University of São Paulo
“Luiz de Queiroz” College of Agriculture

Harvesting maturities of corn silage hybrids on the performance of finishing beef cattle

Andreia Volpato

Thesis presented to obtain the degree of Doctor in Science. Area: Animal Science and Pastures

Piracicaba
2023

Andreia Volpato
Animal Scientist

Harvesting maturities of corn silage hybrids on the performance of finishing beef cattle

versão revisada de acordo com a Resolução CoPGr 6018 de 2011

Advisor:
Prof. Dr. **LUIZ GUSTAVO NUSSIO**

Thesis presented to obtain the degree of Doctor in Science. Area: Animal Science and Pastures

Piracicaba
2023

Dados Internacionais de Catalogação na Publicação
DIVISÃO DE BIBLIOTECA – DIBD/ESALQ/USP

Volpato, Andreia
Harvesting maturities of corn silage hybrids on the performance of finishing beef cattle / Andreia Volpato. - - versão revisada de acordo com a Resolução CoPGr 6018 de 2011. - - Piracicaba, 2023.
34 p.

Tese (Doutorado) - - USP / Escola Superior de Agricultura “Luiz de Queiroz”.

1. Colheita 2. Cultivar 3. Colhedora autopropelida I. Título

"God, grant me the serenity to accept the things I cannot change, the courage to change the things I can, and the wisdom to know the difference."

Reinhold Niebuhr (1892-1971)

ACKNOWLEDGMENTS

First, I thank God for loving me, blessing me, giving me persistence, and never letting me give up.

To my mother Susana, to whom I dedicate all my achievements and who is my example of a strong and independent woman, I thank you for your endless support and for dreaming with me.

To my brother, Eduardo, for whom I try to be a good example and who makes me very proud, thank you for being by my side.

To the "Luiz de Queiroz" College of Agriculture and Animal Science and Pastures Graduate Program for the opportunity and support of the projects.

To my advisor, Prof. Dr. Luiz Gustavo Nussio, for receiving me, supervising, supporting the projects, and for all the professional and personal knowledge transmitted.

To Prof. Dr. Arlindo Saran Netto, for his partnership and support in the development of the project.

To my friends from the Forage Quality and Conservation Group, for all the learning, laughter and help during every step of this work.

To Juliana Machado, thank you for sharing unforgettable moments, sharing knowledge, and helping me. Without your help, this would not have been possible. I wish you much success.

To FAPESP (The State of São Paulo Research Foundation) for my scholarship and financial support.

To CNPq foundation for my first scholarship.

CONTENTS

RESUMO

Maturidades na colheita de híbridos de milho para silagem no desempenho de bovinos de corte em terminação

A silagem de milho planta inteira (SMPI) é o principal volumoso utilizado nas dietas de bovinos de corte em terminação. Tomada de decisões que antecedem a ensilagem, como seleção do híbrido e a maturidade da planta na colheita interferem no valor nutritivo e qualidade da silagem. Neste sentido, um experimento foi conduzido com o objetivo avaliar o efeito do híbrido e maturidade sobre o desempenho de bovinos em terminação. Foram semeados dois híbridos de milho; hibrido A (DKB 390, Dekalb) e hibrido B (BM 3066, Bio Matrix). Para a colheita, foi utilizada colhedora auto propelida com processador de grãos. Parte da lavoura foi colhida 105 dias após a semeadura (DAS) e o restante da lavoura foi colhida 114 dias após a semeadura. As forragens foram ensiladas em quatro silos superfície e armazenadas por 89 dias. Sessenta touros da raça Nelore (402 kg ± 29 kg, 20 meses de idade) foram distribuídos em blocos e alojados em baias individuais por 103 dias. Os tratamentos foram compostos por dois híbridos de milho e dois pontos de colheita em arranjo fatorial, sendo eles: 1) hibrido A colhido com 105 DAS; 2) hibrido A colhido com 114 DAS; 3) hibrido B colhido com 105 DAS; 4) hibrido B colhido com 114 DAS. Em amostras de silagem foram realizadas análises de composição química, pH, produtos de fermentação, contagem microbiana, distribuição de partículas e processamento do grão. O consumo de matéria seca (CMS) dos touros foi determinado diariamente. Variáveis relacionadas aos animais foram mensuradas no início do período experimental e a cada 30 dias. A colheita de SMPI com 114 DAS resultou em maior variação de consumo de matéria seca diária (105 DAS = 7.3 vs. 114 DAS = 8.7%). A interação híbrido e maturidade mostrou tendência para influenciar CMS e ganho de peso médio dos animais. Peso de carcaça quente e rendimento de carcaça foram semelhantes entre os tratamentos. A colheita com 114 DAS resultou em menor deposição de gordura na garupa (105 DAS = 11.5 vs. 114 DAS = 9.7 mm). Os animais que receberam silagem colhida com 105 DAS apresentaram maior preferência por partículas entre 8 e 4-mm. Em conclusão, a colheita tardia da silagem de milho planta inteira aumenta a variação no consumo de bovinos de corte em terminação. A silagem de milho colhida com 114 DAS reduz a deposição de gordura na garupa e a seleção de partículas pequenas de volumoso. O consumo e o ganho de peso dos animais indicaram que os efeitos do avanço da maturidade da planta de milho podem depender do tipo de híbrido.

Palavras-chave: Colheita, Cultivar, Colhedora auto propelida

ABSTRACT

Harvesting maturities of corn silage hybrids on the performance of finishing beef cattle

Whole-plant corn silage (WPCS) is the main roughage used in finishing beef cattle diets. Decisions that precede the ensiling process, such as hybrid selection and plant maturity at harvest, interfere with the nutritional value and quality of the silage. Nonetheless, an experiment was conducted with the objective of evaluating the effect of hybrid and maturity on the performance of finishing cattle. Two corn hybrids were sown: hybrid A (DKB 390, Dekalb) and hybrid B (BM 3066, Bio Matrix). For harvesting, a self-propelled harvester with a grain processor was used. Part of the crop was harvested 105 days after sowing (DAS), and the rest 114 days after sowing. The forages were stored in four silo piles for 89 days. Sixty Nelore bulls (402 kg ± 29 kg, 20 months old) were distributed in blocks and housed in individual pens for 103 days. The treatments consisted of two corn hybrids and two harvesting points in a factorial arrangement, namely: 1) hybrid A harvested with 105 DAS; 2) hybrid A harvested with 114 DAS; 3) hybrid B harvested with 105 DAS; and 4) hybrid B harvested with 114 DAS. In silage samples, analyses of chemical composition, pH, fermentation products, microbial count, particle distribution, and grain processing were carried out. The dry matter intake (I) of the bulls was determined daily. Animal-related variables were measured at the beginning of the experimental period and every 30 days. Harvesting WPCS with 114 DAS resulted in a higher variation in daily dry matter intake (105 DAS = 7.3 vs. 114 DAS = 8.7%). The hybrid and maturity interaction showed a tendency to influence DMI and average weight gain in the animals. The hot carcass weight and dressing were similar between treatments. Harvesting with 114 DAS resulted in less fat deposition on the rump (105 DAS = 11.5 mm vs. 114 DAS = 9.7 mm). Animals that received silage harvested with 105 DAS showed a higher preference for particles between 8 and 4 mm. In conclusion, late harvesting of whole-plant corn silage increases the variation in finishing beef cattle intake. Corn silage harvested with 114 DAS reduces rump fat deposition and the selection of small roughage particles. The consumption and weight gain of the animals indicated that the effects of advancing corn plant maturity might depend on the type of hybrid.

Keywords: Harvest, Cultivar, Self-propelled harvester

LIST OF TABLES

1. INTRODUCTION

Corn silage is known as an abundant source of fiber and high energy value, when compared to other forages, therefore it also contributes to increasing the energy content of finishing diets. Recently, changes in the composition of diets have been observed, such as the replacement of fresh forage, like sugarcane, for conserved forage, such as corn silage, a possible reflection of advances in the intensification of production in the feedlots of Brazil (Millen et al., 2009; Oliveira and Millen, 2014; Silvestre and Millen, 2021). As a result, whole plant corn silage (WPCS) has become the main source of roughage in finishing diets in Brazil (Silvestre and Millen, 2021) and widely used in the United States (Samuelson et al., 2016). The number of feedlot consultant nutritionists who recommend the use of corn silage in diets has grown over the years, increasing from 25.8% in 2009 to 27.3% in 2014, followed by 63.6% in 2016, where it was considered the main source of roughage (Pinto and Millen, 2016).

The harvest point is a very significant factor in silage production and is determined by the phenological stage of the plant. After the last vegetative stage, identified by tasseling, the reproductive stages begin, characterized by grain development. During corn maturation, the sugars in the grains are converted into starch, and their DM content increases (Allen et al., 2003; Ferraretto et al., 2018). Therefore, as corn maturity advances, the proportion of DM in the corn plant changes, resulting from an increase in the proportion of grains and, consequently, a reduction in the proportion of stover (Buxton and O'Kiely, 2003; Ferraretto et al., 2018). Allen et al. (2003) suggested that the optimal harvest point for WPCS would be in the range of 32 to 35% DM. However, with the advancement of technologies, from genetic selection for hybrids with more favorable characteristics for silage production to self-propelled harvesters with processor rollers, harvesting can be carried out at advanced maturity.

Late-maturity harvesting has been suggested as a management tool to increase DM and starch yields per hectare (Owens, 2014). In addition to the increase in starch concentration, late harvesting of WPCS results in a decline in CP, NDF, and ash contents (Johnson et al., 1999; Buxton and O'Kiely, 2003). However, authors have reported that harvesting at advanced maturity can impair the nutrient digestibility of WPCS (Johnson et al., 1999; Ferraretto and Shaver, 2012). The digestibility of the stover portion of corn silage decreases dramatically with progressive maturity due to the increase in lignin content in the cell walls of the plants (Johnson et al., 1999). Ferraretto and Shaver (2012) reported a reduction in the digestibility of starch with a content above 40% DM for WPCS.

The decrease in starch digestibility is related to the increase in the proportion of vitreous endosperm in relation to the proportion of floury endosperm with advancing maturity (Correa et al., 2002). The effect of vitreous endosperm on starch degradation was evidenced when hybrids with different vitreousness at the same maturity stage were compared (Correa et al., 2002). This is because in the vitreous endosperm, the starch granules are surrounded by protein bodies and incorporated into a dense matrix that limits the action of rumen bacteria. In contrast, in the farinaceous endosperm, the starch granules are incorporated into a discontinuous protein matrix and are therefore more accessible to degradation (Kotarski et al., 1992). The grain that has a higher proportion of vitreous endosperm is classified as "flint corn," while the grain consisting mostly of floury endosperm is classified as "dent corn" (Philippeau et al., 1999).

In Brazil, the diversity of corn cultivars with a dent kernel texture is still restricted. In some cases, this classification is applicable only to the shape of the grain and does not cover the proportion of vitreous endosperm. However, the market has a wide variety of maize cultivars available with different characteristics. These cultivars can meet the most varied requirements, whether in terms of germination cycle, planting time, aptitude, productivity, or resistance to pests and diseases, among others. However, grain texture related to vitreous endosperm proportion is rarely evaluated and can be further explored. Although chemical characteristics are directly related to the nutritional value of the plant, physical characteristics, such as grain texture, influence the use of nutrients. It is expected that in the future, the texture of grain will be widespread in Brazil and will be considered in the formulation of diets.

Literature Cited

Allen, M. S., Coors, J. G., Roth, G. W. 2003. Corn silage. In: D. R. Buxton, R. E. Muck, Harrison, H. J., editor Silage Science and Technology. Agron. J., Crop Sci., Soil Sci. Soc. Am. J., Madison, WI. 42:547-608.

Buxton, D. R., and O'Kiely, P. (Eds.). (2003). Preharvest plant factors affecting ensiling. Silage Science and Technology. 42:199-250.

Correa, C. E. S., Shaver, R. D., Pereira, M. N., Lauer, J. G., Kohn, K. 2002. Relationship between corn vitreousness and ruminal in situ starch degradability. J. Dairy Sci. 85:3008-3012.

Ferraretto, L. F., and Shaver, R. D. 2012. Meta-analysis: Effect of corn silage harvest practices on intake, digestion, and milk production by dairy cows. Prof. Anim. Sci. 28(2):141-149.

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. J. Dairy Sci. 101(5): 3937-3951.

Johnson, L., Harrison, J. H., Hunt, C., Shinners, K., Doggett, C. G., Sapienza, D. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. J. Dairy Sci. 82(12):2813-2825.

Kotarski, S. F., Waniska, R. D., Thurn, K. K. 1992. Starch hydrolysis by the ruminal microflora. J. Nutr. 122(1), 178-190.

Millen, D. D., Pacheco, R. D. L., Arrigoni, M. D. B., Galyean, M. L., Vasconcelos, J. T. 2009. A snapshot of management practices and nutritional recommendations used by feedlot nutritionists in Brazil. J. Anim. Sci. 87:3427–3439.

Oliveira, C.A., and D. D. Millen. 2014. Survey of the nutritional recommendations and management practices adopted by feedlot cattle nutritionists in Brazil. Anim. Feed Sci. Technol. 197:64–75.

Owens, F. 2014. New technologies in forage varieties and production. In Proceedings of the 23rd Tri-State Dairy Nutrition Conference, Fort Wayne, Indiana, USA. 103-122.

Philippeau, C., De Monredon, F. L. D., Michalet-Doreau, B. 1999. Relationship between ruminal starch degradation and the physical characteristics of corn grain. J. Anim. Sci. 77(1):238-243.

Pinto, A. C. J., and D. D. Millen, 2016. Situação atual da engorda de bovinos em confinamento e modelos nutricionais em uso. Simpósio de Produção de Gado de Corte (X Simcorte). 1ed. Viçosa/MG: UFV, 1, 103-120.

Samuelson, K. L., Hubbert, M. E., Galyean, M. L., Löest, C. A. 2016. Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State and Texas Tech University survey. J. of Animal Sci. 94:2648-2663.

Silvestre, A. M., and D. D. Millen. 2021. The 2019 Brazilian survey on nutritional practices provided by feedlot cattle consulting nutritionists. Rev. Bras. Zootec. 1-25.

2. EFFECTS OF HYBRID TYPE AND CORN MATURITY ON FINISHING BEEF CATTLE FED WHOLE-PLANT SILAGE

Abstract

The corn harvest point for silage production can influence nutritional composition, nutrient availability, and ensiling efficiency. Corn hybrids may have characteristics that differentiate them and modulate the quality of the silage produced. The objective of this experiment was to evaluate whether the interaction between maturity and type of hybrid influences intake, intake behavior, and performance of finishing beef cattle fed diets containing whole-plant corn silage. The treatments were defined by the combination of maturity and types of hybrids: 1) hybrid A harvested with 105 DAS; 2) hybrid A harvested with 114 DAS; 3) hybrid B harvested with 105 DAS; and 4) hybrid B harvested with 114 DAS. For harvesting, a self-propelled harvester with a grain processor was used. For 103 days, sixty male Nellore cattle (402 kg ± 29 kg, and 20 months old) were used and housed in individual pens. In silage samples, analyses of chemical composition, pH, fermentation products, microbial count, particle distribution, and grain processing were carried out. The dry matter intake (DMI) of the bulls was determined daily. Animal-related variables were measured at the beginning of the experimental period and every 30 days. Harvesting WPCS with 114 DAS resulted in a higher variation in daily dry matter intake (105 DAS = 7.3 vs. 114 DAS = 8.7%). The hybrid and maturity interaction showed a tendency to influence DMI and average weight gain in the animals. Hot carcass weight and carcass yield were similar between treatments. Harvesting with 114 DAS resulted in less fat deposition on the rump (105 DAS = 11.5 mm vs. 114 DAS = 9.7 mm). Animals that received silage harvested with 105 DAS showed a higher preference for particles between 8 and 4 mm. In conclusion, late harvesting of whole-plant corn silage increases the variation in finishing beef cattle intake. Corn silage harvested with 114 DAS reduces rump fat deposition and the selection of small roughage particles. The consumption and weight gain of the animals indicated that the effects of advancing corn plant maturity may depend on the type of hybrid.

Keywords: harvest, cultivar, self-propelled harvester

2.1. Introduction

In addition to its high fiber content, whole-plant corn silage also contains a considerable amount of starch, which makes it a popular feed in ruminant diets in Brazil (Silvestre and Millen, 2021). The maturity stage of the corn plant at harvest is one of the factors that determines the nutritional composition of the silage (Johnson et al., 1999). With the advancement of corn crop maturation, sugars in kernels are converted to starch; thereby, the development of the kernels reduces the fibrous proportion (stalk, leaf, and husk), increases the whole-plant corn DM content (Allen et al., 2003; Ferraretto et al., 2018), and results in a decline in CP, NDF, and ash contents (Johnson et al., 1999; Allen et al., 2003).

Higher DM content at harvest also alters the yield of the crops, ensiling efficiency, and nutrient digestibility. Arriola et al. (2012) harvested at 25, 32, and 37% DM in their study and reported that the yield of DM increased linearly with increasing maturity. The corn silage becomes coarser as the corn plant matures which makes it difficult to compact the forage mass and decreases the packing density (Johnson et al., 2002b). Silage density influences its quality, since it reduces porosity, that is, it prevents oxygen, so harmful to the microorganisms in the silo, from penetrating deeply (Pitt e Muck, 1993). Harvested silage with dry matter between 30 and 40% should be packed to a minimum bulk density of 700 kg as fed/m^3 to keep porosity below 40% (Holmes and Muck, 2007). A plant's maturity also affects its processing. A meta-analysis revealed that the use of processing rollers when WPCS was above 40% DM did not improve grain processing (Ferraretto and Shaver, 2012).

Despite the increase in nutrient concentrations, later maturity at harvest impairs nutrient digestion mainly due the lignification (Ferraretto et al., 2018) of other fibrous plant cell wall components which limits NDF digestibility by ruminal microorganisms (Bal et al., 2000; Jung et al., 2012). Negative effects of maturity on starch digestibility are also reported (Bal et al, 2000; Ferraretto et at., 2015).

A vast diversity of corn cultivars with different characteristics is available on the market. Some characteristics of corn cultivars can define nutrient concentration and digestibility. Selection of hybrids or cultivars that maintain their digestibility with advancing maturity is desirable (Johnson et al., 1999), because combining increased crop yield without compromising animal productivity is more profitable for producers. Starch contributes approximately 50% of the whole-plant corn silage energy (calculated from the NASEM, 2016), so when choosing a corn hybrid for silage, grain characteristics, such as texture, must be considered.

The vitreous endosperm is formed by numerous small polygonal starch granules, surrounded by protein bodies, and are incorporated in the matrix of endosperm cells. This matrix consists mainly of protein and non-starch carbohydrates and is relatively impervious to water and hydrolytic enzymes (Kotarski et al. 1992). In contrast, the farinaceous endosperm is composed of large, rounded starch granules, but most are not encapsulated in the protein matrix (Huntington 1997). Hence, the starch granules in the farinaceous endosperm are more accessible to microorganisms and enzymatic hydrolysis, therefore, they are the most susceptible to digestion (Huntington 1997; Kotarski et al. 1992; Owens et al., 1986).

According to the type and distribution of endosperm in the grains, hybrids can be classified as dented, flint, popcorn, or sweet. Corn hybrids grown in Brazil are flint cultivars or have predominantly flint endosperm (Correa et al., 2002), and flint corn has a greater proportion of vitreous endosperm than dent corn (Philippeau et al., 1999). The representation of the vitreous endosperm proportion is made by vitreousness determined by manual dissection of the grains, where the vitreous endosperm weight is expressed as a percentage of the total endosperm (Dombrink-Kurtzman and Bietz, 1993). With advancing maturity, kernel vitreousness increases while ruminal starch availability decreases, including in dent corn hybrids (Correa et al., 2022).

Therefore, the maturity and type of hybrid can affect the quality of silage and, consequently, the performance of feedlot beef cattle. Neumann et al. (2018) in their study tested two types of hybrids and observed a significant difference in apparent digestibility, which had an impact on greater weight gain, average carcass gain and better feed conversion. However, some studies indicate that although corn hybrids have silages with different nutritional qualities, animal performance was similar (Restle et al., 2006; Rosa et al., 2004). In the work by Zaralis et al. (2014), the corn maturity stage at harvest tended to increase live-weight gain. Nevertheless, Mcgeough et al. (2010) observed that advancing corn maturity at harvest had no effect on body weight or carcass gain.

The objective of this experiment was to evaluate whether the interaction between hybrid type and maturity influences intake, performance, carcass characteristics, and feeding behavior of finishing beef cattle fed diets containing whole plant corn silage.

2.2. Materials and Methods

2.2.1. Ensiling and treatments

At the College of Animal Science and Food Engineering, University of Sao Paulo (Pirassununga, Sao Paulo, Brazil), two hybrids (DKB 390, Dekalb, Monsanto, Dekalb, Illinois, USA, and BM 3066, Biomatrix) were sown on November 7, 2019, at a density of 72,000 seeds per hectare, under a center pivot irrigation system. These hybrids have some different characteristics. The DKB 390 is a simple hybrid with an early maturation cycle that is recommended for grain production and has kernels with a semi-flint texture and an orange color. The BM 3066 is also a simple hybrid with an early maturation cycle, but it is a dual-purpose hybrid that is recommended to produce grains and whole-plant corn silage and has kernels with a dent texture and a yellow color. Companies that developed hybrids shared this information. We named the hybrids A for DKB 390 and B for BM 3066.

The cultural treatments were carried out according to the recommendations for fertilization and liming of the corn crop. The cultural treatments were carried out according to the recommendations for fertilization and liming of the corn crop A fertilizer containing 47 kg ha^{-1} de N + 94 kg ha^{-1} de P_2O_5 + 47 kg ha^{-1} de K_2O was applied in-furrow with the seed. After 13 days of planting, a fertilizer containing 135 kg ha^{-1} de N + 45 kg ha^{-1} de K_2O was applied. Agricultural pesticides applied: Atrazine WG 2.5 kg ha^{-1}; 200 g ha^{-1} of Benzoate; 200 g ha^{-1} of Approach (750 mL/ha).

To define the moment of harvest, the corn plant dry matter content was monitored weekly from crushed samples, which were dried in a forced air circulation oven for 72 h at 55 ºC. Thus, the first harvest occurred 105 days after sowing (DAS), when the corn plant had 37.0% DM (at 55 ºC for 72 hours). At 114 days after sowing (DAS), there was a second harvest when the corn plant had 40.0% DM (at 55 ºC for 72 hours). Then, the treatments were defined by the combination of maturity and types of hybrids: 1) hybrid A harvested with 105 DAS; 2) hybrid A harvested with 114 DAS; 3) hybrid B harvested with 105 DAS; and 4) hybrid B harvested with 114 DAS.

The corn plants were cut 20 cm from the ground with a self-propelled forage harvester (SPFH) New Holland model FR 9060 (New Holland, Pennsylvania, USA) set for a theoretical length of cut (TLOC) of 15-mm and with the cracker processor roller set to a 1-mm roll gap. After harvesting, whole-plant corn forage mass was stored without additive in pile-types silos (approximately 40 tons each) with approximately 6.3 m wide, 1.0 m high, and 14 m long.

2.2.2. Sampling and variables analyzed in forage and silage

One linear meter of plants from both hybrids was manually harvested with 114 DAS for morphological characterization. Corn vitreousness was determined by hand dissection of the grains (Dombrink-Kurtzman and Bietz, 1993) (Table 1). Fifteen ears of each hybrid were collected 114 days after sowing (Correa et al., 2002). Corn grain samples from both hybrids harvested 114 days after sowing were incubated in beef cattle fitted with ruminal cannulas for determination of in situ ruminal starch degradation. Cattles were fed for *ad libitum* intake a diet (% of DM) comprising of 25% corn silage and 75% shelled corn-soybean meal-based concentrate. Corn kernels were dried at 55°C for 72 h, ground through a Wiley mill (4 mm screen; Arthur H. Thomas, Philadelphia, PA), and approximately 5 g of the ground material was weighed into 10 x 25 cm nylon bags. Ruminal incubation times were 7 and 24 hours. Bags were introduced into the rumen at staggered times for removal of all bags at the same time. Immediately after removal from the rumen, bags were washed in a washing machine (Cherney et al., 1990), and dried as described previously.

Table 1. Morphological characteristics of the hybrids.

Item	Hybrid A		Hybrid B	
	Weight[1]	DM basis %	Weight	DM basis %
	Plant components			
Whole plant	3.49	100.0	3.83	100.0
Leaves	0.76	21.8	0.87	22.7
Stalk	0.99	28.4	1.18	30.8
Ear	1.96	56.2	1.76	45.9
Husks, in plant	0.28	8.0	0.54	14.0
Husk, in ear	-	14.3	-	30.7
Kernels, in plant	1.39	39.8	1.40	36.6
Kernels, in ear	-	70.9	-	79.5
Cobs, in plant	0.26	7.44	0.30	7.83
Cobs, in ear	-	13.3	-	17.0
	Other characteristics			
	Hybrid A		Hybrid B	
Total height, m	2.80		2.63	
Ear insertion height, m	1.73		1.54	
Kernel vitreousness, %	53.79		42.60	
Kernel starch degradation 7h, %	65.05		63.69	
Kernel starch degradation 24h, %	93.00		94.01	

[1]Weight in kg of dry matter at 55 ºC for 72 hours.

Forage samples were collected along the forage layers distributed in the silos. After collection, the samples were united and homogenized to form a composite sample per treatment. Samples were dried in a forced-air oven set at 55 ºC for 72 hours, weighed to determine DM content, and then ground in a Wiley-type mill with a 1-mm sieve (A. H. Thomas Scientific, Philadelphia, PA). These dried, ground samples were sent to a commercial laboratory (ESALQ Lab, Piracicaba, SP). Ground samples were scanned on a Foss 5000 Transport near-infrared reflectance spectrophotometer (NIRS) system (Eden Prairie, MN, USA) and processed using NIR calibrations (WinISI version 4.6.11, FOSS Analytical A/S, Denmark) obtained through the Dairy One Forage Laboratory (Ithaca, NY) to determine content of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and ash. The NIR system uses results from chemical analyses to develop calibrations for the equations. A brief description of the analytical methods. Absolute DM was determined by oven drying at 105 °C for 24 hours (Association of Official Analytical Chemists, AOAC Intentional 2012). Crude protein concentration was determined by the Dumas method (Wiles et al., 1998) using a nitrogen analyzer (Leco FP-2000; Leco Corp., St. Joseph, MI, USA). The ash was determined by incinerating the sample at 550 ºC for 8 hours (AOAC, 1990). The neutral detergent fiber (NDF) was analyzed using a TE-149 fiber analyzer (Tecnal Laboratory Equipment, Piracicaba, SP) with the addition of sodium sulfite and thermostable amylase, expressed by discounting the residual ash (Mertens, 2002). The chemical composition of the corn forages, referring to the treatments, is shown in Table 2.

Table 2. Chemical composition of whole-plant corn forage from two hybrids (A and B) and harvested at two maturities (105 and 114 DAS).

Item[1]	105		114	
	A	B	A	B
DM, %	33.6	33.4	36.4	35.9
CP, % DM	10.3	10.5	9.7	10.0
NDF, % DM	36.9	47.0	45.3	42.4
Ash, % DM	5.1	4.9	4.2	4.9

[1]Chemical composition was analyzed by NIRS.

The silages were stored in bunker silos for 89 days before starting the feeding trial. During the feeding period, measurements were made on the silos three times at 30-day intervals. The temperature of the silo panel was measured by inserting a thermometer with a 20 cm stem. To estimate the packing density of each silo, a cylinder (Master Forage probe, Dairy One, Ithaca, NY) was positioned 90 degrees from the panel. This was done at three points at the top, middle and bottom of the silo. The density was calculated considering the diameter and length of the cylinder to determine the volume and mass of silage removed.

The silage samples collected with the cylinder were stored and later used to quantify the fermentation products and chemical composition. Aqueous extracts of the samples were prepared (25 g + 225 g of deionized water and homogenized for 4 min), and after measuring the pH, they were filtered and centrifuged at 10,000 x g for 15 minutes at 4 °C. In gas chromatography with a mass detector (GCMS QP 2010 plus, Shimadzu, Kyoto, Japan) and a capillary column (Stabilwax, Restek, Bellefonte, PA, USA; 60 m, 0.25 mm, id, 0.25 m), volatile fatty acids (VFA), alcohols, and esters were determined. Lactic acid concentrations were determined by colorimetric methods using spectrometry (Pryce, 1969). Microbial counts (molds, yeasts, lactic acid bacteria, clostridia, and aerobic spores) were made by pour planting serial dilutions of aqueous extracts in selective media.

The silage samples were dried and ground to 1mm, then sent to a commercial laboratory (ESALQ Lab, Piracicaba, SP) and analyzed by near infrared spectroscopy (NIR System) as described above. Indigestible NDF (iNDF) was measured by ruminal in situ incubation for 288 h (Huhtanen et al., 1994). Starch content was determined by the modified Back Knudsen method (Hall et al., 2015). Ruminal in situ degradation starch was determined in two beef cattle fitted with ruminal cannula. Silage samples were dried at 55°C for 72 hours and approximately 10 g of the unground material was weighed into 10 x 25 cm nylon bags. Ruminal incubation time was 24 hours. Immediately after removal from the rumen, bags were washed in a washing machine (Cherney et al., 1990), and dried as described previously. The chemical composition, fermentation and microbial profile of whole-plant corn silage are shown in Table 3.

Table 3. Chemical composition and characteristics of whole-plant corn silage from two hybrids (A and B) and harvested at two maturities (105 and 114 DAS).

	105		114	
Item	A	B	A	B
	Chemical composition[1]			
DM, % as fed	35.4±1.6	33.1±0.2	34.8±1.1	35.0±0.7
CP, % DM	7.7±0.6	8.2±0.4	7.9±0.3	8.0±0.1
NDF, % DM	47.0±2.1	48.3±0.7	42.0±2.0	46.2±1.4
iNDF[2], % DM	4.7±0.31	5.54±0.09	3.93±0.33	6.08±0.76
Ash, % DM	4.2±0.3	4.5±0.1	4.8±0.2	4.7±0.6
Starch, % DM	25.9±1.6	25.7±2.4	32.6±2.9	27.3±0.6
Starch degradation 24h, %	84.8±1.7	88.6±0.4	90.3±5.2	87.8±2.1
	Fermentation profile			
pH	3.82±0.17	3.88±0.09	4.04±0.08	4.04±0.06
Lactic acid, % DM	4.15±0.11	5.80±0.45	3.31±0.54	4.25±0.17
Acetic acid, % DMcorr	0.61±0.09	0.84±0.02	0.86±0.13	0.81±0.16
Propionic acid, % DMcorr	0.05±0.01	0.05±0.01	0.05±0.01	0.05±0.01
Ethanol, % DMcorr	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01
Butyric acid, % DMcorr	0.06±0.02	0.06±0.02	0.06±0.02	0.06±0.02
	Silage characteristics			
Density, kg of wet silage/ m^3	422±72.48	490±96.50	436±96.50	475±89.42
Temperature, ºC	38.7±3.70	33.3±3.92	37.4±4.62	36.9±4.27
Loss during feed-out[3], % as fed	9.5±7.83	10.3±7.53	14.5±10.37	13.0±9.65
Daily feed-out rate, cm/ d	10.2±3.43	10.0±3.74	11.2±3.35	10.6±4.58
	Microbial profile			
Lactic acid bacteria, cfu/ g	5.48	5.90	6.15	6.15
Yeasts, cfu/ g	3.30	4.96	5.00	3.00
Moulds, cfu/ g	3.00	3.30	3.30	4.11
Aerobic spores, cfu/ g	5.26	5.30	5.48	4.82
Clostridia, cfu/ g	3.86	3.62	4.07	3.83

[1]DM, CP, NDF, Ash and Starch were analyzed by NIRS. [2]Indigestible NDF determined by 288 h of in situ incubation. [3]Portions of spoiled silage separated and quantified daily.

Undried and unground silage samples had the particle distribution measured from 3 sieves (19, 8, and 4-mm) and a bottom pan, using the Penn State Particle Separator (PSPS). Mean particle length (MPL) was determined using the percentage of particles retained on each sieve (Heinrichs, 2013). The physically effective NDF above the 8-mm sieve (peNDF>8) or above 4-mm sieve (peNDF>4) was determined by sum of the proportion of DM retained on PSPS sieves multiplied by the NDF content of the diet as proposed by Lammers et al. (1996) and Heinrichs (2013), respectively.

The silages were also evaluated for the corn silage processing score (CSPS) as proposed by Ferreira and Mertens (2005). Using dry unground WCPS samples, the kernel was separated from stover fraction by the hydrodynamic separation procedure (Savoie et al., 2004). After separation, the kernel-fraction was re-dried at 55 °C for 72 hours in a forced-air oven and shaking using a Tyler Ro-Tap Shaker (model RX-29, Tyler, Mentor, OH) with a set of 6 sieves with nominal square apertures of 6.70, 4.75, 3.35, 2.36, 1.70, 1.18-mm and a bottom pan. The percentage of kernels smaller than 4.75-mm was determined by the sum of kernels retained at 3.25, 2.36, 1.70, and 1.18-mm sieves and bottom pan (CSPS; Dias Junior et al., 2016). The geometric mean particle size (GMPS, µm) and surface area (cm^2 g^{-1}) were calculated using a log normal distribution (Baker and Herrman, 2002 described by Dias Junior et al., 2016). The physical characteristics of whole-plant corn silage are shown in Table 4.

Table 4. Physical characteristics of whole-plant corn silage from two hybrids (A and B) and harvested at two maturities (105 and 114 DAS).

	105		114	
Item	A	B	A	B
	Silage distribution[1]			
Sieve mm, %				
19	14.8±1.34	9.2±3.13	10.5±3.77	12.5±3.09
8	63.5±1.77	63.5±2.48	63.9±4.43	64.4±2.09
4	11.8±0.97	14.2±1.16	17.0±5.42	12.1±0.77
Pan, %	9.9±0.89	13.1±0.67	8.6±1.91	10.9±0.32
MPL[2], mm	10.72±0.21	9.46±0.41	10.74±1.49	10.29±0.39
Sgm[3]	2.02±0.02	2.06±0.04	1.92±0.05	2.03±0.04
peNDF >8[4], % DM	36.79±1.34	35.12±1.35	31.32±2.93	35.56±1.37
peNDF >4, % DM	42.36±1.80	42.00±0.89	38.38±1.06	41.15±1.35
	Kernel distribution			
Sieve mm, %				
6.70	10.5	9.0	10.1	14.1
4.75	32.4	25.0	34.0	28.6
3.35	20.5	17.5	22.9	19.6
2.36	13.8	15.9	15.0	15.4
1.70	6.0	10.2	5.7	7.0
1.18	5.8	9.6	4.1	5.4
Pan, %	10.9	15.7	8.2	9.9
% kernels < 4.75-mm	57.1	65.9	56.0	57.3
GMPS[6], µm	3.4	2.92	3.65	3.48
Surface area, cm^2/ g	16.9	19.1	15.4	16.5

[1]Particle distribution using Penn State Particle Separator. [2]MPL: mean particle length. [3]Sgm: standard deviation geometric mean. [4]Physically effective NDF above the 8-mm PSPS sieve (Lammers et al. 1996). [5]Porcent of kernels passing through a 4.75-mm sieve. [6]GMPS: geometric mean particle size.

2.2.3. Animals, experimental diets, and evaluations

The animal performance trial was conducted from Junho 4, 2020, to September 16, 2020, in a barn with individual pens. The pens had a concrete floor, each water tank served two animals and individual feed bunk. The adaptation period to the diets and facilities took 18 days and the comparison period for the diets was 103 days. The trial protocol was approved by the Faculty of Animal Science and Food Engineering - Research Ethics Committee (Protocol nº 1063261020).

Sixty Nellore cattle, granted by University of São Paulo, Fernando Costa campus, were arranged in blocks of four cattle according to body weight (391 kg ± 27 kg) and within blocks were random assigned for four treatments. Trial diets were formulated to ensure predetermined fiber intake, meet protein, energy, mineral and vitamin requirements according to NASEM (2016) guidelines, and provide the animal with a weight gain of 1.5 kg d^{-1}. Treatments were represented by diets containing 75% concentrate and 25% whole-plant corn silage from different hybrids and maturities (Table 5). The inclusion of 25% silage in the diets was determined according to the recommendations of 4% to 8% of peNDF>8 (NASEM, 2016).

Table 5. Ingredients and chemical composition of the experimental diets.

Item	105		114	
	A	B	A	B
	Ingredients			
Whole-plant corn silage, %	25.00	25.00	25.00	25.00
Corn kernel, ground %	68.85	68.85	68.85	68.85
Soybean meal, %	3.00	3.00	3.00	3.00
Urea, %	1.20	1.20	1.20	1.20
Limestone, %	1.00	1.00	1.00	1.00
Mineral supplement [1], %	0.75	0.75	0.75	0.75
White salt, %	0.20	0.20	0.20	0.20
	Nutrients composition			
DM, %	60.29±2.91	57.08±0.75	60.48±4.05	59.48±3.96
CP, % DM	15.3±2.1	15.6±1.3	14.7±0.4	15.9±2.3
NDF, % DM	18.5±1.1	18.9±2.0	16.1±2.7	18.9±2.5
Forage NDF, % DM	11.8±0.5	12.1±0.2	10.5±0.5	11.6±0.3
peNDF>8[2], % DM	4.98±1.36	5.17±1.20	4.18±1.01	6.09±2.62
peNDF>4, % DM	7.30±1.57	7.67±1.61	6.26±1.33	8.39±3.13
Ash, % DM	6.8±2.8	6.3±1.2	5.4±1.8	7.0±2.5

[1]Composition per kg: 215 g Ca, 160 mg Co, 2700 mg Cu, 60 g S, 1600 mg F, 160 g P, 135 mg I, 2700 mg Mn, 80 mg Se, 8100 mg Zn, 4000 mg of monensin sodium.
[2]Physically effective NDF above the 8-mm PSPS sieve.

Spoiled silage was removed manually with a fork every morning and then weighed to obtain the percentage of losses. The diet ingredients were mixed by a mixed wagon to obtain a total mixed ration (TMR) (Mod.: Unimix 1200, Casalle). The bulls were fed once a day at approximately 9am for *ad libitum* intake. The orts of the ration offered were collected and weighed daily before the next feed to calculate the dry matter intake (DMI) of each bull. The amount of ration to be offered was daily adjusted according to the previous DMI. Samples of silages were collected twice per week to correct DM and quantity in kg to be added in diets. Throughout the trial, diet samples were collected, dried, and ground to determine DM, CP, NDF and ash (Table 5).

Individual samples of orts and TMR were collected to determine the particle size distribution (Kononoff et al., 2003). Undried and unground samples had the particle distribution measured with Penn State Particle Separator (PSPS). Sorting behavior was determined by the observed intake of each fraction retained in each sieve, expressed as a percentage of the predicted intake (% as fed); values below 100% indicate selective refusals, values above 100% indicate a preferential consumption and values equal to 100% indicate no preference (Leonardi and Armentano, 2003).

The chewing activity behavior was evaluated three times at 30-days intervals with the visual observation of buccal activity every 10 minutes for 24 h (Maekawa et al., 2002). The activities considered were eating, drinking water, ruminating, and idleness. Chewing time was defined as the sum of eating and rumination time. Meal size, meal duration, break between meals, number of daily meals, and duration of first meal were calculated. The chewing per unit of DMI and DMI per meal were calculated using the DMI measured on the day of the determination of chewing activity.

Shrunk body weight (SBW) was measured after 14 hours of fasting (during the night) at the beginning of the feeding trial and every 30 days. The SBW was used to calculate the average daily gain (ADG), based on the trend of the SBW linear regression on days of comparison of the diets. Feed efficiency was calculated using ADG/DMI.

Carcass traits were evaluated using ultrasonography at the beginning and end every 30 days (Mod.: Aloka SSD500). For measuring the ribeye area and back fat thickness, the ultrasound probe was placed above the *Longissimus dorsi* muscle, between the 12th and 13th ribs. Regarding fat thickness in the rump, the probe was positioned at the intersection of the *Gluteus medius* muscle and the *Biceps femoris*, located between the ileum and ischium bones. The images generated by ultrasound were interpreted using software Bia Pro Plus (Designer Genes Technology). A energia líquida para mantença (NEm) e energia líquida para ganho (NEg) das dietas foram estimadas por meio das equações propostas por Zinn e Shen (1998).

On September 16, 2020, the bulls were shipped to a near commercial slaughterhouse (Cordeiropolis, SP, Brazil), after 16-hours of fasting, respecting pre-slaughter practices. The hot carcass weight was determined to calculate the dressing (hot carcass/SBW).

2.2.4. Statistical analysis

The characteristics of silage and forage were presented as mean ± standard deviation. The statistical design used to analyze the animal performance data was complete randomized blocks, with factorial treatment structure, two corn hybrids and two maturities in corn harvest. The data were submitted to analysis of variance and the averages were compared by Tukey's test ($P<0.05$) using the PROC MIXED feature of the SAS program (v 9.4), with random effect for block, described by the following model: $Y_{ijk} = \mu + B_i + D_j + T_k + DT_{jk} + e_{ijk}$; in which: μ = overall mean; B_i = random effect of blocks ($i = 1,\ldots,15$); D_j = fixed effect of hybrids (j = A, B); T_k = fixed effect of maturities (k = 105, 114); DT_{jk} = interaction between hybrids and maturities; e_{ijk} = residual error.

The completely randomized design was applied to data from chemical, physical and digestibility analyses. The days of the collection were used as repeated measurements within the model. The model included the fixed effects of hybrids, maturities, and the interaction hybrids x maturities.

2.3. Results

Forage morphology and chemical composition data do not include statistical analysis, but we can observe some relevant differences (Tables 1 and 2). Hybrid B showed higher green mass (the whole plant, leaves, and stalks), but hybrid A had heavier ears. Hybrid A corn plants were taller than B hybrid plants (A = 2.80 m vs. B = 2.63 m). Grain A showed the highest vitreousness, while the difference between the hybrids was 12.19%. Grain starch degradation indicated that A degraded more at 7 hours (A = 64.05% vs. B = 63.69%) while B hybrid degraded more at 24 hours (A = 93% vs. B = 94.01%).

In table 2, the final dry matter of the forages of the two hybrids was similar at the two harvesting points (105 = 33.5±0.16% vs. 114 = 36.2±0.34%). Crude protein and ash were also similar at both harvest maturities (CP: 105 = 10.4±0.14% vs. 114 = 9.9±0.21%; Ash: 105 = 5.0±0.14% vs. 114 = 4.6±0.49%). While the FDN for hybrid A increased with maturation (8.4%), the FDN for B decreased by 4.6%.

The chemical composition of silage suggests that the proportion of some nutrients was influenced by maturity. The NDF: starch ratio decreased with advancing maturity for both hybrids. The NDF of the hybrid A decreased by 5% and that of the hybrid B dropped by 2.1%, while starch increased by 6.7 and 1.7%, respectively. Starch degradation in hybrid A silages increased from 84.8 to 90.3% as maturity increased from 105 to 115 DAS. However, for B hybrid silage, starch disappearance decreased from 88.6 to 87.8%.

The pH of silage harvested with 114 DAS was higher than the pH of silage harvested with 105 DAS (105 = 3.85±0.04 vs. 114 = 4.04±0.00). Lactic acid concentration declined with advancing maturity in both hybrids (105 = 4.98±1.17% DM vs. 114 = 3.78±0.66% DM). However, the acetic acid concentration was similar in all treatments (0.84±0.03% DMcorr), except for treatment A at 105 DAS with 0.61% DMcorr.

The average packing density was 456±32 kg of wet silage/m3. Except for the B treatment at 105 DAS with an average temperature of 33.3 ºC, the temperature of the silages was similar (37.7±0.9 ºC). Losses during feed-out were higher in late harvest silages (105 = 9.9±0.6% vs. 114 = 13.8±1.1%). Daily feed-out rates were similar between treatments (10.5±0.5 cm/d).

The amount of colony forming units of lactic acid bacteria increased with maturity in the silages of both hybrids (105 = 5.69±0.30 cfu/g vs. 114 = 6.15±0.0 cfu/g). Except for the B treatment at 114 DAS with 4.11 cfu/g of molds, the mold count of the silages was similar (3.20±0.17 cfu/g).

The distribution of silages in Penn State Particle Size suggests that maturity influenced the cut. Maturity decreased the proportion of particles larger than 19 mm (105 = 14.8 vs. 115 = 10.5%) and increased particle retention on the 4-mm sieve (105 = 11.8 vs. 114 = 17.0%) for the A hybrid. The opposite was observed for the B hybrid; maturity increased the proportion of particles larger than 19 mm (105 = 9.2 vs. 114 = 12.5%) and decreased particle retention in the 4 mm pear (105 = 14.2 vs. 114 = 12.1%). However, the mean particle length was similar regardless of hybrid or maturity (mean 10.30±0.6). The peNDF of the hybrid A suffered a considerable decrease of 5.5% and 4.0% for peNDF>8 and peNDF>4, respectively.

The percentage of kernel below the 4.75-mm sieve indicates the efficiency of grain processing. A decrease from 57.1% at 105 DAS to 56.0 at 114 DAS was observed for the A hybrid. However, the proportion of grain below the 4.75-mm sieve dropped aggressively from 65.9% for B hybrid silage harvested at 105 DAS to 57.3% when harvested at 114 DAS. The kernel processing scores of both hybrids declined with advancing maturity. The processing declined by 1.1% and 8.6% for hybrids A (105 = 57.1 vs. 114 = 56.0%) and B (105 = 65.9 vs. 114 = 57.3%), respectively

The bulls that received silage harvested at 114 DAS showed higher daily DMI variation (105 = 7.29% vs. 114 = 8.71%; P = 0.02) (Table 6). Factors H and DAS influenced NDF consumption (P = 0.02; P = 0.02). The NDF consumption was higher for the B hybrid and for the harvest at 114 DAS. Forage NDF intake showed a trend (P = 0.06), in which the hybrid B was higher (A = 1.05 kg d^{-1} vs. B = 1.13 kg d^{-1}). There were trends for the interaction between hybrid and DAS for the variables DMI, ADG and carcass gain (P < 0.10). In treatments of the hybrid A, the DAS content at harvest showed a tendency to increase animal performance parameters, with higher gains when harvested at 114 DAS. The DMI was 0.5 kg MS d^{-1} higher, increasing ADG by 0.112 kg d^{-1} and carcass gain (1.151 kg d^{-1} vs. 1.241 kg d^{-1}). However, for treatments with hybrid B, the DAS content at harvest had an inverse effect on animal performance, decreasing gains when harvested at 114 DAS. The ADG was 0.204 kg d^{-1} lower a result of the decrease in DMI (10.02 kg d^{-1} vs. 9.13 kg d^{-1}), also reducing carcass gain (1.288 kg d^{-1} vs. 1.179 kg d^{-1}). No differences were observed for initial BW, final BW, and feed efficiency.

Table 6. Hybrid effects (A vs. B) on whole-plant corn silage harvested at two maturities (105 vs. 114 DAS) in the diet on the performance of Nellore bulls.

Item	105		114		SEM[1]	*P-value*[2]		
	A	B	A	B		H	DAS	H*DAS
DMI, kg d^{-1}	9.34	10.02	9.84	9.13	0.202	0.97	0.58	0.06
Dairy DMI variation, %	7.07	7.51	8.17	9.24	0.312	0.21	0.02	0.61
Intake NDF, kg d^{-1}	1.73	1.89	1.58	1.73	0.038	0.02	0.02	0.85
Intake fNDF, kg d^{-1}	1.08	1.14	1.02	1.11	0.023	0.06	0.28	0.68
Initial BW, kg	401	403	400	404	3.71	0.29	0.92	0.70
Final BW, kg	560	586	571	566	6.51	0.28	0.61	0.13
ADG, kg d^{-1}	1.543	1.774	1.655	1.570	0.045	0.38	0.58	0.06
Carcass gain, kg d^{-1}	1.151	1.288	1.241	1.179	0.032	0.52	0.87	0.09
Feed efficiency	0.165	0.175	0.170	0.172	0.003	0.37	0.84	0.52

[1]SEM: standard error of the mean. [2]H: hybrid. DAS: days after sowing. H*DAS: interaction between hybrid and days after sowing

The DAS at harvest influenced biceps femoris fat thickness (P < 0.01), which was 1.75 mm higher for bulls that intake silage harvested at 105 DAS (105 = 11.45 mm vs. 114 = 9.7 mm). For backfat thickness (P = 0.09), the DAS at the harvest showed a tendency to decrease according to the increase in DAS (105 = 9.2 mm vs. 114 = 7.9 mm). Regarding carcass traits, no other differences were observed (Table 7).

Table 7. Hybrid effects (A vs. B) on whole-plant corn silage harvested at two maturities (105 vs. 114 DAS) in the diet on the carcass traits of Nellore bulls.

Item	105		114		SEM[1]	*P-value*[2]		
	A	B	A	B		H	DAS	H*DAS
Hot carcass weight, kg	319	334	328	324	4.45	0.42	0.87	0.15
Dressing, %	56.9	56.9	57.4	57.1	0.22	0.72	0.38	0.79
Back fat thickness, mm	8.6	9.8	7.7	8.1	0.38	0.30	0.09	0.55
Rump fat thickness, mm	11.4	11.5	9.1	10.3	0.34	0.31	<0.01	0.37
LM area, cm^2	97.2	98.0	96.3	98.8	1.27	0.48	1.00	0.72
NEm, Mcal/ kg	2.43	2.52	2.45	2.45	0.028	0.37	0.63	0.46
NEg, Mcal/ kg	1.72	1.80	1.73	1.74	0.024	0.36	0.63	0.45

[1]SEM: standard error of the mean. [2]H: hybrid. DAS: days after sowing. H*DAS: interaction between hybrid and days after sowing

The feeding behavior of the bulls is shown in Table 8. The only difference observed in the feeding behavior of bulls regards the duration of the first meal, which tended to reduce in response to the increase in days after sowing (105 = 46.32 min vs. 114 = 37.66 min). The means for eating, ruminating, and chewing were 206 min, 263 min, and 469 min, respectively.

Table 8. Hybrid effects (A vs. B) on whole-plant corn silage harvested at two maturities (105 vs. 114 DAS) in the diet on the feeding behavior of Nellore bulls.

Item	105		114		SEM[1]	*P-value*[2]		
	A	B	A	B		H	DAS	H*DAS
Eating, min/d	200	209	213	202	5.24	0.90	0.79	0.33
Ruminating, min/d	272	260	254	266	7.07	1.00	0.67	0.41
Chewing, min/d	472	469	467	467	7.40	0.93	0.83	0.91
Chewing/DMI, min/kg DM	33.66	31.37	31.79	31.64	0.775	0.35	0.54	0.41
First meal, min	48.44	44.20	35.33	40.00	2.533	0.97	0.09	0.37
Meals, /d	9.1	9.3	9.7	9.8	0.20	0.76	0.11	0.95
Meal size, g DM/ meal	1717	1784	1599	1666	58.9	0.53	0.27	1.00
Meal lenght, min/ meal	20.7	21.3	21.5	20.3	0.551	0.77	0.95	0.46
Intermeal interval, min	145	135	131	134	3.28	0.51	0.19	0.25
Intake rate, g DM/ min	78.0	78.1	76.4	82.4	2.96	0.51	0.76	0.52

[1]SEM: standard error of the mean. [2]H: hybrid. DAS: days after sowing. H*DAS: interaction between hybrid and days after sowing

In general, bulls from all treatments preferred TMR particles larger than 4 mm (values > 100%) and selected against particles smaller than 4 mm (values < 100%) (Table 9). However, for particles retained on the 4-mm sieve, bulls that received silage harvested at 105 DAS showed a greater preference (P = 0.04) (105 = 109.5 % vs. 114 = 105.85 %).

Table 9. Hybrid effects (A vs. B) on whole-plant corn silage harvested at two maturities (105 vs. 114 DAS) in the diet on the particle sorting index of Nellore bulls.

Item	105		114		SEM[1]	*P-value*[2]		
	A	B	A	B		H	DAS	H*DAS
19 mm, %	117.2	117.9	119.8	117.5	0.74	0.58	0.49	0.33
8 mm, %	115.7	115.9	115.3	116.2	0.71	0.71	0.97	0.81
4 mm, %	109.1	110.0	105.8	105.9	0.90	0.80	0.04	0.81
Pan, %	92.3	90.9	93.3	91.9	0.44	0.10	0.25	0.99

[1]SEM: standard error of the mean. [2]H: hybrid. DAS: days after sowing. H*DAS: interaction between hybrid and days after sowing

2.4. Discussion

The vitreousness of the B hybrid (42.60% with 72.36% DM) is in accordance with the grain texture (dented) classification attributed by the company and with data from other tests. Correa et al. (2002), studying Brazilian flint and American dent hybrids, observed that the average vitreousness of Brazilian flint hybrids with 92.0% DM was 73.1% (64.2% to 80.0%), while the average vitreousness of American dent hybrids with 87.1% DM was 48.2% (34.9% to 62.3%). In a study with American hybrids, Philippeau and Michalet-Doreau (1997), found 66.2% vitreousness in flint hybrids and 45.4% vitreousness in dent in the advanced stage of maturity (39.6% DM). In another study, vitreousness was 71.8% for flint and 51.4% for dent hybrids (Philippeau et al., 2000). The vitreousness of the A hybrid was lower than the flint hybrids and higher than the dent hybrids (54.79% with 72.22% DM); thus, the texture classification of the semi-flint grain attributed by the company is consistent with the vitreousness.

Grain B harvested with 114 DAS, which had lower vitreousness than A, showed more starch degradation. Correa et al. (2002) observed that increasing maturity had affected the ruminal availability of grains with higher vitreousness (55.2%) more than grains with low vitreousness (36.3%). Corroborated by Johnson et al. (2002a), corn hybrids with high vitreousness may have a more pronounced decrease in starch digestibility in response to delayed harvest. In this experiment, corn samples were milled through a 2 mm Wiley screen. The standardization of particle size may have reduced the sensitivity of the *in situ* assay to detect differences in degradation between hybrids.

Grain texture may also interfere with starch degradation in whole-plant maize silage (Bal et al., 2000). Starch degradation of silage harvested with 105 DAS was 3.8% higher for hybrid B. There was a 5.5% increase in the starch degradation of silage for hybrid A, from 105 to 114 DAS. Bal et al. (2000) observed an increase in the disappearance of ruminal starch from the early dent stage to 1/4 milk line and from this to 2/3 milk line, but a decrease from 2/3 milk line to the black layer. In hybrid B, starch degradation decreased by 0.8%.

It is common that after vegetative growth, as the maturation stage advances, the greatest changes are associated with grain development, which causes increases in DM content and a reduction in the fibrous portion (Bal et al., 2000; Ferraretto et al., 2018). The NDF contents of both hybrids decreased with advancing maturity (A = 5.0% vs. B = 2.1%), while starch concentrations increased (A = 6.7% vs. B = 1.6%). The change in the NDF:starch ratio was more pronounced in the hybrid A, while in B the change was more subtle.

Measuring the pH and quantifying the organic acids and alcohols are important to evaluate the fermentation profile of the silage (Kung Jr. et al., 2018). The pH and lactic acid concentrations in this experiment (3.95 and 4.38%, respectively) were within the typical range of 3.7-4.0 and 3-6%, respectively (Kung Jr. et al., 2018). Lactic acid is usually the most abundant acid in silage and is the one that most contributes to the drop in pH because it is stronger than the others are. Typical concentrations of acetic acid are between 1 and 3% for corn silage harvested between 30 and 40% DM (Kung Jr. et al., 2018). However, the acetic acid concentrations in this experiment were below 1%. Low concentrations of acetic acid may be one of the factors that explain why these silages tend to be less aerobically stable. Der Bedrosian et al. (2012), found no effect of hybrid type on acetic acid concentration, nor did they observe interactions between hybrid, maturity, and storage length factors. The propionic acid and butyric acid concentrations of the silages were within the expected values (<0.1 and 0%, respectively); however, the average ethanol concentration was below the ideal range of 1-3% (Kung Jr. et al., 2018).

To produce good quality silage, it is necessary to achieve adequate fermentation and for this to occur oxygen cannot be involved in this process as it allows plant enzymes and aerobic microorganisms to breathe, consuming readily available nutrients and energy leading to production water, carbon dioxide, heat, free ammonia and contributing to DM loss (McAllister and Hristov, 2000). The detrimental effect of oxygen can be mitigated by reducing porosity and decreasing the rate of movement of oxygen through the silage when exposed to it. For this reason, density plays a fundamental role in the quality of the silage, as its increase decreases porosity (Pitt and Muck, 1993). The density recommendation is 705 kg m^{-3} (Holmes and Muck, 2007). The packing densities found in this trial indicate a packing density lower than the recommendation for WPCS, with 422 to 490 kg m^{-3} being found. However, some studies showed that bunker silos had a higher DM density than silage piles (Norell et al., 2013; Visser, 2005). Density decreases with advancing corn plant maturity, but it is possible to achieve the recommended density by limiting the DM content to the ideal range of 30 to 40% (Borreani et al., 2018; Johnson et al 2002a; Holmes and Muck 2007). Furthermore, the densities of treatments in this trial were similar regardless of forage dry matter content. The forage delivery rate in the silo may have influenced the compaction efficiency (Visser, 2005).

In addition to producing high-quality silage, its preservation is essential even after opening the silo and an adequate feed-out rate can mitigate aerobic deterioration. Thus, the recommended feed-out rate was 250 kg m^{-2} (Bernardes et al., 2021), but the data presented show that the ideal rate was not achieved and may have influenced DM losses.

The data show losses are higher at 114 DAS during feed-out. According to the literature, the ideal moisture content for ensiling corn whole-plant is 30–35% under normal conditions, and the most significant losses are more frequently detected in extremely humid silages (<30% DM) (Guyader et al., 2018; McDonald et al., 1991). However, dry matter loss is negatively related to packing density and feeding rate (Borreani et al., 2018). Therefore, the DM losses in this study may have been a result of the low packing densities and feeding rates presented by all treatments. Particle retention in the 19-mm sieve was higher than 10%; insufficient compaction (due to high harvesting capacity and forage delivery in the silo); and the absence of an oxygen barrier may have contributed to higher DM losses. Therefore, the late corn harvest did not compromise the fermentative pattern and the silage densities, even with slightly higher feed-out losses (a sign of lower aerobic stability).

In this study, spoiled silage was removed, mainly from the top of the silo, weighed (to estimate losses) and discarded, before removing silage suitable for animal feed. This practice of discarding spoiled silage is not common among producers (Bernardes and Rego, 2014).

Harvesting the B hybrid with 114 DAS resulted in an increase in the proportion of particles larger than 19 mm. This was accompanied by a decrease in the proportion of particles retained on the 4-mm sieve and bottom. This resulted in an increase in the average particle length of the B silage. However, for the hybrid silage A, the results point to the opposite. The higher proportion of particles retained on the 19-mm sieve at 105 DAS may be related to the higher NDF content at this maturity.

The geometric mean particle size (GMPS) increased when harvested at advanced maturity. Grain particle size has a negative relationship with the disappearance of ruminal DM (Dias Junior et al., 2016). The increase in DAS content decreased the percent of kernel passing through a 4.75-mm sieve, which reinforces the data of Ferraretto and Shaver (2012), who reported that kernel processing is influenced by the maturity stage at harvest. When the water content of the plants has decreased below 60% (>40% DM) it becomes difficult to process the kernels even with the use of processor rollers. However, this reduction in kernel processing did not interfere with the starch degradation of the hybrid A.

Treatments that showed higher DMI resulted in higher ADG. The productive performance of animals is the result of the intake, digestibility, and metabolism of nutrients, but among these factors, intake has the greatest influence. Intake is controlled by physiological, physical, and psychogenic factors (Mertens, 1994). Energy level in the diet greater than the animal's requirement can limit consumption physiologically, while the amount and quality of forage in the diet can cause physical filling, which also limits consumption. Therefore, it is important to set the roughage level below the physical restriction point to increase DMI and NEg (Galyean and Hubbert, 2014). In Brazilian feedlot diets in which corn silage is the main source of roughage, its inclusion is around 16.8% DM (Silvestre and Millen, 2021). The level of inclusion of silage in the diets was the same for all treatments (25% of the diet).

The peNDF is used as an indicator of the limit of the proportion of NDF coming from long fibers that do not interfere with intake (NASEM, 2016). However, a relationship was observed between peNDF and DMI, in which treatment with higher peNDF had lower intake. Forage NDF can also be used to control rumen fill. The performance efficiency of feedlot cattle may decrease as the aNDFom forage level decreases by 6% (Galyean and Defoor, 2003). Salinas-Chavira et al. (2013) reported that increasing aNDFom forage level did not affect ADG but tended to reduce gain efficiency and the net energy estimation of the diet. Therefore, the reduction of forage NDF in the diets may have contributed to the effects on intake of NDF, DMI, ADG, and carcass gain.

Both hybrids' starch content increased with maturity, but not to the point that it interferes with their daily intake of the animals. However, the animals fed silage harvested at 114 DAS tended to finish the first meal in a shorter time. This suggests that starch may have acted on the satiety of the animals. When microorganisms in the rumen ferment starch, it produces propionic acid, which is absorbed into the small intestine as propionate, which is recognized by the organism of ruminants as an energetic regulator (Allen, 2000). Krehbiel et al. (2006) reported that finishing cattle present lower consumption in response to the high energy density of the diet.

In general, the animals preferred longer particles associated with roughage; this behavior was evident and recurrent. Bulls from Nellore often sort particles in favor of roughage, especially when their diets are high in concentrates (Caetano et al., 2015). Ferreira (2003) asserts that animals can choose food that meets their nutritional needs as well as their metabolic or physiological needs. Silages harvested at 105 DAS showed a higher percentage of NDF and a lower percentage of starch compared to silages harvested at 114 DAS. The effect of maturity on the preference for particles between 8 and 4 mm indicates the opportunity for further studies to better understand this response.

Metabolic digestive disturbances, such as subclinical acidosis, are commonly associated with large daily changes in feeding behavior and erratic feed intake (Schwartzkopf-Genswein et al., 2003). There was a significant difference in the daily variation of consumption, even though DMI only showed a trend. This trial, conducted with individually fed animals, favored the detection of intake fluctuations (Owens, 1998). Schwartzkopf-Genswein et al. (2003) reported that multiple feed deliveries per day are one of the feedlot management's practices that helps to regulate feeding behavior and decrease variations in feed intake; however, it was not possible to adopt this practice in this study. Few studies have demonstrated that voluntary variability in *ad libitum* feed intake impairs the growth performance of cattle (Schwartzkopf-Genswein et al., 2003). Although this may have happened especially for treatments with hybrid B, the animals that showed higher DMI variation had lower ADG (silage harvested at 105 DAS). While for the hybrid A, the daily variation of consumption did not interfere with the performance of the animals because, even with a higher DMI variation, they presented a higher ADG (silage harvested at 114 DAS).

Although there was no significant difference in hot carcass weight and carcass yield, the animals showed differences in rump fat thickness. Dressing was like the average of other experiments with Nellore bulls aged close to 24 months (Caetano et al., 2015; Caetano et al., 2021; Parra et al., 2021). The mean final body weight, as well as the ADG, exceeded the estimated mean (556.5 kg for 103 days) based on the formulation targeting a weight gain of 1.5 kg d^{-1}. By subtracting the final weight obtained from the predicted one we observed that the animals fed silage harvested at 105 DAS gained 16.5 kg more than expected. In contrast, those fed 114 DAS gained 12.0 kg. To prevent the muscle fibers from shortening due to cold, back fat thicker than 3 mm is desirable (Resende et al., 2019). The animals had an average of 8.55 mm of fat thickness. Fat thickness was greater for hybrid B harvested at 105 DAS, probably because the ADG (1.774 kg d^{-1}) has been higher than predicted. Whereas the effect of maturity on fat thickness in the A 105 DAS treatment is contradictory. This is because it was with silage at 114 DAS, with a higher percentage of starch, that the animals showed greater consumption and weight gain.

2.5. Conclusions

Our results suggest that the late harvest of whole-plant corn silage increases the variation in consumption of finishing beef cattle, an indicator of rumen health. Late-maturity corn silage reduces subcutaneous fat deposition and the selection of small roughage particles. Hybrid A can promote better performance when harvested with 114 DAS, in contrast to hybrid B, which can promote better performance with 105 DAS. Hybrid B harvested with 105 DAS tended to be the best choice based on average daily weight gain. Therefore, the intake and weight gain of the animals indicated that harvesting corn for silage with advanced maturity can negatively affect the performance of finishing beef cattle; however, this effect can be positive depending on the type of hybrid.

Literature Cited

Allen, M. S., Coors, J. G., Roth, G. W. 2003. Corn silage. In: D. R. Buxton, R. E. Muck, Harrison, H. J., editor Silage Science and Technology. Agron. J., Crop Sci., Soil Sci. Soc. Am. J., Madison, WI. 42:547-608.

AOAC International. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., International, Arlington, VA.

AOAC International. 2012. Official Methods of Analysis. 19th ed. Assoc. Off. Anal. Chem. International, Arlington, VA.

Arriola, K. G., Kim, S. C., Huisden, C. M., Adesogan, A. T. 2012. Stay-green ranking and maturity of corn hybrids: 1. Effects on dry matter yield, nutritional value, fermentation characteristics, and aerobic stability of silage hybrids in Florida. J. Dairy Sci. 95(2): 964-974.

Baker, S., and T. Herrman. 2002. Evaluating particle size. MF-2051. Kansas State Univ., Manhattan.

Bal, M. A., Shaver, R. D., Shinners, K. J., Coors, J. G., Lauer, J. G., Straub, R. J., Koegel, R. G. 2000. Stage of maturity, processing, and hybrid effects on ruminal in situ disappearance of whole-plant corn silage. Anim. Feed Sci. Technol. 86(1-2):83-94.

Bernardes, T. F., and A. C. Rêgo. 2014. Study on the practices of silage production and utilization on Brazilian dairy farms. J. Dairy Sci. 97(3):1852-1861.

Caetano, M., Goulart, R. S., Silva, S. D. L., Drouillard, J. S., Leme, P. R., Lanna, D. P. D. 2015. Effect of flint corn processing method and roughage level on finishing performance of Nellore-based cattle. J. Anim. Sci. 93(8):4023-4033.

Caetano, M., Goulart, R. S., Silva, S. L., Leme, P. R., Pflanzer, S. B., Dos Santos, A. C., Lanna, D. P. D. 2021. Effects of the Duration of Zilpaterol Hydrochloride Supplementation and Days on Feed on Performance, Carcass Traits and Saleable Meat Yield of Nellore Bulls. Animals. 11(8): 2450.

Cherney, D. J. R., Patterson, J. A., Lemenager, R. P. 1990. Influence of in situ bag rinsing technique on determination of dry matter disappearance. J. Dairy Sci. 73(2):391-397.

Correa, C. E. S., Shaver, R. D., Pereira, M. N., Lauer, J. G., Kohn, K. 2002. Relationship between corn vitreousness and ruminal in situ starch degradability. J. Dairy Sci. 85:3008-3012.

Der Bedrosian, M. C., Nestor Jr, K. E., Kung Jr, L. 2012. The effects of hybrid, maturity, and length of storage on the composition and nutritive value of corn silage. J. Dairy Sci. 95(9):5115-5126.

Dias Junior, G. S., Ferraretto, L. F., Salvati, G. G. S., Resende, L. C., de, Hoffman, P. C., Pereira, M. N., Shaver, R. D. 2016. Relationship between processing score and kernel-fraction particle size in whole-plant corn silage. J. Dairy Sci. 99:2719-2729.

Dombrink-Kurtzman, M.A., Bietz, J. A. 1993. Zein composition in hard and soft endosperm of maize. Cereal Chem. 70:105-108.

Ferraretto, L. F., Crump, P. M., Shaver, R. D. 2015. Effect of ensiling time and exogenous protease addition to whole-plant corn silage of various hybrids, maturities, and chop lengths on nitrogen fractions and ruminal in vitro starch digestibility. J. Dairy Sci. 98(12):8869-8881.

Ferraretto, L. F., and R. D. Shaver, 2012. Meta-analysis: Effect of corn silage harvest practices on intake, digestion, and milk production by dairy cows. Prof. Anim. Sci. 28(2):141-149.

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. J. Dairy Sci. 101(5):3937-3951.

Ferreira, F. A. 2003. Efeito do processamento do concentrado sobre a seleção de dieta por bovinos. Dissertation (Master’s in Veterinary Medicine) – Faculty of Veterinary Medicine and Animal Science, University of Sao Paulo, Pirassununga, 1-109.

Ferreira, G., and D. R. Mertens. 2005. Chemical and physical characteristics of corn silages and their effects on in vitro disappearance. J. Dairy Sci. 88:4414-4425.

Galyean, M. L., Defoor, P. J. 2003. Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 81: E8-E16.

Galyean, M. L., and M. E. Hubbert, 2014. Review. Tradicional and alternative sources of fiber – roughage values, effectiveness, and levels in starting and finishing diets. Prof. Anim. Sci. 30:571-584.

Hall, M. B. 2015. Determination of dietary starch in animal feeds and pet food by an enzymatic-colorimetric method. Collaborative study. J. AOAC Int. 98:397-409.

Heinrichs, A. J. 2013. The Penn State Particle Separator. Extension publication DSE 2013-186. Pennsylvania State University, College Park.

Holmes, B.J., and E. R. Muck. 2007. Packing Bunkers and Piles to Maximize Forage Preservation. In: 6th International Dairy Housing Conference, 2007, Minneapolis, MN, USA.

Huhtanen, P., Kaustell, K., Jaakkola, S. 1994. The use of internal markers to predict total digestibility and duodenal flow of nutrients in cattle given six different diets. Anim. Feed Sci. Technol. 48:211-227.

Huntington, G. B. 1997. Starch utilization by ruminants: from basics to the bunk. J. Anim. Sci. 75(3):852-67.

Johnson, L., Harrison, J. H., Hunt, C., Shinners, K., Doggett, C. G., Sapienza, D. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. J. Dairy Sci. 82(12):2813-2825.

Johnson, L. M., J. H. Harrison, D. Davidson, J. L. Robutti, M. Swift, W. C. Mahanna, and K. Shinners. 2002a. Corn silage management I: Effects of hybrid, maturity, and mechanical processing on chemical and physical characteristics. J. Dairy Sci. 85:833–853.

Johnson, L. M., Harrison, J. H., Davidson, D., Mahanna, W. C., Shinners, K., & Linder, D. 2002b. Corn silage management: effects of maturity, inoculation, and mechanical processing on pack density and aerobic stability. J. Dairy Sci. 85(2):434-444.

Jung, H. J. G., Samac, D. A., Sarath, G. 2012. Modifying crops to increase cell wall digestibility. Plant Sci. 185: 65-77.

Kononoff, P. J., Heinrichs, A. J., Bunckmaster, D. R. 2003. Modification of the Penn State forage and total mixed ration particle separator and the effects of moisture content on its measurements. J. Dairy Sci. 86:1858-1863.

Kotarski, S. F., Waniska, R. D., Thurn, K. K. 1992. Starch hydrolysis by the ruminal microflora. J. Nutr. 122(1), 178-190.

Krehbiel, C. R., Cranston, J. J., McCurdy, M. P. 2006. An upper limit for caloric density of finishing diets. J. Anim. Sci. 84:34-49.

Kung Jr., L., Shaver, R. D., Grant, R. J., Schmidt, R. J. 2018. Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. J. Dairy Sci. 101(5):4020-4033.

Lammers, B. P., Buckmaster, D. R., Heinrichs, A. J. 1996. A simple method for the analysis of particle sizes of forage and total mixed rations. J. Dairy Sci. 79:922-928.

Leonardi, C., and L. E. Armentano, 2003. Effect of quantity, quality, and length of alfalfa hay on selective consumption by dairy cows. J. Dairy Sci. 86:557-564.

Maekawa, M., Beauchemin, K. A., Christensen, D. A. 2002. Effect of concentrate level and feeding management on chewing activities, saliva production, and ruminal pH of lactating dairy cows. J. Dairy Sci. 85(5):1165-1175.

Mc Geough, E. J., O'Kiely, P., Foley, P. A., Hart, K. J., Boland, T. M., Kenny, D. A. 2010. Methane emissions, feed intake, and performance of finishing beef cattle offered maize silages harvested at 4 different stages of maturity. J. Anim. Sci. 88(4):1479-1491.

Mertens, D.R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80(7):1463-81.

National Academies of Sciences, Engineering, and Medicine Research (NASEM). 2016. Nutrient requirements of beef cattle. 8th Revised Edition. Washington, DC: The Natl. Acad. Press.

Neumann, M., Horst, E. H., Bueno, A. V. I., Venancio, B. J., Santos, L. C., Júnior, E. S. S., Leão, G. F. M. 2018. Desempenho de novilhos confinados alimentados com silagens de diferentes híbridos de milho. Revista de Ciências Agrárias. 41(2):548-556.

Norell, R. J., Hines, S., Chahine, M., Fife, T., De Haro Marti, M., Parkinson, S. C. 2013. Comparing Three Different Methods for Assessing Corn Silage Density. J. Ext. 51(5): Article 34.

Different Methods for Assessing Corn Silage Density. The Journal of Extension, 51(5), Article 34.

Owens, F. N., Secrist, D. S., Hill, W. J., Gill, D. R. 1998. Acidosis in cattle: A review. J. Anim. Sci. 76(1):275-286.

Owens, F. N., Zinn, R. A., Kim, Y. K. 1986. Limits to starch digestion in the ruminal small intestine. J. Animal Sci. 63:1634-1648.

Parra, F. S., Ronchesel, J. R., Martins, C. L., Perdigão, A., Pereira, M. C. S., Millen, D. D., Arrigoni, M. D. B. 2019. Nellore bulls in Brazilian feedlots can be safely adapted to high-concentrate diets using 14-day restriction and step-up protocols. Anim. Prod. Sci.. 59(10):1858-1867.

Philippeau, C., De Monredon, F. L. D., Michalet-Doreau, B. 1999. Relationship between ruminal starch degradation and the physical characteristics of corn grain. J. Anim. Sci. 77(1):238-243.

Philippeau, C., Michalet-Doreau, B. 1997. Influence of genotype and stage of maturity of maize on rate of ruminal starch degradation. Anim. Feed Sci. Technol. 68(1-2):25-35.

Philippeau, C., Landry, J., Michalet-Doreau, B. 2000. Influence of the protein distribution of maize endosperm on ruminal starch degradability. J. Sci. Food Agric. 80(3):404-408.

Pitt, R. E., Muck, R. E.1993. A diffusion model of aerobic deterioration at the exposed face of bunker silos. J. Agric. Eng. Res. 55:11-26.

Pryce, J. D. 1969. A modification of Barker-Summerson method for determination of lactic acid. Analyt. 94:1151-1152.

Restle, J., Pacheco, P. S., Alves Filho, D. C., Freitas, A. K. D., Neumann, M., Brondani, I. L., Arboitte, M. Z. 2006. Silagem de diferentes híbridos de milho para produção de novilhos superjovens. R. Bras. Zootec. 35:2066-2076.

Rosa, J. R. P., Restle, J., Silva, J. H. S. D., Pascoal, L. L., Pacheco, P. S., Faturi, C., Santos, A. P. D. 2004. Avaliação da silagem de diferentes híbridos de milho (Zea mays, L.) por meio do desempenho de bezerros confinados em fase de crescimento. R. Bras. Zootec. 33:1016-1028.

Salinas-Chavira, J., Alvarez, E., Montaño, M. F., Zinn, R. A. 2013. Influence of forage NDF level, source and pelletizing on growth performance, dietary energetics, and characteristics of digestive function for feedlot cattle. Anim. Feed Sci. Technol. 183(3-4): 106-115.

Savoie, P., Shinners, K. J., Binversie, B. N. 2004. Hydrodynamic separation of kernel and stover components in corn silage. Appl. Biochem. Biotechnol. 113-116:41-54.

Schwartzkopf-Genswein, K. S., Beauchemin, K. A., Gibb, D. J., Crews Jr, D. H., Hickman, D. D., Streeter, M., McAllister, T. A. 2003. Effect of bunk management on feeding behavior, ruminal acidosis, and performance of feedlot cattle: A review. J. Anim. Sci. 81:E149-E158.

Silvestre, A. M., and D. D. Millen. 2021. The 2019 Brazilian survey on nutritional practices provided by feedlot cattle consulting nutritionists. R. Bras. Zootec. 50.

Visser, B. 2005. Forage density and fermentation variation: A survey of bunkers, piles and bags across Minnesota and Wisconsin dairy farms. In Four-State Dairy Nutrition and Management Conference Proceedings. Dubuque, IA, USA, Pages 233-240.

Wiles, P. G., Gray, I. K., Kissling, R. C. 1998. Routine analyses of protein by Kjeldahl and Dumas methods: Review and inter-laboratory study using dairy products. J. AOAC Int. 81:620-632.

Weatherburn, M. W. 1967. Phenol-hypochlorite reaction for determination of ammonia. Analytical Chemistry. 39:971-974.

Weissbach, F. 2009. Correction of dry matter content of silages used as substrate for biogas production. Pages 483-484 in Proceedings of the 15th international Silage Conference, US Dairy Forage Research Center, Madison, WI.

Zaralis, K., Nørgaard, P., Helander, C., Murphy, M., Weisbjerg, M. R., Nadeau, E. 2014. Effects of maize maturity at harvest and dietary proportion of maize silage on intake and performance of growing/finishing bulls. Livest. Sci. 168: 89-93.

Zinn, R. A., Shen, Y. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J. Anim. Sci. 76:1280-1289.