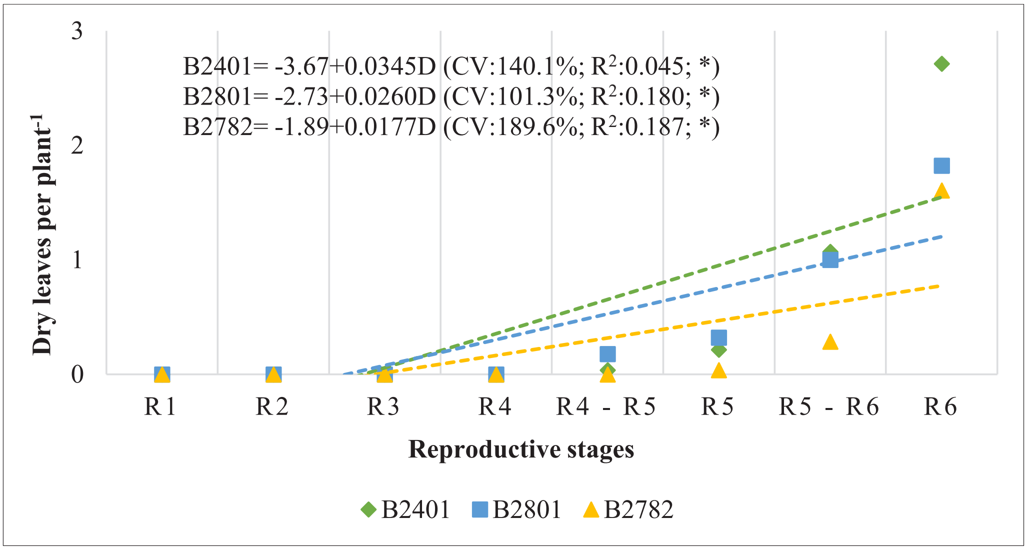

Figure 4. Number of dry leaves per plant[-1] of different corn hybrids harvested at different reproductive stages for silage making. R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

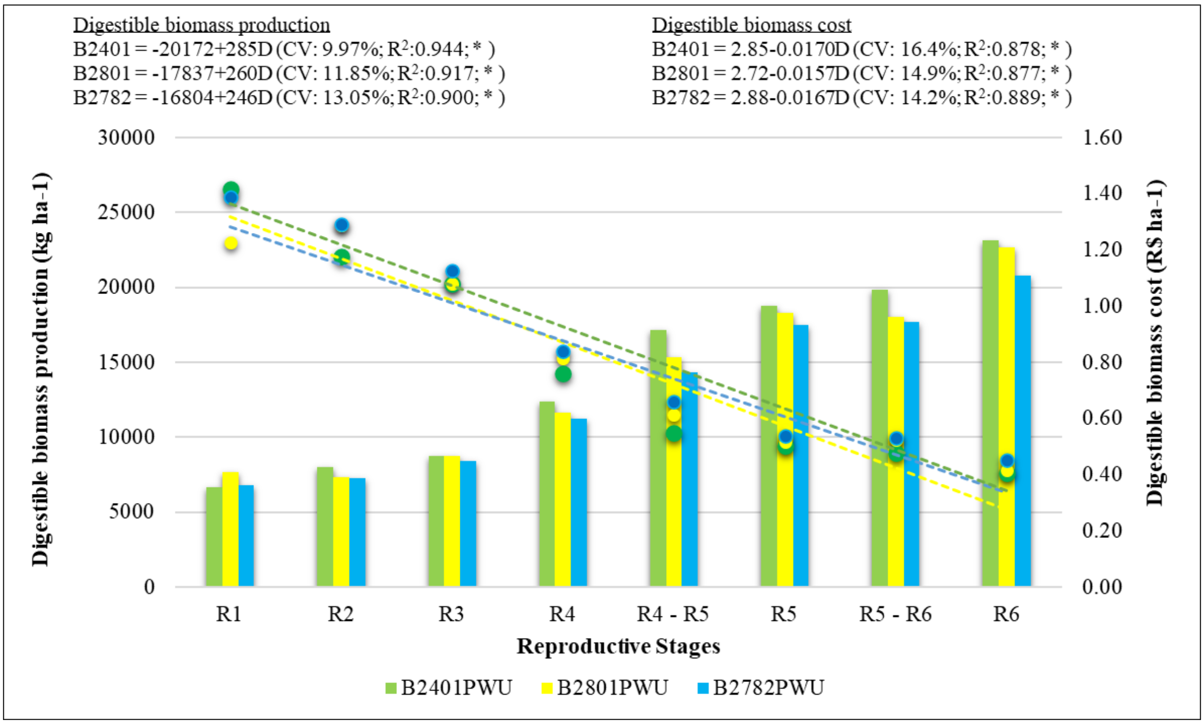

Figure 5. Production and cost of digestible biomass of different corn hybrids harvested at different reproductive stages for silage making. R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

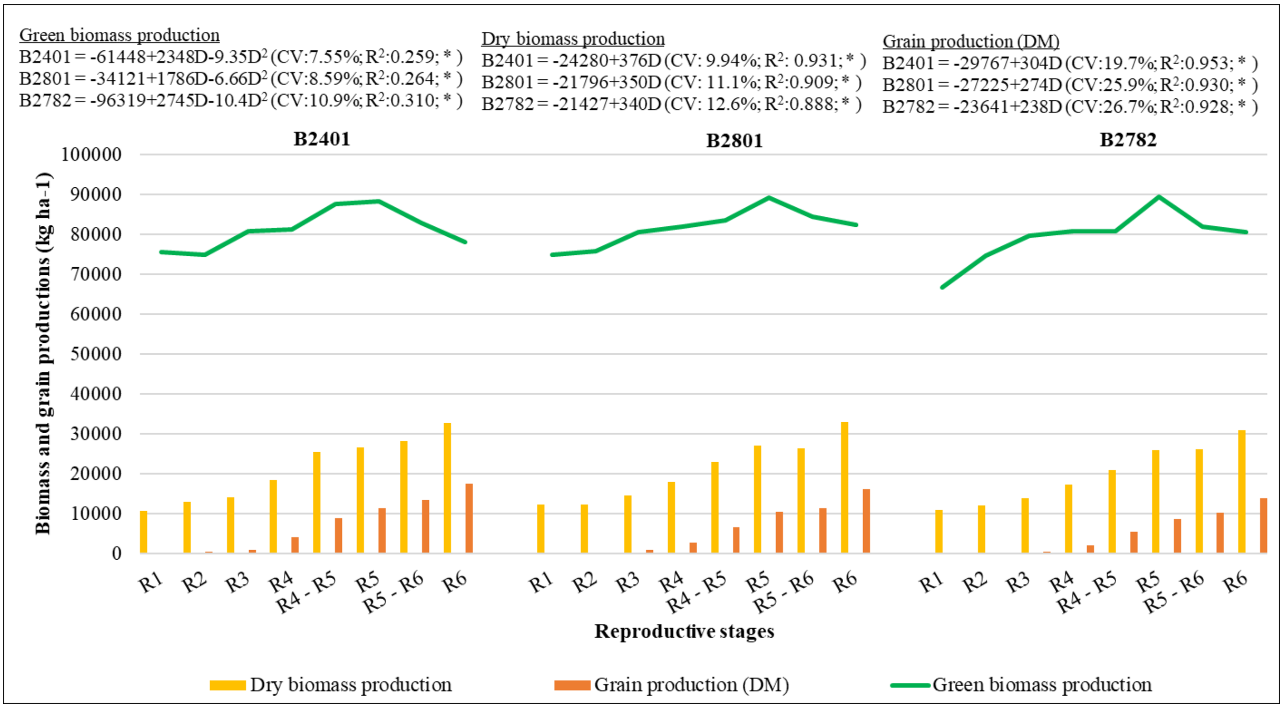

Figure 6. Productive agronomic characterization of corn plants harvested at different reproductive stages for silage making.
R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

Effect of the progression of reproductive stages of corn plants on chemical parameters

Figure 9 shows that the average results for the chemical analysis of mineral matter and crude protein showed a linear decrease of 0.04 and 0.13% day^{-1} in dry matter, respectively. Non-fiber carbohydrates plus ether extract presented a linear increase with the progression of the reproductive stages of the plant, with an average of 0.37% in DM per day^{-1}.

For the NDF and ADF analyses, Figure 10 reveals a decreasing linear behavior in dry matter of 0.2% day^{-1} for the three hybrids. The same trend was observed for lignin, with a smaller decrease per day^{-1} of 0.02% in DM as the reproductive stages of the corn crop advanced.

The ruminal dry matter degradation rates were evaluated at 24, 48, 72, and 168 hours of incubation (Figure 11) and showed quadratic behavior as the reproductive cycle advanced for all times. In this context, maximum ruminal DM degradability was found at the R4-R5 stage for all incubation times.

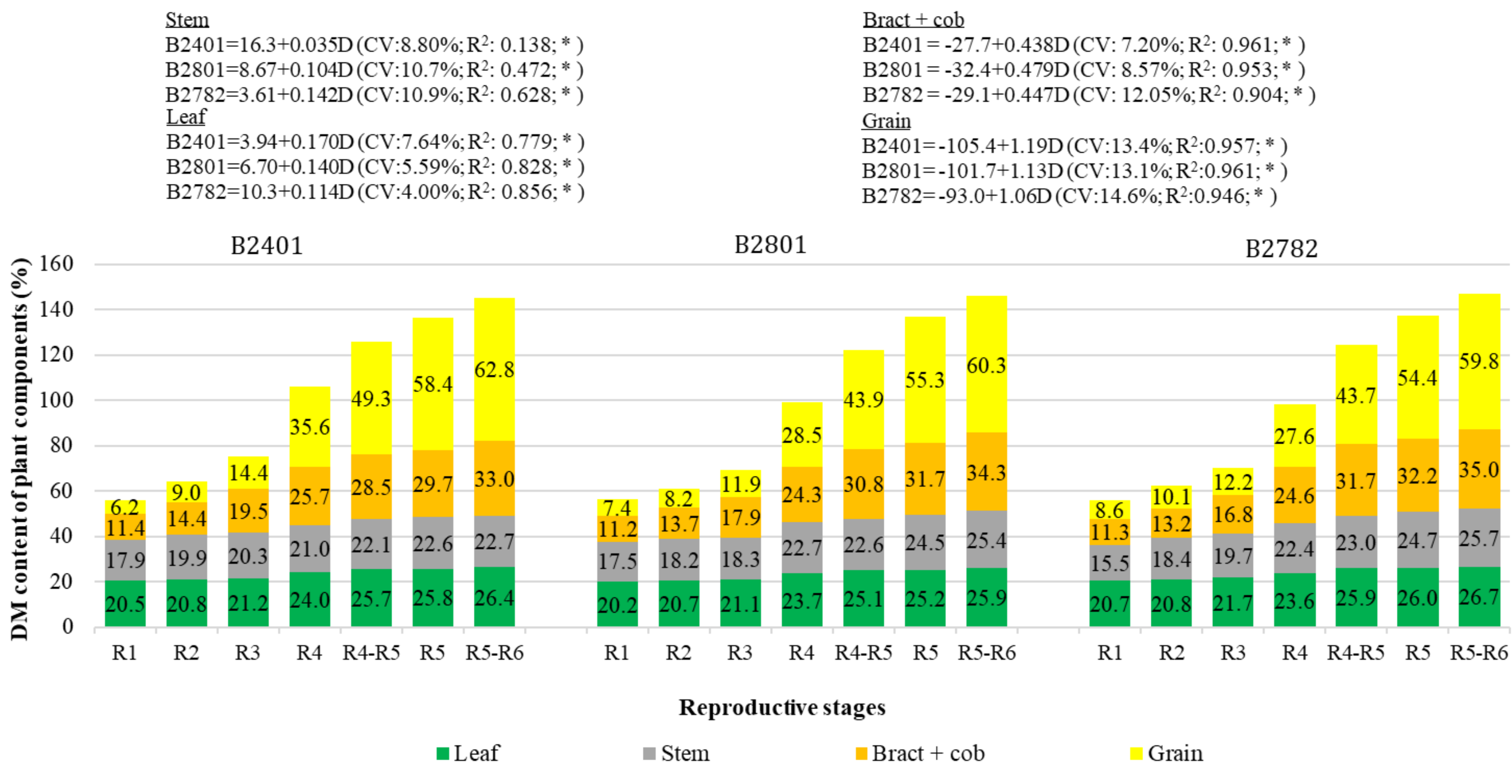

Figure 7. Dry matter contents of plant components of different corn hybrids harvested at different reproductive stages for silage making.

R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

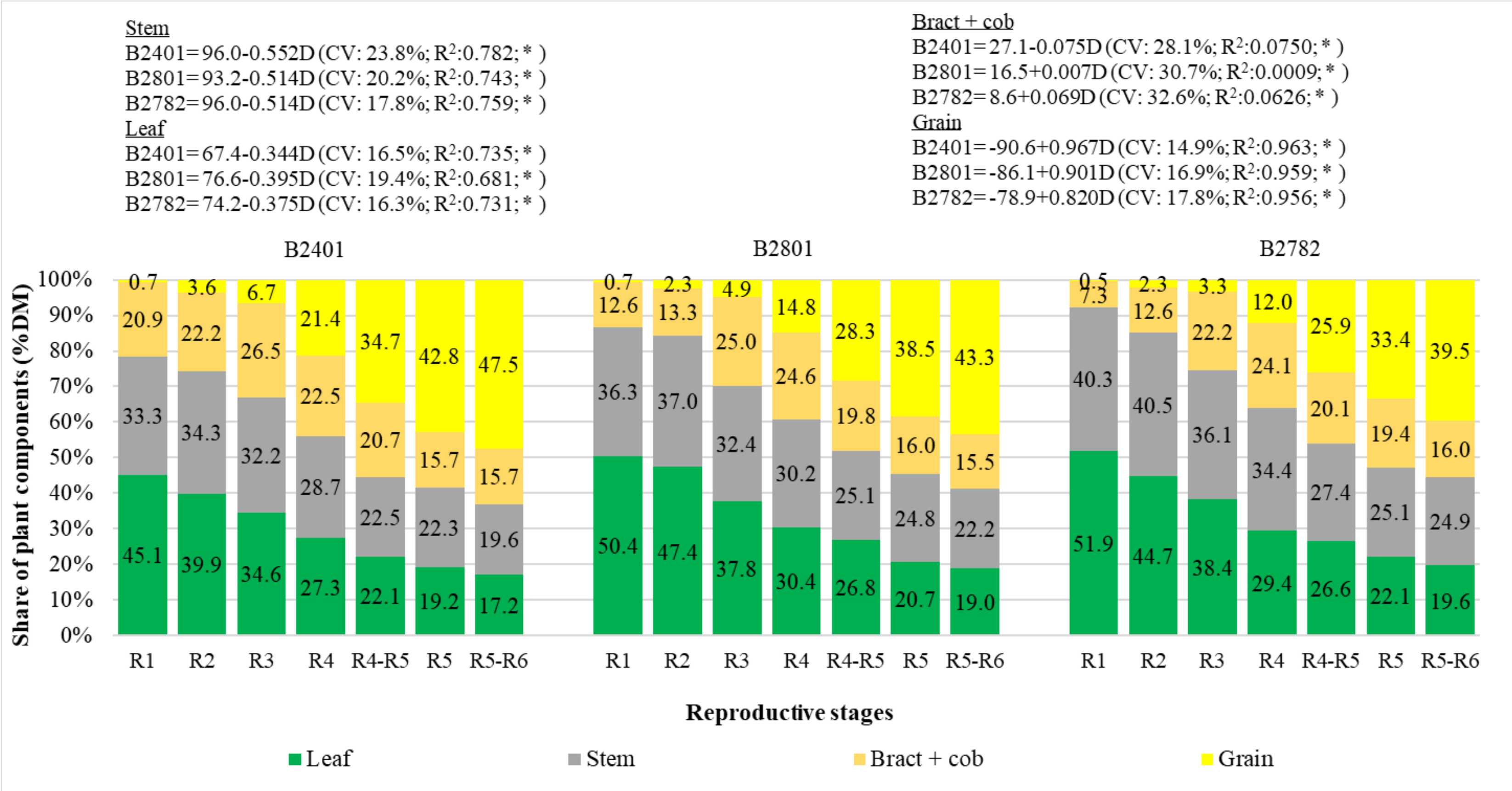

Figure 8. Participation of components in the structure of the corn plant harvested at different reproductive stages for silage making.

R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

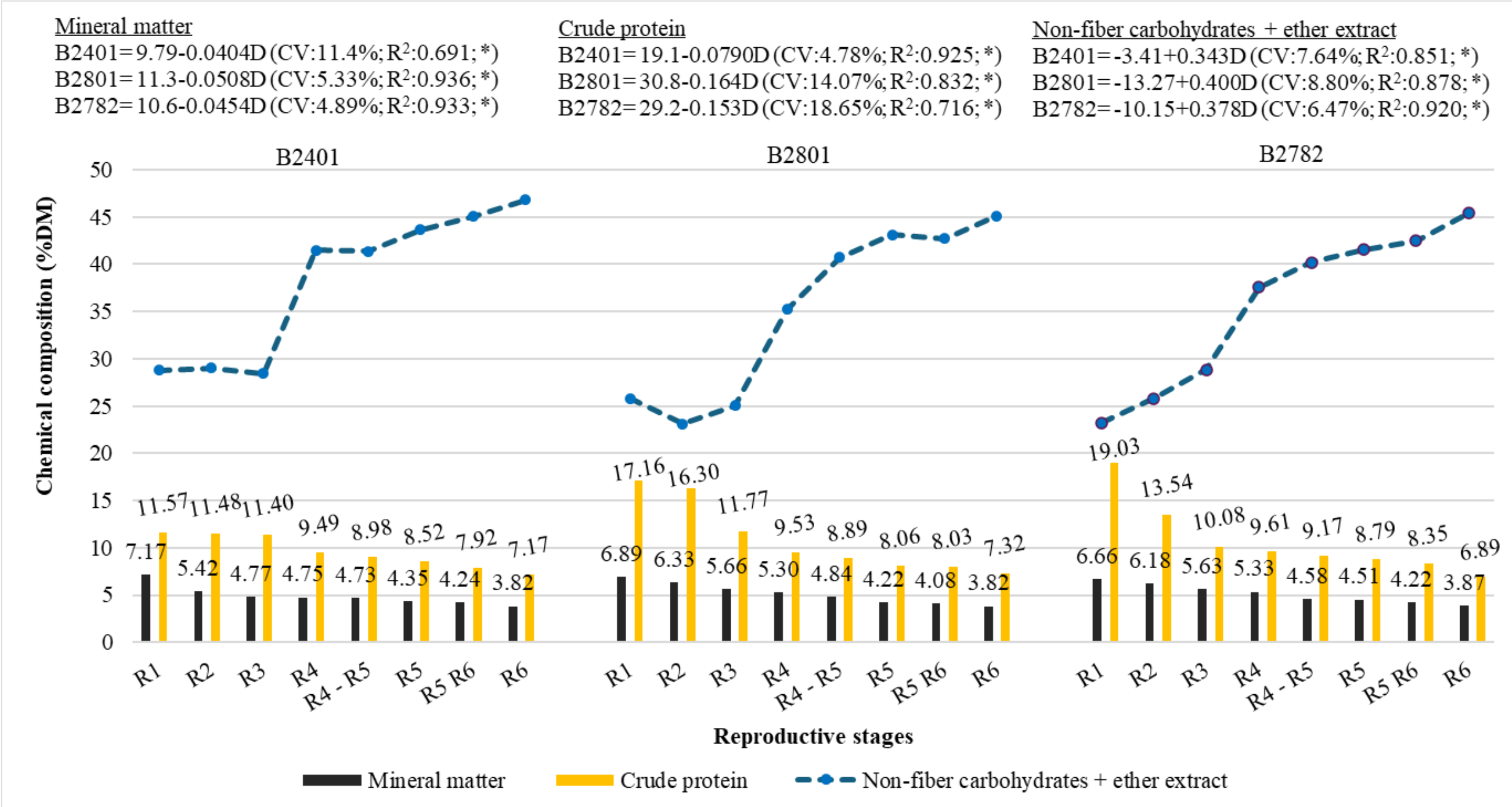

Figure 9. Chemical composition (mineral matter, crude protein, and non-fiber carbohydrates plus ether extract) of the corn plant harvested at different reproductive stages for silage making.

R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

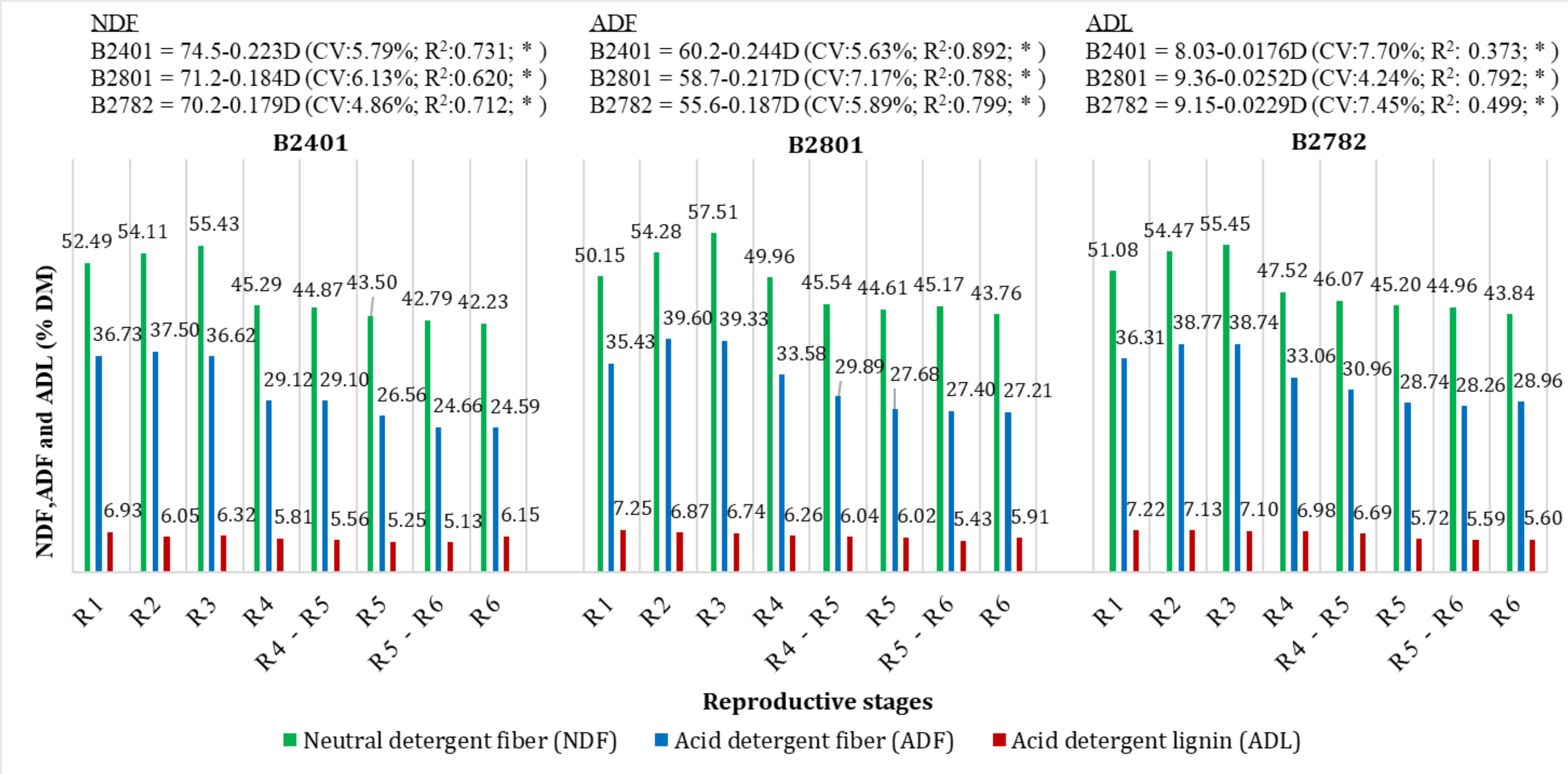

Figure 10. Average contents of the fiber fractions of the corn plant harvested at different reproductive stages for silage making. R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

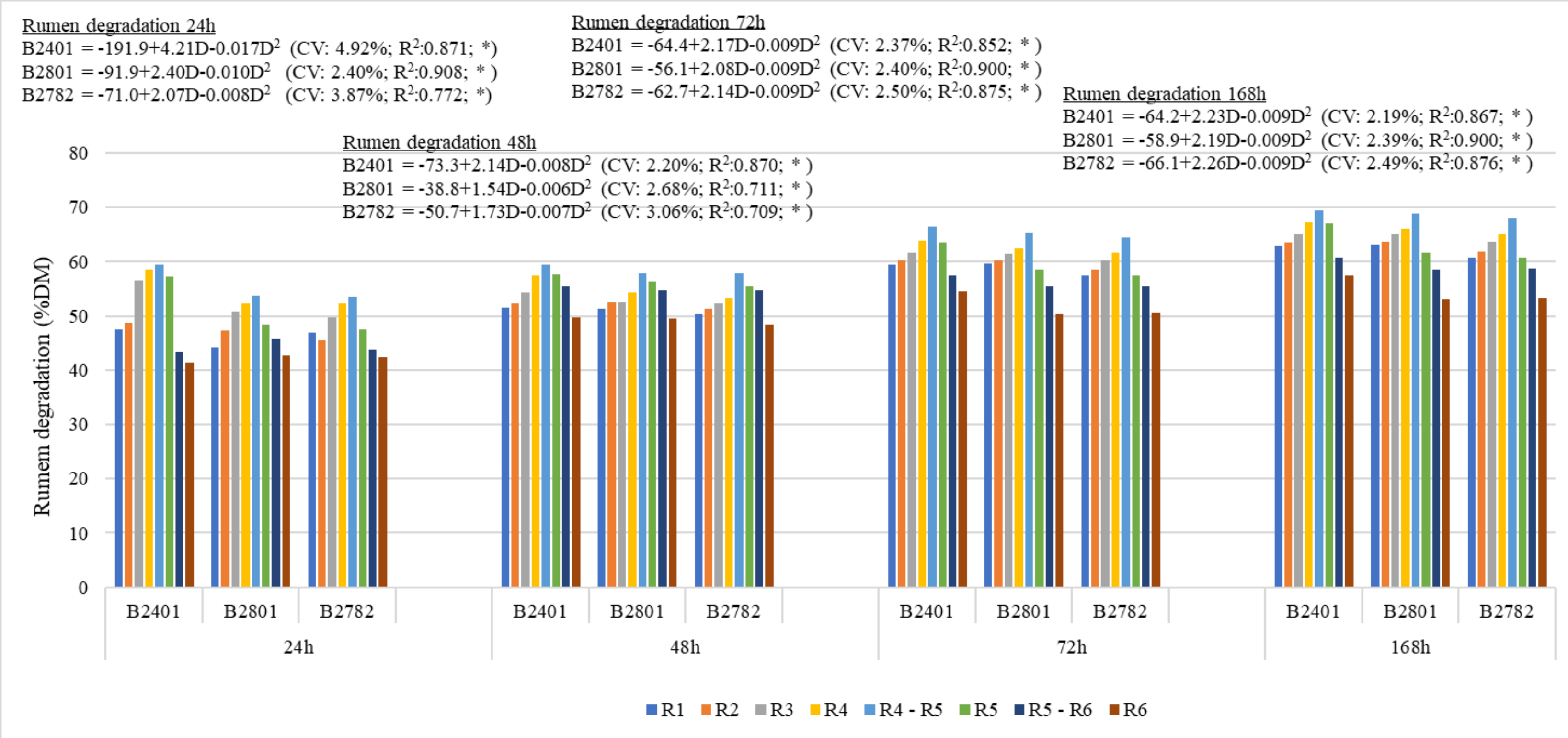

Figure 11. Rumen degradation (RD) of DM, with incubation of 24, 48, 72, and 168 hours of the corn plant at different reproductive stages for silage making.

R - Maize maturation scale adapted from Ritchie et al. (2003); D = days after sowing (92 to 152); CV = Coefficient of variation; R^2 = Coefficient of determination; * = significant by Tukey's test; ns = non-significant by Tukey's test.

Discussion

The harvest time of corn plants for silage production is correlated with the progression of the reproductive stages of the crop, which presents very intense variations in the resulting nutritional values (Lima et al., 2022). The dry matter content of the whole plant is one of the main factors of harvest, and the ideal time is between the R4 and R5 stages, with 30 and 38% DM, respectively (Kung et al., 2018; Neumann et al., 2020). In this study, a minimum DM content of 30% was reached at the R5 stage by the three hybrids.

Stay-green, the plant's potential to remain green during grain maturation, confers quality to the silage and expands the harvest window (Neumann et al., 2018) and is partly explained by the number of dry leaves in the plant. The hybrids evaluated here presented dry leaves from the R4-R5 stage, which explains their quality for silage making and corroborates the DM content presented.

The dry matter content of the plant is not only defined by the progression of reproductive stages, but also by a set of factors, such as fertilization, hybrids, climate, pressure from weeds, insects, diseases, and application of agricultural pesticides (Cardoso, 2020; Ferraretto et al., 2018; Neumann et al., 2017; Ritchie et al., 2003). Given this, the conflict with some studies becomes evident and overturns the theory previously disseminated in the literature, which always relates the dry matter content of silage only to the harvest stage of the plant.

These factors also interfere with other parameters for a good forage hybrid, such as plant and ear height, which are characteristics to be considered along with the proportion of grains in the plant, in addition to adequate adaptability to different cultivation regions (Zopollatto et al., 2009). Considering these factors, no statistical difference was detected, which corroborates other studies (Oliveira et al., 2013; Souza et al., 2022) and occurs because, according to Ritchie et al. (2003), the plant after stage R1 is stagnant in terms of height growth.

The plant demonstrates a pattern of increased biomass production during its reproductive period. Over time, as the weight of the plant increases and nutrients are transferred from the fiber fractions to the ear, there is a dilution of fiber content. This phenomenon results from increased starch deposition and a corresponding decrease in fiber digestibility, ultimately impacting the resulting silage quality (Skonieski et al., 2014). Levels of fiber components increase daily, following the trend described by Zopollatto et al. (2009), and represent the capacity of each structure to retain nutrients (Neumann et al., 2020).

The DM content of each fraction that constitutes the plant varied with the progression of the reproductive cycle of the crop, and consequently, the DM content of the entire plant. A study carried out by Lima et al. (2022) listed the main components that interfere with the final DM, and the result was that the fiber composition is predominant over the grains, and other factors stand out over the chemical composition.

One of the key points for monitoring the harvest window is the DM content of the grains, whose ideal value is 50-60% DM, which confers quality (Neumann et al., 2010) and is directly related to the production of digestible biomass per unit area, consequently reducing production costs. In this study, it reached an average of 56% at the R5 stage and 60% at the R5-R6 stage. Higher values have already been described for the production of other types of silage (Daniel et al., 2019), such as wet grains. Hybrids must have nutritional stability in all parts because the participation of the components is linked to the quality of the reproductive stage of corn (Ferraretto et al., 2015). According to Di Marco et al. (2002), this is an influential factor in the digestibility of the entire set (fiber fraction and grains) of silage.

Regarding the participation of each component, there was an increase in grains and a decrease in fiber portions, indicating that the plant directs its nutrients to the composition of grains as reproductive stages advance, and a greater presence of grains can increase digestibility as a whole (Krämer-Schmid et al., 2016). The qualitative aspects of the plant parts determine the final quality of the diet; that is, the nutritional quality of silage is strongly related to the proportion of vegetative components containing grains (Domingues et al., 2012).

Chemical characteristics correspond to the nutritional value of plant fractions and are affected by variations in fiber and starch content (Jensen et al., 2005). Starch increases because of the mobilization of carbohydrates available in the plant to the grains (Buso et al., 2018; Hetta et al., 2012), increasing the production of non-fiber carbohydrates due to starch deposition in the ear (Santos et al., 2014). The content of these carbohydrates in corn silage plays a fundamental role in animal production (meat and milk) as they directly affect their performance (Neumann et al., 2024).

Another important factor is crude protein, which is important in animal nutrition because it is one of the main components of diets. It presented levels close to those described in the literature as ideal for corn silage (Faria et al., 2021). Harvest time interferes with CP content because, as the reproductive stages advance, there is a decrease due to a response to the conversion/dilution of nitrogen compounds into fiber compounds (Macome et al., 2017).

Parameters such as NDF and ADF are related to the content of cellulose, hemicellulose, and lignin, which are linked to the fiber aspects of the plant (Souza et al., 2021). Initially, these parameters increase, and as the reproductive cycle progresses, they decrease, altering the quality of fiber digestibility (Jensen et al., 2005). After the plant reaches the physiological maturity stage (R6), these values tend to increase owing to the increase in lignin and reduction of the other constituents of the fiber fraction (Sena et al., 2014), which may lead to a reduction in plant digestibility. Ferraretto et al. (2018) argued that grain digestibility also decreases at this stage because the protein matrix formed by zeins makes it difficult for ruminal microorganisms to access starch.

The quadratic behavior of ruminal degradation shows an increase up to the R4-R5 stage, grains with a dough-dent characteristic, followed by a decline due to changes in fiber and starch content. Although the degradation rate is a crucial factor in determining the optimal harvest time, it should not be the sole consideration. For high-quality corn silage, early harvest should be avoided because of the high moisture content and fewer grains, which have lower energy content and create a favorable environment for the growth of spoilage bacteria, leading to losses through effluents (Khan et al., 2015; Macêdo et al., 2019). Late harvest is also undesirable, as a plant after physiological maturity contains very high dry matter (DM) levels, primarily due to the presence of extremely dry leaves and grains that do not compact properly. This can result in poor fermentation due to increased air presence and reduced digestibility due to challenges in processing fibers and grains (Neumann et al., 2020).

Conclusions

The corn plant for silage making must show quantity and quality in all its parts to be considered a silage hybrid. The physiological changes in plants are affected by several environmental factors and treatments to control pests and diseases. The progression of the reproductive stages is driven by the deposition of starch in grains, and the stay-green trait leads to excellent fiber quality, resulting in plants with good agronomic and chemical quality.

Determining the optimal harvest time requires an assessment of the productive and nutritional potential of the reproductive stages, and their transition should be considered an influencing factor. All evaluated hybrids presented suitable productive and chemical characteristics for making silage.

Acknowledgments

We thank the Nupran Group, the agriculture division of UNICENTRO/PR, and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

References

Association of *Official Analytical Chemists* (1995). Official methods of analysis (16nd ed.). AOAC.

Bolsen, K. K., Ashbell, G., & Weinberg, Z. G. (1996). Silage fermentation & silage additives. Review. *Asian-Australasian Journal of Animal Sciences, 9*(5), 483-494. doi: 10.5713/ajas.1996.483

Buso, W. H. D., Machado, A. S., Ribeiro, T. B., & Silva, L. O. (2018). Produção e composição bromatológica da silagem de híbridos de milho sob duas alturas de corte. *Revista de Agricultura Neotropical, 5*(4), 74-80. doi: 10.32404/rean.v5i4.2682

Cardoso, F. C. (2020). Invited review: applying fungicide on corn plants to improve the composition of whole-plant silage in diets for dairy cattle. *Animal Science, 36*(1), 57-69. doi: 10.15232/aas.2019-01905

Daniel, J. L. P., Bernardes, T. F., Jobim, C. C., Schmidt, P., & Nussio, L. G. (2019). Production and utilization of silages in tropical areas with focus on Brazil. *Grass and Forage Science, 74*(2), 188-200. doi: 10.1111/gfs.12417

Di Marco, O. D., Aello, M. S., Nomdedeu, M., & Van Houtte, S. (2002). Effect of maize crop maturity on silage chemical composition and digestibility (in vivo, in situ and in vitro). *Animal Feed Science and Technology, 99*(1), 37-43. doi: 10.1016/S0377-8401(02)00077-9

Domingues, A. N., Abreu, J. G. D., Cabral, L. D. S., Galati, R. L., Oliveira, M. A. D., & Reis, R. H. P. D. (2012). Nutrition value of silage from corn hybrids in the State of Mato

Grosso, Brazil. *Acta Scientiarum. Animal Sciences, 34*(2), 117-122. doi: 10.4025/actascianimsci.v34i2.11782

Faria, T. F. R., Pinese, F., Gimene, F. M. A., Demarchi, J. J. A. A., Campos, F. P., Premazzi, L. M., & Gerdes, L. (2021). Bromatological composition of commercial corn silages produced in Brazil. *Archivos de Zootecnia, 70*(269), 20-27. doi: 10.21071/az.v70i269.5414

Ferraretto, L. F., Shaver, R. D., Massie, S., Singo, R., Taysom, D. M., & Brouilette, J. P. (2015). Effect of ensiling time and hybrid type on fermentation profile, nitrogen fractions, and ruminal in vitro starch and neutral detergent fiber digestibility in whole-plant corn silage. *The Professional Animal Scientist, 31*(2), 146-152. doi: 10.15232/pas.2014-01371

Ferraretto, L. F., Shaver, R. D., & Luck, B. D. (2018). Silage review: recent advances and future technologies for whole-plant and fractionated corn silage harvesting. *Journal of Dairy Science, 101*(5), 3937-3951. doi: 10.3168/jds.2017-13728

Goering, H. K., & Van Soest, P. J. (1970). *Forage fiber analysis (apparatus, reagents, procedures, and some applications).* Agriculture Handbook.

Hetta, M., Mussadiq, Z., Gustavsson, A. M., & Swensson, C. (2012). Effects of hybrid and maturity on performance and nutritive characteristics of forage maize at high latitudes, estimated using the gas production technique. *Animal Feed Science and Technology, 171*(1), 20-30. doi: 10.1016/j.anifeedsci.2011.09.015

Horst, E. H., Bumbieris, V. H., Jr., Neumann, M., & López, S. (2021). Effects of the harvest stage of maize hybrids on the chemical composition of plant fractions: an analysis of the different types of silage. *Agriculture, 11*(8), 786. doi: 10.3390/agriculture11080786

Jensen, C., Weisbjerg, M. R., Norgaard, P., & Hvelplund, T. (2005). Effect of maize silage maturity on site of starch and NDF digestion in lactating dairy cows. *Animal Feed Science and Technology, 118*(3), 279-294. doi: 10.1016/j.anifeedsci.2004.10.011

Khan, N. A., Yu, P., Ali, M., Cone, J. W., & Hendriks, W. H. (2015). Nutritive value of maize silage in relation to dairy cow performance and milk quality. *Journal of the Science of Food and Agriculture, 95*(2), 238-252. doi: 10.1002/jsfa.6703

Krämer-Schmid, M., Lund, P., & Weisbjerg, M. R. (2016). Importance of NDF digestibility of whole crop maize silage for dry matter intake and milk production in dairy cows. *Animal Feed Science and Technology, 219,* 68-76. doi: 10.1016/j.anifeedsci.2016.06.007

Kung., L., Jr., Shaver, R. D., Grant, R. J., & Schmidt, R. J. (2018). Silage review: interpretation of chemical, microbial, and organoleptic components of silages. *Journal of Dairy Science, 101*(5), 4020-4033. doi: 10.3168/jds.2017-13909

Lima, L. M., Bastos, M. S., Avila, C. L. S., Ferreira, D. D., Casagrande, D. R., & Bernardes, T. F. (2022). Factors determining yield and nutritive value of maize for silage under tropical conditions. *Grass and Forage Science, 77*(3), 201-215. doi: 10.1111/gfs.12575

Macêdo, A. J. S., César, J. M., Neto, Silva, M. A., & Santos, E. M. (2019). Potencialidades e limitações de plantas forrageiras para ensilagem: revisão. *Revista Brasileira de Higiene e Sanidade Animal, 13*(2), 320-337. doi: 10.5935/1981-2965.20190024

Macome, F. M., Pellikaan, W. F., Hendriks, W. H., Dijkstra, J., Hatew, B., Schonewille, J. T., & Cone, J. W. (2017). In vitro gas and methane production of silages from whole-plant corn harvested at 4 different stages of maturity and a comparison with in vivo methane production. *Journal of Dairy Science, 100*(11), 8895-8905. doi: 10.3168/jds.2017-12953

Melo, A. V., Taubinger, M., Santos, V. M. dos, Cardoso, D. P., & Nunes, H. V. (2017). Capacidade combinatória de milho visando à produção de silagem. *Revista Engenharia na Agricultura, 25*(5), 381-395. doi: 10.13083/reveng.v25i5.765

Michalovicz, L., Müller, M. M. L., Tormena, C. A., Warren, A., Dick, M. V., & Meert, L. (2019). Soil chemical attributes, nutrient uptake and yield of no-till crops as affected by phosphogypsum doses and parceling in southern Brazil. *Archives of Agronomy and Soil Science, 65*(3), 385-399. doi: 10.1080/03650340.2018.1505041

Neumann, M., Baldissera, E., Alessi Ienke, L., Martins de Souza, A., Piemontez de Oliveira, P. E., & Harry Bumbieris, V., Jr. (2024). Nutritional value evaluation of corn silage from different mesoregions of southern Brazil. *Agriculture, 14*(7), 1055. doi: 10.3390/agriculture14071055

Neumann, M., Horst, E. H., Dochwat, A., Leão, G. F. M., Carneiro, M. K., & Mello, R. P. de. (2017). Agronomic characteristics of corn for silage under nitrogen and potassium levels by covering fertilization. *Scientia Agraria Paranaensis, 16*(1), 69-77. doi: 10.18188/1983-1471/sap.v16n1p69-77

Neumann, M., Poczynek, M., Leão, G. F. M., Figueira, D. N., & Souza, A. M. (2018). Desempenho de híbridos de milho para silagem cultivados em diferentes locais com três densidades populacionais. *Revista Brasileira de Milho e Sorgo, 17*(1), 49-62. doi: 10.18512/1980-6477/rbms.v17n1p49-62

Neumann, M., Restle, J., & Brondani, I. L. (2010). Avaliação de silagens de sorgo (Sorghum bicolor, L. Moench) ou milho (*Zea mays*, L.) na produção do novilho superprecoce. *Revista Brasileira de Milho e Sorgo, 3*(3), 438-452. doi: 10.18512/1980-6477/rbms.v3n03p%25p

Neumann, M., Venancio, B. J., Horst, E. H., Cristo, F. B., Petkowicz, K., Pontarolo, G. B., Mendes, M. C., & Martins, M. B. A. (2020). Corn hybrid silage quality according to harvesting time. *Semina: Ciências Agrárias, 41*(2), 369-382. doi: 10.5433/1679-0359.2020v41n2p369

Nocek, J. (1988). In situ and other methods to estimate ruminal protein and energy digestibility: a review. *Journal of Dairy Science, 71*(8), 2051-2069. doi: 10.3168/jds.S0022-0302(88)79781-7

Oliveira, M. R., Neumann, M., Jobim, C. C., Ueno, R. K., Marafon, F., & Neri, J. (2013). Composição morfológica e nutricional de plantas e silagens de milho em diferentes estádios de maturação. *Revista Brasileira de Milho e Sorgo, 12*(2), 183-192. doi: 10.18512/1980-6477/rbms.v12n2p183-192

Rabelo, C. H. S., Basso, F. C., Lara, E. C., Jorge, L. G. O., Harter, C. J., Mesquita, L. G., & Reis, R. A. (2018). Effects of Lactobacillus buchneri as a silage inoculant and as a probiotic on feed intake, apparent digestibility and ruminal fermentation and microbiology in wethers fed low-dry matter whole-crop maize silage. *Grass and Forage Science, 73*(1), 67-77. doi: 10.1111/gfs.12303

Ritchie, S. W., Hanway, J. J., & Benson, G. O. (2003). Como a planta de milho se desenvolve. *Arquivo do Agrônomo, 15*(103), 1-20. http://brasil.ipni.net/ipniweb/region/brasil.nsf/0/81A0BBD6E936445D83257AA0003A892E/$FILE/Encarte103.pdf

Santos, C. G., Amaral, P. N. C., Carpejan, G. C., & Junges, L. (2014). Produção de silagem de milho híbrido com diferentes idades de corte. *Revista Científica de Produção Animal, 16*(1), 32-45. doi: 10.15528/2176-4158/rcpa.v16n1p32-45

Sena, L. S., Rocha, V. R., Jr., Reis, S. T., Oliveira, L. M., Marques, K. M. S., & Tomich, T. R. (2014). Degradabilidade das silagens de diferentes frações da parte aérea de quatro cultivares de mandioca. *Ciência Animal Brasileira, 15*(3), 249-258. doi: 10.1590/1809-6891v15i316567

Silva, D. J., & Queiroz, A. C. (2009). *Análise de alimentos, métodos químicos e biológicos* (3nd ed.). Universidade Federal de Viçosa.

Silvestre, A. M., & Millen, D. D. (2021). The 2019 Brazilian survey on nutritional practices provided by feedlot cattle consulting nutritionists. *Revista Brasileira de Zootecnia, 50*, e20200189. doi: 10.37496/rbz5020200189

Skonieski, F. R., Nörnberg, J. L., Kessler, J. D., David, D. B., Azevedo, E. B., Brüning, G., & Pimentel, C. M. M. (2014). Corn plant arrangement and its effect on silage quality. *Revista Brasileira de Zootecnia, 43*(3), 114-119. doi: 10.1590/S1516-35982014000300002

Sociedade Brasileira de Ciência do Solo, Núcleo Estadual Paraná (2017). *Manual de adubação e calagem para o Estado do Paraná.* SBCS/NEPAR.

Souza, A. M., Neumann, M., Bumbieris, V. H., Jr., Manchur, A. D., Pontarolo, G. B., Heker, J. C., Jr., Gavlak, T. F., & Plodoviski, D. C. (2021). Effect of advancing maturity stages of corn for silage on chemical characterization, digestibility and production costs. *Semina: Ciências Agrárias, 42*(1), 283-300. doi: 10.5433/1679-0359.2021v42n1p283

Souza, A. M., Neumann, M., Rampim, L., Almeida, E. R., Matchula, A. F., Cristo, F. B., & Faria, M. V. (2022). Effect of storage time on the chemical composition of whole and grainless corn plant silage harvested at different maturity stages. *Revista Brasileira de Zootecnia, 51*, e20200180. doi: 10.37496/rbz5120200180

SAS Institute (1993). SAS Language reference. Version 6. Cary, NC: SAS Institute Inc.

Van Soest, P. J. (1994). *Nutritional ecology of the ruminant.* Cornell University Press.

Zopollatto, M., Nussio, L. G., Mari, L. J., Schmidt, P., Duarte, A. P., & Mourão, G. B. (2009). Alterações na composição morfológica em função do estádio de maturação em cultivares de milho para produção de silagem. *Revista Brasileira de Zootecnia, 38*(3), 452-461. doi: 10.1590/S1516-35982009000300008