University of São Paulo
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Strategies to improve the nutritive value of whole-plant corn silage in diets for finishing beef cattle

Juliana Machado

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

Piracicaba
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versão revisada de acordo com a Resolução CoPGr 6018 de 2011

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CONTENTS

RESUMO

Estratégias para melhorar o valor nutritivo da silagem de milho planta inteira em dietas para bovinos de corte em terminação

A silagem de milho planta inteira (SMPI) é a principal fonte de forragem para bovinos de corte confinados no Brasil. Durante o processo de ensilagem, o tipo de equipamento utilizado durante a colheita e as estratégias de vedação do silo podem provocar alterações na silagem e afetam seu valor nutritivo. Nesse sentido, dois experimentos foram conduzidos para avaliar o efeito do processamento e o nível de inclusão e estratégias de vedação sobre o desempenho de bovinos em terminação. No primeiro experimento o objetivo foi avaliar o efeito do processamento da SMPI com colhedora autopropelida ou tracionada, sobre o desempenho de bovinos de corte em dietas com alta e baixa inclusão de forragem. A SMPI foi colhida com 30% de matéria seca (MS) com colhedora de forragem tracionada pelo trator (CFTT, sem processador de grãos, New Pecus PRF 2-4555) ou colhedora de forragem autopropelida (CFAP, com processador de grãos, New Holland FR 500), ajustadas para comprimento teórico de corte de 10 mm. O tempo de armazenamento foi de 219 dias. Sessenta touros da raça Nelore (405 kg ± 29,1 kg, 24 meses de idade) foram distribuídos em blocos e alocados em 20 baias (3 animais por baia) por 102 dias (12 dias de adaptação + 90 dias de comparação de dietas). As dietas experimentais foram assim constituídas em arranjo fatorial: 1) 15% de SMPI colhida com CFTT; 2) 33% de SMPI colhida com CFTT; 3) 15% de SMPI colhida com CFAP; 4) 33% de SMPI colhida com CFAP. Amostras de silagem foram retiradas do painel dos silos, para avaliar a composição química, produtos de fermentação, temperatura, densidade, pH e perdas. O consumo de matéria seca (CMS) foi avaliado diariamente, enquanto que o peso corporal (PC) e demais variáveis animais foram medidas no início, meio e final do período de comparação das dietas. Os dados da silagem foram apresentados como média e desvio padrão, e o desempenho animal foi analisado como um delineamento de blocos completos ao acaso. A inclusão de 33% de SMPI aumentou o CMS em 10% (9,88 vs. 10,91 kg MS/d) e o ganho médio diário em 14% (1,386 vs. 1,585 kg/dia). O ganho e peso de carcaça também foram melhorados com 33% de SMPI na dieta. Além disso, o aumento das atividades de ruminação, mastigação, o número de refeições e a taxa de ingestão, foram resultados de uma maior inclusão de SMPI na dieta. O desempenho e as características de carcaça dos bovinos foram semelhantes para SMPI processada com diferentes colhedoras. A interação entre colhedora e inclusão mostrou que os bovinos que consumiram 15% de SMPI processada com CFAP tiveram preferência por partículas maiores que 19 mm e partículas médias entre 8-19 mm. Houve seleção contra partículas finas. A energia líquida de mantença e o os nutrientes digestíveis totais da silagem foram maiores quando a dieta passou de 15 para 33% de SMPI. A pressão e saturação de oxigênio no sangue aumentaram, enquanto o pH fecal reduziu, para os bovinos do tratamento com 15% de SMPI. Em conclusão, a maior inclusão de SMPI na dieta melhorou o desempenho de bovinos de corte em terminação. O desempenho dos bovinos não foi influenciado pelo tipo de colhedora utilizada durante a colheita da SMPI. O objetivo do segundo estudo foi comparar o desempenho de bovinos de corte em terminação alimentados com dietas a base de SMPI vedada com filmes plásticos, com ou sem barreira ao oxigênio, protegidos com cobertura anti-ultravioleta (anti-UV) ou filme polietileno dupla face. A SMPI foi colhida com 32% de MS e armazenada em quatro silos duplicados (total de oito silos), simultaneamente. Os silos foram divididos na dimensão transversal e foram aplicados quatro tratamentos em cada metade, sendo: filme barreira ao oxigênio (BO) de 45 μm coberto com proteção anti-ultravioleta (anti-UV+BO); filme BO de 45 μm coberto com filme polietileno dupla face (PE) de 120 μm (PE120+BO); filme PE de 50 μm coberto com proteção anti-UV (anti-UV+PE50); filme PE de 50 μm coberto com PE dupla face de 120 μm (PE120+PE50). Foram preparados dois silos para cada tratamento e o tempo de armazenamento dos primeiros quatro silos foi de 300 dias e dos outros quatro de 347 dias. Amostras de silagem foram retiradas do painel exposto de cada silo para medir a composição química, produtos de fermentação, contagem microbiana, temperatura, pH e perda de MS da silagem. Sessenta e quatro novilhos Nelore (456 ± 42,8 kg) foram distribuídos em blocos pelo peso corporal inicial e alocados em baias individuais por 103 dias (13 dias de adaptação + 90 dias de comparação de dietas). As dietas experimentais continham (em base MS) a inclusão de 70% de concentrado e 30% de SMPI oriunda das diferentes estratégias de vedação. O CMS foi avaliado diariamente, enquanto que o PC e demais variáveis animais foram medidas no início, meio e final do período de comparação das dietas. Os dados de silagem e desempenho dos animais foram apresentados como um delineamento de blocos completos ao acaso. As silagens armazenadas sob filme de BO apresentaram maiores contagens de fungos filamentosos. As perdas durante a retirada da silagem foram maiores para os filmes cobertos com PE120. Durante o armazenamento, a estratégia de vedação com cobertura anti-UV apresentou 9,60°C superior às 11:00 horas e 4,22°C superior às 16:00 horas, comparado com a cobertura realizada por filme de PE120. As maiores temperaturas foram verificadas na camada superior e as maiores densidades para a camada inferior do silo. Animais que receberam dieta contendo silagem do tratamento PE120+BO apresentaram maior variação diária do CMS. O CMS, ganho de peso diário e demais características de carcaça foram semelhantes entre os tratamentos. Os resultados sugerem que a cobertura de ambos os filmes com uma cobertura anti-UV ou PE120 afetaram de forma igual a qualidade da silagem e o desempenho animal.

Palavras-chave: Colhedora de forragem, Cobertura do silo, Desempenho animal, Filme de vedação

ABSTRACT

Strategies to improve the nutritive value of whole-plant corn silage in diets for finishing beef cattle

Whole-plant corn silage (WPCS) is a major source of forage for feedlot beef cattle in Brazil. During the ensilage process, the type of harvesting equipment and the silo sealing, cause changes in the silage and affect its nutritional value. Nonetheless, two trials were conducted to evaluate the effect of processing and inclusion level of WPCS and sealing strategies on the performance of finishing beef cattle. In the first trial, the objective was to evaluate the effect of WPCS processing with self-propelled or pull-type forage harvester on the performance of beef cattle in diets with high and low forage inclusion. The WPCS was harvested with approximately 30% dry matter (DM) with pull-type forage harvester (PTFH, without kernel processor, New Pecus PRF 2-4555) or self-propelled forage harvester (SPFH, with kernel processor, New Holland FR 500), adjusted for theoretical length of cut of 10 mm. Storage time was 219 days. Sixty Nellore bulls (405 kg ± 29,1 kg, 24 months old) were distrusted in blocks and allocated in 20 pens (3 animals per pen) for 102 days (12 days of adaptation + 90 days of diets comparison). The experimental diets were: 1) 15% WPCS harvested with PTFH; 2) 33% WPCS harvested with PTFH; 3) 15% WPCS harvested with SPFH; 4) 33% WPCS harvested with SPFH. Silage samples were collected from the silo panel to evaluate composition, fermentation products, temperature, density, pH and losses. Dry matter intake (DMI) was measured daily, whereas shrunk body weight (SBW) and other animal variables were measured at the beginning, middle and end of the diet comparison period. Silage data were presented as mean and standard deviation, and animal performance was analyzed as a randomized complete block design. The inclusion of 33% WPCS increased DMI by 10% (9.88 vs. 10.91 kg DM/d) and average daily gain by 14% (1.386 vs. 1.585 kg/d). Gain and carcass weight also improved with 33% WPCS in the diet. In addition, the increase in rumination, chewing, number of meals, and intake rate were results of a greater inclusion of WPCS in the diet. The performance and carcass characteristics of the cattle were similar for WPCS processed with different harvesters. The interaction between harvester and inclusion showed that cattle that the intake of 15% WPCS processed with SPFH had a preference for particles larger than 19 mm and medium particles between 8-19 mm. There was selection against fine particles. The net energy of maintenance and the total digestible nutrients of the silage were higher when the diet changed from 15 to 33% WPCS. Pressure and oxygen saturation increased, while fecal pH decreased, for cattle of treatment with 15% WPCS. In conclusion, the greater inclusion of WPCS in the diet improved the performance of finishing beef cattle. The performance of the cattle was not influenced by type of harvester used during WPCS harvesting. The objective of the second study was to compare the performance of beef cattle fed diets based on WPCS sealed with plastic films, with or without oxygen barrier (OB), protected with an anti-ultraviolet (anti-UV) cover or double-sided polyethylene (PE) film. The WPCS was harvested at 32% DM and packed in four duplicate silos (total of eight silos), simultaneously. The silos were divided in the transversal dimension and four treatments were applied to each one, as follows: 45 μm OB film protected with anti-UV cover (anti-UV+OB); 45 μm OB film protected with 120 μm double-sided PE film (PE120+OB); 50 μm PE film protected with anti-UV cover (anti-UV+PE50); 50 μm PE film protected with 120 μm double-sided PE film (PE120+PE50). Two silos were prepared for each treatment and the storage time of the first four silos was 300 days and the other four, 347 days. Silage samples were taken from the exposed panel of each silo to determine silage composition, fermentation products, microbial count, temperature, pH and dry matter loss. Sixty-four Nellore bulls (456 ± 42.8 kg) were divided in blocs by initial SBW and allocated to individual pens for 103 days (13 days of adaptation + 90 days of diet comparison). The experimental diets contained (on a DM basis) 70% concentrate and 30% of WPCS from the different sealing strategies. Dry matter intake (DMI) was measured daily, while SBW and other animal variables were measured at the beginning, middle and end of the feeding trial period. Silage and animal performance data were analyzed as a complete randomized block design. The silages stored under OB film protected with PE120 showed higher mold counts. Losses during silage feed-out were higher for films protected with PE120. During storage, the sealing strategy with anti-UV cover showed 9.60°C higher at 11:00 am and 4.22°C higher at 4:00 pm, compared to cover by PE120 film. The highest silage temperatures were verified in the upper layer, and the highest densities, in the bottom layer of the silo. Animals that received a diet containing silage from the PE120+OB treatment showed greater daily variation in DMI. The DMI, average daily gain and other carcass characteristics were similar between treatments. The results suggest that the protection of both films with an anti-UV or PE120 cover, equally affected silage quality and animal performance.

Keywords: Forage harvester, Silo cover, Animal performance, Sealing film

LIST OF TABLES

1. INTRODUCTION

The inclusion of forage in high-concentrate finishing diets provides a healthy rumen environment, prevent digestive disorders, and stimulates dry matter intake (DMI) (Galyean and Defoor, 2003; Galyean and Hubbert, 2012; Owens et al., 1998; Salinas-Chavira et al., 2013). The level of roughage inclusion in Brazilian finishing diets is on average 16.8% of diet DM (Silvestre and Millen, 2021), with 42% decrease when compared with the very first feedlot survey conducted in 2009 (Millen et al., 2009). In U.S. feedlots the inclusion of roughage in diets is greater, varied from 0% to 13.5% of diet DM (Vasconcelos and Galyean, 2007).

Concentrate-based diets, containing lower levels of forage, or even the abrupt consumption of rapidly fermentable carbohydrates (e.g. sorting behavior) change the fermentation pattern, increase the risk of acute and subacute ruminal acidosis (SARA) (Owens et al., 1998; Nagaraja and Titgemeyer, 2007). In the rumen, the accumulation of short-chain fatty acids (SCFA) and lactate, from of these quickly fermentable carbohydrates, lowers ruminal pH to below normal fermentation conditions (pH < 5.6), and negatively affects animal health and production (Nagaraja and Titgemeyer, 2007). Mertens (1997) introduced the term physically effective neutral detergent fiber (peNDF) as a means to classify different roughage sources, and represent the ability of a feed to allow for to promote chewing and rumination, important in maintaining a desirable rumen pH. The first proposed critical size was 1.18 mm at which feed particles are considered physically effective for dairy cows (Mertens, 1997). Maulfair et al. (2011) proposed that critical particle size for rumen escape is larger than 1.18 mm. Lammers et al. (1996) introduced the sum of DM proportion retained on sieves of 19 mm and 8 mm of Penn State Particle Separator (PSPS) multiplied by the NDF content of the diet (peNDF$_{>8}$). Heinrichs (2013) recommend 4 mm as a more suitable particle size for estimating peNDF.

Whole-plant corn silage (WPCS) is the predominant roughage in Brazilian feedlots (Silvestre and Millen, 2021), has high yield of low-cost starch per hectare, high concentration of metabolizable energy (Wilkinson and Rinne, 2018), flexibility to harvest corn for forage or kernel (Allen et al., 2003) and ease of ensiling (Nigon et al., 2016), in addition is an important source of energy and peNDF for ruminants (Dias Junior et al., 2016; Ferraretto et al., 2018). The quality of silage depends on the integration of all factors associated with the production process, from seeding to feed-out, considering from processing (Ferraretto et al., 2018) and silo sealing (Borreani et al., 2007; Silva et al., 2015). Processing during harvesting of the maize plant has been proposed to improve the nutritional value of silage, to maintain adequate particle size of the vegetative fraction and maximum kernel processed (Dias Junior et al., 2016). Harvesting equipment has different operating systems that change in efficiency and performance (Shinners et al., 2000; Ferraretto and Shaver, 2012a,b). Forage harvesters can be pull-type forage harvester (PTFH; 1 to 4 cutting lines) or self-propelled forage harvester (SPFH; 4 to 12 cutting lines) with grain processing rollers (Dias Junior, 2016). Processed WPCS with SPFH contains less whole cob and long fiber fractions as a percentage of total mass (Shinners et al., 2000). The use of PTFH without a kernel processor is very common in Brazil, mainly due to the high cost of SPFH (Bernardes and Rêgo, 2014). However, in beef cattle production systems, it uses SPFH, through customized services (Daniel et al., 2019).

The processed forage is stored, mainly in horizontal silos, due to the less expensive building cost, ease of filling and unloading, but its conformations determine a large exposure surface (Savoie and Jofriet, 2003), silages are more susceptible to aerobic deterioration and, consequently, to greater losses (Ashbell and Weinberg, 1992; Borreani et al., 2007). Sealing is essential to reduce dry matter losses (Bolsen et al., 1993), decrease mycotoxin production

(Cheli et al., 2013) and limit the growth of pathogenic microorganisms (Ivanek et al., 2006; Spadaro et al., 2015), which may cause a reduction of feed intake and dry matter digestibility by animals (Whitlock et al., 2000).

The mechanical properties and oxygen impermeability of the plastic films used to seal silage, has a great effect on reducing spoilage losses (Borreani et al., 2007). The plastic industry has developed several films for sealing silos, the most common are polyethylene (PE) films, mainly due to their low cost (Borreani and Tabacco, 2017). However, PE films do not completely prevent the gas exchange and permeability, because protection is variable, and often changes during storage (Savoie, 1988) and with increasing ambient temperature (Degano, 1999).

In an attempt to reduce the influx of oxygen during silage storage and preserve nutrients, oxygen barrier (OB) films with good mechanical characteristics (Borreani et al., 2011) and reduced oxygen permeability compared to standard PE films, were developed (Borreani et al., 2007). PE/OB films 40-50 µm thick are fragile to solar radiation, need protection with other materials or even another plastic film (2-step cover system) (Borreani et al., 2014). The adoption of sealing strategies reduces the removal of spoiled silage, increases the recovery of digestible nutrients and, consequently, improves the productive efficiency of lactating dairy cows (Amaral et al., 2014) and weight gain in dairy heifers (Parra et al., 2021).

There are few studies in the literature that consider all these parameters on the quality of corn silage for finishing beef cattle. Few experimental studies in beef cattle have studied WPCS processing with different harvesting equipment and forage levels in the diet, and only one study evaluated sealing films on the conservation of WPCS in the diet of finishing cattle. Therefore, two studies were conducted. The first study evaluated the effect of WPCS processing using either a pull-type or self-propelled forage harvester on the performance of beef cattle in feedlot diets with high or low forage inclusion. The second study evaluated the WPCS from a horizontal silo sealed with thin films with or without oxygen barrier, protected with an anti-UV or double-sided PE film on the conservation of ensiled corn for finishing beef cattle.

Literature cited

Allen, M. S., J. G. Coors, and G. W. Roth. 2003. Corn silage. In: D.R. Buxton, R.E. Muck, J.H. Harrison, editor, Silage Science and Technology. Agron. J., Crop Sci., Soil Sci. Soc. Am. J., Madison, WI. 42:547–608. doi:10.2134/agronmonogr42.c12.

Amaral, R. C., M. C. Santos, J. L. P. Daniel, A. S. Neto, A. W., Bispo, E. H. Cabezas-Garcia, T. F. Bernardes, and L. G. Nussio. 2014. The influence of covering methods on the nutritive value of corn silage for lactating dairy cows. R. Bras. Zootec. 43:471–478. doi:10.1590/S1516-35982014000900003.

Ashbell, G., and Z. G. Weinberg. 1992. Top silage losses in horizontal silos. Can. Agric. Eng. 34:171–175.

Bernardes, T. F., and A. C. do Rêgo. 2014. Study on the practices of silage production and utilization on Brazilian dairy farms. J. Dairy Sci. 97:1852–1861. doi:10.3168/jds.2013-7181.

Bolsen, K. K., J. T. Dickerson, B. E. Brent, R. N. Sonon, B. S. Dalke, C. Lin, and J. E. Boyer Jr. 1993. Rate and extent of top spoilage losses in horizontal silos. J. Dairy Sci. 76:2940–2962. doi:10.3168/jds.S0022-0302(93)77634-1.

Borreani, G., S. Piano, and E. Tabacco. 2014. Aerobic stability of maize silage stored under plastic films with different oxygen permeability. J. Sci. Food Agric. 94:2684–2690. doi:10.1002/jsfa.6609.

Borreani, G., and E. Tabacco. 2017. Charter 9: Plastics in animal production, In: Orzolek, M. (Ed.), A Guide to the Manufacture, Performance, and Potential of Plastics in Agriculture. Elsevier Ltd., Amsterdam, p. 145–185. doi:10.1016/B978-0-08-102170-5.00009-9.

Borreani, G., E. Tabacco, and de Angelis, D. 2011. Special EVOH: based films improve quality and sanity of farm corn silage. In: Proc. Int. Conf. Agri. Hort. Film Ind. Applied Market Information Ltd., Barcelona, Spain, p. 1–15.

Borreani, G., E. Tabacco, and L. Cavallarin. 2007. A new oxygen barrier film reduces aerobic deterioration in farm-scale corn silage. J. Dairy Sci. 90:4701–4706. doi:10.3168/jds.2007-0310.

Cheli, F., A. Campagnoli, and V. Dell'Orto. 2013. Fungal populations and mycotoxins in silages: from occurrence to analysis. Anim. Feed Sci. Technol. 183:1–16. doi:10.1016/j.anifeedsci.2013.01.013.

Daniel, J. L. P., T. F. Bernardes, C. C. Jobim, P. Schmidt, and L. G. Nussio. 2019. Production and utilization of silages in tropical areas with focus in Brazil. Grass Forage Sci. 74:188–200. doi:10.1111/gfs.12417.

Degano, L., 1999. Improvement of silage quality by innovative covering system. In: Proc. XII Int. Silage Conf., Uppsala Sweden, p. 296–297.

Dias Junior, G. S., L. F. Ferraretto, G. G. S. Salvati, L. C. de Resende, P. C. Hoffman, M. N. Pereira, and R. D. Shaver. 2016. Relationship between processing score and kernel fraction particle size in whole-plant corn silage. J. Dairy Sci. 99:2719–2729. doi:10.3168/jds.2015-10411.

Ferraretto, L. F., and R. D. Shaver. 2012a. Effect of corn Shredlage on lactation performance and total tract starch digestibility by dairy cows. Prof. Anim. Sci. 28:639–647. doi:10.15232/S1080-7446(15)30423-X.

Ferraretto, L. F., and R. D. Shaver. 2012b. Meta-analysis: Impact of corn silage harvest practices on intake, digestion and milk production by dairy cows. Prof. Anim. Sci. 28:141–149. doi:10.15232/S1080-7446(15)30334-X.

Ferraretto, L. F., R. D. Shaver, and B. D. Luck. 2018. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J. Dairy Sci. 101:3937–3951. doi:10.3168/jds.2017-13728.

Galyean, M. L., and P. J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 81:E8–E16. doi:10.2527/2003.8114.

Galyean, M. L., and M. E. Hubbert. 2012. Traditional and alternative sources of fiber–roughage values, effectiveness, and concentrations in starting and finishing diets. In: Proc. Plains Nutrition Counc., San Antonio, TX. p. 75–97.

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

Ivanek, R., Y. Grohn, and M. Wiedmann. 2006. Listeria monocytogenes in multiple habitats and host populations: review of available data for mathematical modeling. Foodborne Pathog. Dis. 3:319–336. doi:10.1089/fpd.2006.3.319.

Lammers, B. P., D. R. Buckmaster, and A. J. Heinrichs. 1996. A simple method for the analysis of particle sizes of forage and total mixed rations. J. Dairy Sci. 79:922–928. doi:10.3168/jds.S0022-0302(96)76442-1.

Maulfair, D. D., M. Fustini, and A. J. Heinrichs. 2011. Effect of varying total mixed ration particle size on rumen digesta and fecal particle size and digestibility in lactating dairy cows. J. Dairy Sci. 94:3527–3536. doi:10.3168/jds.2010-3718.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80:1463–1481. doi:10.3168/jds.S0022-0302(97)76075-2.

Millen, D. D., R. D. L. Pacheco, M. D. B. Arrigoni, M. L. Galyean, and J. T. Vasconcelos. 2009. A snapshot of management practices and nutritional recommendations used by feedlot nutritionists in Brazil. J. Anim. Sci. 87:3427–3439. https://doi.org/10.2527/jas.2009-1880.

Nagaraja, T. G., and E. C. Titgemeyer. 2007. Ruminal acidosis in beef cattle: the current microbiological and nutritional outlook. J. Dairy Sci. 90:17–38. doi:10.3168/jds.2006-478.

Nigon, B. J., K. J. Shinners, and D. E. Cook. 2016. Harvester modifications to alter composition and dry matter of corn-silage. Appl. Eng. Agric. 32:157–167. doi:10.13031/aea.32.11417.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: a review. J. Anim. Sci. 76:275–286. doi:10.2527/1998.761275x.

Parra, C. S., J. M. Bragatto, F. A. Piran Filho, S. M. S. Silva, B. F. Tuzzi, C. C. Jobim, and J. L. P. Daniel. 2021. Effect of sealing strategy on the feeding value of corn silage for growing dairy heifers. J. Dairy Sci. 104:6792–6802. doi:10.3168/jds.2020-19895.

Salinas-Chavira, J., E. Alvarez, M. F. Montaño, and R. A. Zinn. 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. 183:106–115. doi:10.1016/j.anifeedsci.2013.05.004.

Savoie, P. 1988. Optimization of plastic covers for stack silos. J. Agric. Engineering Research. 41:65–73. doi:10.1016/0021-8634(88)90189-8.

Savoie, P., and J. C. Jofriet. 2003. Silage storage. In: Buxton, D. R., R. E. Muck, J. H. Harrison (Eds.), Silage Science and Technology. Agronomy Monograph 42. American Society of Agronomy, Madison, WI, USA, Chapter 9, p. 405–467.

Shinners, K. J., A. G. Jirovec, R. D. Shaver, and M. Bal. 2000. Processing whole-plant corn silage with crop processing rolls on a pull-type forage harvester. Appl. Eng. Agric. 16:323–331. doi:10.13031/2013.5214.

Silva, M. S. J., C. C. Jobim, E. C. Poppi, T. T. Tres, and M. P. Osmari. 2015. Production technology and quality of corn silage for feeding dairy cattle in Southern Brazil. R. Bras. Zootec. 44:303–313. doi:10.1590/S1806-92902015000900001.

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. doi:10.37496/rbz5020200189.

Spadaro, D., M. P. Bustos-Lopez, M. L. Gullino, S. Piano, E. Tabacco, and G. Borreani. 2015. Evolution of fungal populations in corn silage conserved under polyethylene or biodegradable films. J. Appl. Microbiol. 119:510–520. doi:10.1111/jam.12852.

Vasconcelos, J. T., and M. L. Galyean. 2007. Nutritional recommendations of feedlot consulting nutritionists: the 2007 Texas Tech University survey. J. Anim. Sci. 85:2772–2781. doi:10.2527/jas.2007-0261.

Whitlock, L. A., M. K. Siefers, R. S. Pope, B. E. Brent, and K. K. Bolsen. 2000. Effect of surface spoiled silage on the nutritive value of corn silage-based rations. In: Kansas State University Agricultural Experimental Station Report of Progress 861. p. 36–38.

Wilkinson, J. M., and R. Rimini. 2002. Effect of triple co-extruded film on losses during the ensilage of ryegrass. In: Proc. XIII Int. Silage Conf., Scotland: Auchincruive, p. 168–169.

2. PROCESSING AND INCLUSION LEVEL OF WHOLE-PLANT CORN SILAGE IN DIETS FOR FINISHING BEEF CATTLE

Abstract

Whole-plant corn silage (WPCS) is the main source of forage for beef cattle in confinement in Brazil. Forage harvester cause modifications to the WPCS that affect animal performance. The objective of this study was to evaluate the extent of the effect of processing WPCS with either a self-propelled or a pull-type forage harvester on the performance of beef cattle in diets with high and low forage inclusion. The WPCS was harvested to reach approximately 30% dry matter (DM) with pull-type forage harvester (PTFH, without kernel processor, New Pecus PRF 2-4555) or self-propelled forage harvester (SPFH, with kernel processor, New Holland FR 500), both adjusted for theoretical length of cut of 10 mm. After 219 days of storage, the silos were opened for feeding to 60 Nellore bulls (405 kg ± 29.1 kg, 24 months of age). The cattle were blocked by initial shrunk body weight (SBW), distributed in 20 pens (3 animals per pen) for 102 days (12 days of adaptation + 90 days of diets comparison). The experimental diets were set in a factorial design: 1) 15% WPCS harvested with PTFH; 2) 33% WPCS harvested with PTFH; 3) 15% WPCS harvested with SPFH; 4) 33% WPCS harvested with SPFH. Silage samples were collected from the exposed feed face to measure chemical composition, fermentation products, temperature, density, pH and losses. Dry matter intake (DMI) was measured daily, whereas SBW and other animal variables were measured at the beginning, middle and end of the diet comparison period. Silage data were presented as mean and standard deviation, and animal performance was analyzed as a randomized complete block design. The 33% WPCS diet increased DMI by 10% (9.88 vs. 10.91 kg DM/d) and average daily gain by 14% (1.386 vs. 1.585 kg/d). Gain and carcass weight also improved with 33% WPCS in the diet. In addition, the increase in rumination, chewing, number of meals, and intake rate were results of a greater inclusion of WPCS in the diet. The performance and carcass characteristics of the cattle were similar for both harvesters. The interaction between harvesters and level of inclusion showed that cattle fed the 15% WPCS processed with SPFH preferred particles longer than 19 mm and medium particles between 8-19 mm. There was selection against fine particles. The estimated net energy of maintenance and the total digestible nutrients of the silage were higher when the diet changed from 15 to 33% WPCS. Pressure and oxygen saturation in blood samples increased, while fecal pH decreased, for cattle of treatment with 15% WPCS. In conclusion, the greater inclusion of WPCS in the diet improved the performance of finishing beef cattle. The forage harvester used WPCS processing did not influence the performance of beef cattle in feedlot.

Keywords: feeding, feedlot, harvester, Nellore

2.1. Introduction

The increase in consumption of rapidly fermentable carbohydrates along with a decrease in lower-fiber of diets of finishing cattle, causes an unbalance in ruminal fermentation, and increase to volatile fatty acids (VFA) (Owens et al., 1998). The accumulation of acids, especially lactic acid, may reduce ruminal pH below 5.2 (acute ruminal acidosis), which may impair ruminal fermentation (Nagaraja and Titgemeyer, 2007).

Forages are "functional" feedstuffs, mainly in high-concentrate diets, can reduce risk of digestive dysfunctions in feedlot cattle (Salinas-Chavira et al., 2013). The inclusion of forage in the cattle diet provides a healthy rumen environment and stimulates dry matter intake (DMI) to maintain energy intake required by the animal (Galyean and Defoor, 2003), in addition to the improve gain and gain efficiency (Stock et al., 1990). Forages have different levels of neutral detergent fiber (NDF) that correlates with the chemical characteristics but not with the physical aspects of the fibrous fraction of diets (Allen, 1997). The physically effective neutral detergent fiber (peNDF) is the fraction of the fiber that stimulating the chewing activity and the production of saliva (Mertens, 1997), increase rumen pH and provides a suitable rumen environment for the digestibility of dry matter (DM) and fiber of diet (Allen, 1997; Stone, 2004). Fox and Tedeschi (2002), mentioned in NASEM (2016), suggested that beef cattle feedlot diets should have between 7 and 10% peNDF (on DM basis) to keep ruminal pH above 5.7.

The whole-plant corn silage (WPCS) is the most used roughage source in the diet of feedlot beef cattle in Brazil (Silvestre and Millen, 2021). The WPCS provides energy (starch in the kernel fraction) and peNDF (vegetative fraction) that improve animal performance and maintain a healthy rumen (Ferraretto et al., 2018). The development of harvesting practices for silage is an alternative to improve the physical and chemical characteristics of the forage, supports the fermentation process in the silo (Johnson et al., 2003) and increases the digestibility of nutrients (Ferraretto and Shaver, 2012; Ferraretto et al., 2018). The strategies adopted during the forage harvest keep the particle size of the vegetative fraction adequate and provide maximum kernel processing (Dias Junior et al., 2016).

Forage harvester with different operating systems can be used for silage production. The pull-type forage harvester (PTFH; harvest 1 to 4 corn lines) is the most common in Brazil (90.4%; Bernardes and Rêgo, 2014), however, it seldom have specialized kernel processor displays (Bernardes et al., 2012; Bernardes et al., 2018). In these harvesters, silages may have low particle size uniformity, with a predominance of long particles, resulting in greater deterioration due to the lower silage density and increased oxygen input (Muck et al., 2003), in addition, the processing of kernels is normally only obtained by reducing the theoretical length of cut (TLC) (Dias Junior et al., 2016).

The self-propelled forage harvester (SPFH; harvest 4 to 12 corn lines) has kernel processor rolls (Dias Junior et al., 2016) and induces greater changes in the physical properties of the kernel than PTFH (Shinners et al., 2000). The SPFH is more efficient in harvesting because it has higher operating speeds, wider platforms and greater production capacity (Ferraretto et al., 2018). The possible adjustments in SPFH can increase the peNDF of diets (Mertens, 1997) and improve starch digestibility (Ferraretto and Shaver, 2012). The inclusion and processing of WPCS in ruminant diets, may affect performance and maintenance of rumen health (Owens et al., 1997; Turgeon et al., 2010). The hypothesis of our study was that to obtain greater use of nutrients in the diet with greater inclusion of WPCS and better fermentation in the silo, would be required a processing with a self-propelled harvester. However, the study objective of this evaluates the effect of processing the whole-plant corn for silage through a self-propelled or pull-type forage harvester, on the performance of beef cattle in diets with medium and low forage inclusion.

2.2. Materials and Methods

2.2.1. Ensiling

The experiment was conducted at the Department of Animal Science, University of São Paulo, Faculty of Animal Science and Food Engineering, Pirassununga, São Paulo, Brazil. The ensiling occurred at 118 days, when the plants had approximately 30% dry matter (DM). During the harvest, two types of forage harvester were used: 1) self-propelled forage harvester (SPFH) New Holland FR 500 (New Holland, Pennsylvania, USA) with duracracker processor roller set to 3-mm roll gap; 2) pull-type forage harvester (PTFH) New Pecus PRF 2-4555 (Nogueira, São João da Boa Vista, São Paulo, Brazil) without processing rolls, both set to cut with theoretical average particle size of 10 mm. The forage was stored without additive in two silage piles (approximately 100 tons each) with approximately 7.0 m wide, 2.5 m high and 30 m long, and stored for 219 days before animal feeding. At the end of the storage period, the silages were fed as total mixed rations (TMR) for finishing beef cattle.

2.2.2. Sampling and variables analyzed in silage

During the feeding test, the face of the exposed silos was sampled three times at 30-day intervals. On each sampling occasion, the temperature (°C) was measured in the panel by a bulb thermometer at 20 cm deep from the face panel. The density of the mass (kg of wet silage/m^3) stored in each silo was estimated using a cylindrical probe, from the top, middle and bottom of the vertical axis from the silo, by considering the diameter and length of the cylinder to determine the volume and silage mass removed.

The silage samples were collected at the same temperature assessment sites to prepare aqueous extracts (25 g + 225 g of deionized water). After measuring the pH (DM 20 pH meter, Digimed Analítica, São Paulo, Brazil), analyzed lactic acid concentration by spectrometry (Pryce, 1969) and fermentation products (volatile fatty acids, alcohols and esters) using a gas chromatograph with a mass detector (GDMI QP 2010 plus, Shimadzu, Kyoto, Japão) and a capillary column (Stabilwax, Restek, Bellefonte, PA; 60 m, 0.25 mm, id, 0.25 90 m). The dry matter content corrected for volatiles (DMcorr) was calculated using the equation of Weissbach (2009): DMcorr (% as fed) = oven DM (% as fed) + n-alcohols (% as fed) + 2,3-butanediol (% as fed) + 0.95 × volatile fatty acids (% as fed) + 0.77 × 1,2-propanediol (% as fed) + 0.08 × lactic acid (% as fed).

The panel samples from the silos were dried in a forced air circulation oven at 55°C for 72 hours. After drying, they were ground to pass through a 1-mm Wiley mill screen, to then determine the definitive DM in an oven at 105°C, the ash concentration and the ether extract (EE) according to the Association of Official Analytical Chemists (AOAC, 1990), methods 934.01, 924.05 e 920.39, respectively. Concentration of crude protein (CP) was determined by the Dumas method (990.03 method; AOAC, 2006) using a nitrogen analyzer (Leco FP-2000; Leco Corp., St. Joseph, MI, USA) multiplied by 6.25. The concentration of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by a TE-149 fiber analyzer (Tecnal Laboratory Equipment, Piracicaba, Brazil) with the addition of sodium sulfite and thermostable amylase, expressed by discounting the residual ash (Mertens, 2002). The indigestible NDF (iNDF) was obtained by in situ incubation for 288 hours (Huhtanen et al., 1994). The non-fibrous carbohydrate (NFC) content was calculated as NFC = 100 - (CP + NDF + EE + ash) (Hall, 2000). The starch content was analyzed according to Hall et al. (2009). The kernel processing score (KPS) was calculated as the percent of starch passing a 4.75-mm sieve as described by Ferreira and Mertens (2005).

The distribution and mean particle length (MPL) of the silage were performed using a Penn State Particle Separator with three sieves (19, 8 and 1.18 mm) and a bottom pan (Kononoff et al., 2003). The kernels fraction of the silage sample was hydrodynamically separated through the differences in buoyancy between the kernels and the stover (Savoie et al., 2004). After separation, the kernels were dried at 55°C for 72 h in a forced-air oven and sieved using a Tyler Ro-Tap shaker (model RX-29, Tyler, Mentor, OH) with a set of sieves with nominal square apertures of 9.52, 6.70, 4.75, 2.36, 1.18, 0.59-mm and bottom pan. The geometrical mean particle size (GMPS; mm) and surface area (cm^2/g) were calculated using a log normal distribution (Baker and Herrman, 2002) as described by Dias Junior et al. (2016). The proportion of kernels smaller than 4.75-mm was calculated by the sum of percentages retained at 3.35, 2.36, 1.70, 1.18 and 0.59-mm sieves and pan (Dias Junior et al., 2016). The chemical composition, fermentation profile and physical characteristics of whole-plant corn silage are shown in Table 1.

Table 1. Chemical and physical characteristics of whole-plant corn silage under pull-type forage harvester (PTFH) or self-propelled forage harvester (SPFH) (mean±standard deviation).

Item	Treatment[1]	
	PTFH	SPFH
	Chemical composition	
DMcorr[2], % as fed	30.1±1.12	28.2±0.43
CP, % DM	6.38±0.18	6.28±0.15
EE, % DM	1.72±0.23	1.95±0.23
NDF, % DM	47.33±1.01	46.78±1.27
iNDF, % DM	20.29±0.29	20.35±0.92
peNDF$_{>8}$[3], % DM	31.98±1.21	34.90±1.14
peNDF$_{>1.18}$[4], % DM	37.58±1.00	39.97±0.75
ADF, % DM	30.02±2.69	30.70±2.12
Ash, % DM	4.91±0.78	5.90±0.81
Starch, % DM	25.80±1.92	28.15±1.38
	Fermentation profile	
pH	3.87±0.26	3.98±0.29
Lactic acid, % DMcorr	3.66±0.26	2.40±0.09
Acetic acid, % DMcorr	3.16±0.19	2.49±0.19
Propionic acid, % DMcorr	0.35±0.07	0.29±0.07
Ethanol, % DMcorr	0.06±0.02	0.06±0.02
Butyric acid, mg/kg DMcorr	47.07±0.15	43.33±0.19
	Silage characteristics	
Density, kg of wet silage/m^3	566±11.74	580±9.95
Temperature, °C	31.8±2.57	34.4±2.57
Loss during feed-out[5], % as fed	6.30±1.62	8.81±0.79
Daily feed-out rate, cm/d	26.32±7.87	29.01±7.64
	Forage distribution	
Sieve[6]		
>19-mm, %	12.7±4.93	7.1±4.08
8-mm, %	59.3±6.65	76.2±5.88
1.18-mm, %	17.4±3.43	11.8±4.02
Pan, %	10.6±3.63	4.9±1.36
MPL, mm	8.5±1.51	10.0±0.97
	Kernel distribution	
Sieve, mm		
9,52	21.74±1.17	7.60±1.91
6,70	3.92±1.39	13.76±1.52
4,75	9.42±1.93	15.55±1.31
2,36	25.59±1.65	30.14±1.70
1,18	12.94±0.79	12.80±1.61
0,59	5.54±1.53	5.12±1.05
Pan	2.41±0.75	3.26±1.16
% kernels < 4.75-mm sieve[7]	46.48±1.47	51.32±1.53
GMPS, mm	1.0±0.07	1.8±0.15
KPS[8], %	55.5±1.05	54.8±0.98

[1]PTFH: pull-type forage harvester; SPFH: self-propelled forage harvester. [2]Dry matter content corrected for volatiles was calculated using the equation of Weissbach (2009): DMcorr (% as fed) = oven DM (% as fed) + n-alcohols (% as fed) + 2,3-butanediol (% as fed) + 0.95 × volatile fatty acids (% as fed) + 0.77 × 1,2-propanediol (% as fed) + 0.08 × lactic acid (% as fed). [3]Physically effective NDF above the 8-mm PSPS sieve calculated as proposed by Lammers et al. (1996). [4]Physically effective NDF above the 1.18-mm PSPS sieve calculated as proposed by Kononoff et al. (2003). [5]Portions of spoiled silage separated and quantified daily. [6]Distribution was measured using the Penn State particle size separator. [7]Proportion of hydrodynamically separated kernel fraction passing through a 4.75-mm sieve. [8]Percent of starch passing a 4.75-mm sieve; processing score was measured as described by Ferreira and Mertens (2005).

2.2.3. Animals, experimental diets and evaluations

Animal care and handling procedures were approved by the Ethics Committee for Animal Use of the University of São Paulo, Faculty of Animal Science and Food Engineering, Pirassununga, São Paulo, Brazil (protocol number 3881121119 – CEUA/FZEA).

Sixty Nellore (405 kg ± 29.1 kg, 24 months of age) were housed in 20 pens (three animals per pen), with a concrete floor, individual feed bunk and waterer. The feeding period was 102 days, with the first 12 days for adaptation to the diets and facilities and the last 90 days for diet comparison. At the end of the adaptation period, animals were weighed, blocked according to initial body weight (initial BW), and assigned to each treatment. The treatments consisted of TMR formulated according to the recommendations of NASEM (2016) aiming at a weight gain of 1.5 kg/d. The experimental design was based on the peNDF recommendations proposed by NASEM (2016) thus treatment diets were designed to contain values of 4% to 8% of $peNDF_{>8}$, representing the inclusion of WPCS in the diet of 15% and 33%, respectively, totaling four experimental diets (Table 2): 1) SPFH corn silage and 15% inclusion in DM; 2) SPFH corn silage and 33% inclusion in DM; 3) PTFH corn silage and 15% inclusion in DM; 4) PTFH corn silage and 33% inclusion in DM.

Table 2. Ingredients and chemical composition of the experimental diets.

Item	Treatment[1]			
	PTFH		SPFH	
	15	33	15	33
	Ingredients			
Corn silage PTFH, %	15.00	33.00	-	-
Corn silage SPFH, %	-	-	15.00	33.00
Corn kernel, ground %	78.00	60.00	78.00	60.00
Soybean meal, %	3.90	3.90	3.90	3.90
Limestone, %	0.55	0.55	0.55	0.55
Urea, %	1.30	1.30	1.30	1.30
Salt, %	0.50	0.50	0.50	0.50
Mineral premix[2], %	0.75	0.75	0.75	0.75
	Nutrients			
DM, %	69.31	54.32	67.73	52.23
CP, % DM	12.09	11.89	12.08	11.86
NDF, % DM	20.68	26.20	20.60	26.02
Forage NDF, % DM	7.09	15.61	7.01	15.43
ADF, % DM	7.78	11.09	8.26	10.18
EE, % DM	2.96	2.65	2.99	2.73
Ash, % DM	1.98	2.64	2.13	2.97
NFC, % DM	62.29	56.61	62.20	56.42
Starch, % DM	60.92	52.72	61.18	52.99
$peNDF_{>8}$[3], % DM	4.05	7.83	4.06	8.81
$peNDF_{>1.18}$[4], % DM	8.76	12.47	8.28	12.31

[1]PTFH: pull-type forage harvester; SPFH: self-propelled forage harvester. [2]Composition per kg: 200 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 e 4000 mg of monensin sodium. [3]Physically effective NDF above the 8-mm PSPS sieve calculated as proposed by Lammers et al. (1996). [4]Physically effective NDF above the 1.18-mm PSPS sieve calculated as proposed by Kononoff et al. (2003).

Every morning, silages were judged according to appearance as edible or inedible, unloaded manually using a fork and weighed. The visually deteriorated portions were separated and quantified, obtaining daily panel advance values and the percentage of total losses. The TMR was offered once daily with supply adjustment according to the previous day's orts. The dry matter intake (DMI) of the animals was determined by subtracting the orts from the feed provided, which were collected and weighed daily, before the supply of the treatment. Diet ingredient samples were dried at 55°C for 72 hours, ground to 1-mm (Willey mill, Arthur H. Thomas, Philadelphia, PA) to determine DM and ash, the concentration of CP, EE, NDF and ADF, as previously described (Table 2).

The particle size distribution of TMR and orts, were determined on fresh and unground samples using a Penn State particle separator (Kononoff et al., 2003). The offered ration and refusals were sampled three times during the feeding trial, with 30-day intervals. The sorting index was calculated by the observed intake of each fraction retained in each sieve expressed as a percentage of the predicted intake (as fed basis). Values $< 100\%$ indicate refusal, values $> 100\%$ indicate preference and values $= 100\%$ no sorting (Leonardi and Armentano, 2003).

Chewing behavior was evaluated on day 31 and 62. Animals were observed every 10 min during 24 h (Maekawa et al., 2002). Chewing activity was obtained by the sum of eating and rumination activities. The number of meals per day, meal size, meal length, meal interval, intake rate and duration of the first meal were also recorded.

The shrunk body weight (SBW) was recorded after 14 h of fasting (during the night) in the beginning of the comparison period and every 28 days. Average daily gain (ADG) was determined as the slope of the SBW linear regression on days of diet comparison. Feed efficiency was computed as ADG/DMI. Total-tract apparent digestibility was determined using indigestible NDF (iNDF) as an internal marker (Huhtanen et al., 1994).

The individual DMI and ADG data, diet net energy was estimated using the equations proposed by Zinn and Shen (1998). Energy requirement for gain was calculated as: $\text{Eg (Mcal/d)} = (0.0493 \times ((\text{BW} \times 478 / \text{MFW})^{0.75}) \times \text{ADG}^{1.097})$, where BW is mean SBW, 478 is standard reference shrunk weight and MFW is mature final weight. Energy requirement for maintenance was calculated as: $\text{Em (Mcal/d)} = 0.077 \times \text{BW}^{0.75}$. Diet net energy for maintenance was estimated by the equation: $\text{NEm (Mcal/kg DM)} = (-b - (b^2 - 4ac)^{0.5}) / 2a)$, where: $a = (-0.877 \times \text{DMI})$, $b = (0.877 \times \text{Em} + 0.41 \times \text{DMI} + \text{Eg})$, and $c = (-0.41 \times \text{Em})$. Diet net energy for gain was calculated as: $\text{NEg (Mcal/kg DM)} = (0.877 \times (\text{NEm} - 0.41))$. Silage NEm and NEg were estimated by difference according to Owens et al. (1997).

The feces of the animals were collected during four consecutive days and the pH was measured. Blood samples were collected at the beginning and end of the experimental period by jugular vein puncture after 6 hours of feeding (Zotti et al., 2017). The samples were collected in 10 mL tubes without anticoagulant for the measurement of pH, partial pressure of carbon dioxide (pCO_2), oxygen pressure (pO_2), oxygen saturation (sO_2), total carbon dioxide (TCO_2), base excess (BE), bicarbonate (HCO_3^-) and lactate concentration, using an i-STAT clinical analyzer with CG4+ cartridges (i-STAT Corp., Princeton, NJ).

At the beginning of the experiment and every 30 days, carcass traits were evaluated via ultrasound probe (Aloka SSD500). Images were collected using a 17 cm, 3.5 MHz probe. Ribeye area and rib fat thickness were measured between the 12th and 13th rib transversally to the longissimus muscle. Biceps femoris fat thickness was also recorded. A single trained technician scanned all animals (Upton et al., 1999). The images were analyzed using the software Bia Pro Plus (Designer Genes Technology). Bulls were slaughtered after an 18-hour fast (final BW) in a commercial slaughterhouse in accordance with animal welfare and pre-slaughter practices established by the local sanitary inspection. The hot carcass weight was recorded, and dressing calculated as hot carcass weight/SBW.

2.2.4. Statistical analysis

Silage characteristics were presented as mean ± standard deviation. The experimental design for animal performance was a randomized complete block, in a 2x2 factorial arrangement: 2 harvesters x 2 WPCS inclusions, totaling four treatments and five replications per treatment (pen as experimental unit). The animal performance outcomes were analyzed from the model including fixed effects of harvester, inclusion and interaction of the harvester x inclusion, the block was considered as a random effect. The means were corrected by LSMEANS, and compared by Tukey's test at 5% probability through PROC MIXED of the SAS program (v 9.4).

2.3. Results

The means (% of DM) for nutrients from WPCS were 6.33, 1.83, 47.05 and 30.36, for CP, EE, NDF and ADF, respectively. The DMcorr (% as fed) between treatments was 29.1%. The pH of the silages was 3.92, the density of 573 kg of kg of wet silage/m^3 and the losses during feed-out of 7.55% as fed (Table 1). The average concentrations of lactic acid, acetic acid and butyric acid were 3.03% DMcorr, 2.82% DMcorr and 45.2 mg/kg DMcorr, respectively. The level of $peNDF_{>1.18}$ intake from the silage was on average 38.77% DM. The percentage of WPCS particles retained above the 19 mm sieve in the treatments were 12.7 ± 4.93 for PTFH and 7.1 ± 4.08 for SPFH, and for 8-19 mm sieve of 59.3 ± 6.65 for PTFH and 76.2 ± 5.88 for SPFH. The KPS (% DM) value was similar for PTFH (55.5 ± 1.05) and SPFH (54.8 ± 0.98) (Table 1).

The WPCS inclusion level influenced the DMI ($P < 0.01$). The DMI increased to 1.03 kg DM/d for those who received 33% WPCS in the diet (15% = 9.88 kg DM/d vs. 33% = 10.91 kg DM/d). The inclusion of roughage influenced ($P < 0.01$) the performance of the animals, with an increase in gains when the inclusion went from 15% to 33%. The ADG ($P < 0.01$) was 0.199 kg/d more for animals that intake 33% WPCS (33% = 1.585 kg/d vs. 15% = 1.386 kg/d), affecting the final BW ($P < 0.01$; 15% = 524.5 kg vs. 33% = 548.5 kg), carcass gain ($P < 0.01$; 15% = 0.977 kg/d vs. 33% = 1.101 kg/d) and, consequently, the hot carcass weight ($P < 0.01$, 15% = 289.5 kg vs. 33% = 301.5 kg). No other differences were observed in the performance or carcass characteristics (Table 3).

Table 3. Effects of processing (PTFH vs. SPFH) in whole-plant corn silage at two inclusion levels in the diet (15 vs. 33%) on performance of Nellore cattle.

Item	Treatment[1]				SEM[2]	*P*-value[3]		
	PTFH		SPFH					
	15	33	15	33		H	I	H*I
	Performance							
DMI, kg/d	10.06	10.92	9.70	10.90	0.370	0.45	<0.01	0.39
Daily DMI variation, %	5.76	5.99	6.17	5.71	0.447	0.88	0.78	0.40
Initial SBW, kg	403	408	404	400	13.9	0.18	0.81	0.11
Final SBW, kg	531	550	518	547	14.3	0.27	<0.01	0.42
ADG, kg/d	1.459	1.575	1.314	1.595	0.063	0.33	<0.01	0.20
Carcass gain, kg/d	1.016	1.065	0.938	1.137	0.039	0.94	<0.01	0.06
Feed efficiency (ADG/DMI)	0.141	0.144	0.130	0.155	0.010	0.96	0.13	0.22
	Carcass traits							
Hot carcass weight, kg	293	301	286	302	8.6	0.40	<0.01	0.32
Dressing, %	55.1	54.5	55.3	55.2	0.38	0.24	0.31	0.44
Backfat thickness at 12th-rib, mm	4.69	4.08	4.88	4.25	0.428	0.67	0.15	0.97
Biceps femoris fat thickness, mm	6.56	5.92	6.14	6.55	0.508	0.83	0.82	0.30
Longissimus muscle area at 12th-rib, cm^2	93.0	89.0	91.1	92.6	1.67	0.61	0.47	0.10

[1]PTFH: pull-type forage harvester; SPFH: self-propelled forage harvester. [2]SEM: standard error of the mean. [3]H: harvester. I: inclusion. H*I: interaction between harvester and inclusion.

The inclusion of 33% of WPCS increased rumination by 46.36% (15% = 220 min/d vs. 33% = 322 min/d; $P < 0.01$), chewing by 25.82% (15% = 422 min/d vs. 33% = 531 min/d; $P < 0.01$), the number of meals by 13.25% (15% = 8.3 vs. 33% = 9.4; P = 0 .01) and the intake rate by 15.02% (15% = 53.9 g DM/min vs. 33% = 62.0 g DM/min; $P = 0.03$) (Table 4). The bulls had a preference for TMR particles larger than 19 mm ($P < 0.01$) and medium particles between 8-19 mm ($P = 0.05$), animals from the SPFH+15 treatment also had a greater preference (114%) for these particles (19 and 8-19 mm). There was selection against ($P = 0.02$) particles retained on the bottom pan for the type of harvester (PTFH = 97% vs. SPFH = 95%).

Table 4. Feeding behavior and particle sorting index in Nellore cattle fed two levels of inclusion in diets (15 vs. 33%) and two processing (PTFH vs. SPFH) of whole-plant corn silage.

Item	Treatment[1]				SEM[2]	*P-value*[3]		
	PTFH		SPFH					
	15	33	15	33		H	I	H*I
	Feeding behavior							
Eating, min/d	212	213	191	204	12.3	0.21	0.55	0.58
Ruminating, min/d	225	326	215	318	12.1	0.45	<0.01	0.94
Chewing, min/d	438	540	406	523	16.8	0.16	<0.01	0.64
Chewing/DMI, min/kg DM	42.74	44.86	42.08	43.91	1.687	0.63	0.23	0.93
Meals, /d	8.3	10.0	8.4	8.8	0.41	0.20	0.01	0.15
Meal size, g DM/meal	1361	1299	1300	1529	94.2	0.37	0.38	0.12
Meal length, min/meal	27.0	22.4	25.0	24.9	1.66	0.86	0.16	0.18
Intermeal interval, min	164	132	168	158	11.3	0.18	0.07	0.33
Intake rate, g DM/min	52.4	59.7	55.5	64.3	3.69	0.30	0.03	0.83
Duration of first meal, min	42.3	35.3	39.0	38.3	3.62	0.95	0.22	0.30
	Particle sorting index							
>19-mm, %	111^{b}	107^{c}	114^{a}	103^{c}	1.0	0.70	<0.01	<0.01
8-mm, %	107^{b}	103^{c}	114^{a}	104^{bc}	1.5	<0.01	<0.01	0.05
1.18-mm, %	101	100	101	101	2.3	0.20	0.27	0.14
Pan, %	97	97	95	96	0.9	0.02	0.57	0.87

[1] PTFH: pull-type forage harvester; SPFH: self-propelled forage harvester. [2] SEM: standard error of the mean. [3] H: harvester. I: inclusion. H*I: interaction between harvester and inclusion. [a,b,c] Different superscripts indicate significant differences between means within a row ($P < 0.05$).

The diet energy was not affected by treatments (Table 5); however, the inclusion of 33% of WPCS increased ($P < 0.01$) the NEm (1.54 vs. 0.67 Mcal/kg DM) and the TDN (67.73 vs. 27.34%) of the silage compared at 15% of inclusion.

Table 5. Digestibility and net energy values of diets and whole-plant corn silage under two inclusion levels in the diet (15 vs. 33%) and two processing (PTFH vs. SPFH).

Item	Treatment[1]				SEM[2]	*P*-value[3]		
	PTFH		SPFH					
	15	33	15	33		H	I	H*I
Total-tract DM digestibility, %	71.75	73.75	71.61	74.17	3.157	0.73	0.49	0.18
	Diet and silage energy[4]							
Diet NEm[5], Mcal/kg DM	1.84	1.85	1.78	1.86	0.067	0.71	0.51	0.64
Diet NEg[6], Mcal/kg DM	1.20	1.21	1.15	1.22	0.060	0.68	0.51	0.64
Diet TDN[7], %	76.94	77.36	75.05	79.24	2.235	0.99	0.30	0.40
Silage NEm, Mcal/kg DM	0.70	1.53	0.64	1.55	0.179	0.89	<0.01	0.82
Silage NEg, Mcal/kg DM	0.58	0.97	0.75	1.06	0.205	0.55	0.11	0.85
Silage TDN, %	28.34	65.30	26.34	70.16	5.875	0.80	<0.01	0.55

[1] PTFH: pull-type forage harvester; SPFH: self-propelled forage harvester. [2] SEM: standard error of the mean. [3] H: harvester. I: inclusion. H*I: interaction between harvester and inclusion. [4] Calculated from animal performance data according to Owens et al. (1997), Zinn and Shen (1998). [5] Net energy for maintenance. [6] Net energy for gain. [7] Total digestible nutrients.

The treatments did not affect lactate and other blood parameters (Table 6), although, the diets with 15% WPCS increased O_2 pressure (40.09 mm Hg vs. 37.36 mm Hg; P = 0.04), O_2 saturation (64.33% vs. 60.21%; P = 0.05) and decreased (P < 0.01) fecal pH (5.48 vs. 5.69), when compared to 33% WPCS.

Table 6. Blood parameters and fecal pH of Nellore cattle fed diets with two inclusion levels in the diet (15 vs. 33%) and two processing (PTFH vs. SPFH) of whole-plant corn silage.

Item	Treatment[1]							
	PTFH		SPFH			*P*-value[3]		
	15	33	15	33	SEM[2]	H	I	H*I
Lactate, mg/dl	12.15	15.70	13.46	14.08	3.112	0.95	0.47	0.61
Blood pH	7.33	7.32	7.33	7.33	0.012	0.57	0.50	0.61
pCO_2, mm Hg	39.80	41.78	39.85	37.64	1.199	0.09	0.92	0.08
pO_2, mm Hg	40.03	38.03	40.16	36.70	1.309	0.64	0.04	0.57
TCO_2, mmol/l	22.03	23.60	22.23	20.90	0.783	0.11	0.88	0.07
HCO_3, mmol/l	20.83	22.08	21.06	19.85	0.739	0.18	0.97	0.10
BE, mmol/l	-4.50	-3.16	-4.33	-5.56	0.870	0.20	0.95	0.14
sO_2, %	64.5	60.71	64.16	59.71	2.095	0.75	0.05	0.87
Fecal pH	5.49	5.66	5.47	5.72	0.035	0.58	<0.01	0.15

[1]PTFH: pull-type forage harvester; SPFH: self-propelled forage harvester. [2]SEM: standard error of the mean. [3]H: harvester. I: inclusion. H*I: interaction between harvester and inclusion.

2.4. Discussion

The data on the characteristics of the silages present in Table 1, do not include statistical analysis, but the SPFH increased particles in the 8 mm sieve and, as a consequence, increased the MPL. Salvati et al. (2020) evaluated the effect of 3 TLC configurations (6, 12 and 18 mm) in an SPFH with processor roller set to 3-mm gap, and observed the same effect, the increase of the TLC from 6 to 18 mm increased the percentage of particles retained on the 8 mm sieve (56.2% to 63.1%) and MPL (7.7 mm to 10.7 mm). The increase in medium particle size (8 to 19 mm) for WPCS harvested with SPFH is also in agreement with other studies (Andrae et al., 2001; Jonhson et al., 2002).

Pull-type forage harvester had more particles retained on the top sieve (>19mm) and fine particles (<8 mm). This harvester may increase porosity and the risk of silage deterioration (Muck, Moser and Pitt, 2003) and increase on the feed sorting in the feedbunk (Sova et al., 2013). The reduction of particles in the 19 mm sieve with the SPFH is in agreement with Ferraretto et al. (2018), they reported that the mechanical processing of WPCS is able to reduce 20% of the particles retained above 19 mm sieves, due to the processing rollers that, in addition to kernel damage, crush and cut the fibrous fraction and decreased long particles (Jonhson et al., 2003).

In the present study, the KPS values were 55.5% ± 1.05% for PTFH and 54.8% ± 0.98% for SPFH, classified as adequate, according to Shinners and Holmes (2013). Carbonare (2020) compared the performance of PTFH and SPFH in Brazil, and observed KPS averages equal to 45.3% and 48.5%, respectively, demonstrating the inadequate processing of kernels and that adjustments in the harvesters during harvest are necessary, despite still being a challenge for the Brazilian reality. The processing of WPCS is influenced by maturity stage at harvest. Ferraretto and Shaver (2012) reported kernel processing effects only when the DM content was of 32.1-36.0 or 36.1-40%. In our trial, the DM content of WPCS during harvest was at approximately 30%, may explain the lack of effect of harvester type on forage.

The analysis of physico-chemical characteristics were performed on silage samples without replicates, so it was not possible to proceed with any statistical analysis. However, the fermentation profile of the silages suggest that the corn was well preserved (Kung et al., 2018). The data show higher losses during silage feed-out and higher panel temperature for material harvested with SPFH. In normal conditions, the ideal moisture content of silage materials is 30–35% (Guyader et al., 2018). The greater losses for SPFH, are most often detected in extremely wet (< 30% DM) silages characterized by unwanted fermentations (McDonald et al., 1991). Despite the higher losses during silage feed-out and the higher panel temperature for the material collected with SPFH, the DMI and performance of animals were not affected.

The higher DMI for diet with 33% of WPCS is result of an increase in the intake rate and meals per day. The increment on DMI in fed animals with 33% WPCS might have improve ruminal conditions led to greater and these results reflected in the highest ADG, both in carcass gain and final SBW. In general, forage consumption is increased as a result of addition of minimal inclusion of concentrate, as nutrients stimulate microbial growth and increase NDF degradation, reducing rumen filling (Allen, 2000; NASEM, 2016). In high grain diets, Jennings et al. (2019) reported increasing levels of roughage (5%, 9.96% and 15% of corn stalk, DM basis) also showed an increase in DMI (7.7, 8.2 and 8.1 kg/d, respectively). Generally, zebu cattle prefer higher fiber content in the diet than european breeds, due to the lower maintenance requirement of Bos indicus (Frisch and Vercoe, 1977).

Galyean and Hubbert (2014) reported that it is important to set a roughage level below the physical restriction point, to increase DMI and NEg. The peNDF values may be indicative of consumption limitation, as demonstrated by Alhadas et al. (2021) which reported that values from 6.14 to 10.2% of peNDF$_{>4}$ optimize the DMI, and that there is only intake limitation above 10.2% of peNDF. In the present study, peNDF values above the 8 mm sieve for the 33% WPCS diet (~8.32% peNDF$_{>8}$) were not enough to limit the animal DMI.

The typical level of roughage inclusion in Brazilian finishing diets is 16.8% of DM and the corn silage is the primary (69.4%) roughage source in in these diets (Silvestre and Millen, 2021). The greater use of corn silage contributes for increasing the energy content, and the use of peNDF is important to monitor the particle size of feedlot diets, to assure a minimum level of fiber to stimulate rumination and rumen buffering (NASEM, 2016). Silvestre and Millen (2021) reported that the use of peNDF is the preferred method used by nutritionists in Brazil and the average is 14.3% DM of peNDF. Increasing the TLC of forages might be a strategy to increase the peNDF of diets (Mertens, 1997). In the present study, the level of peNDF of diet with 15% WPCS was below the conventional (4.05% peNDF$_{>8}$ and 8.52% peNDF$_{>1.18}$), so is recommended greater settings TCL on the harvesters to increase the peNDF, mainly in diets with high inclusion of concentrate.

The longer intermeal interval although those were only numerically higher, suggests that hunger was delayed, resulting in fewer daily meals and lower DMI in cattle fed with 15% of WPCS. The decrease in dietary feed intake is a consistent response pattern in finishing cattle due to the increased dietary energy density (Krehbiel et al., 2006). It might have a chance that osmotic control of consumption occurred (Allen, 2000) in animals treated with a 15% WPCS diet (85% concentrate). Propionic acid is mainly produced by the fermentation of starch by microorganisms in the rumen and can be absorbed as propionate (Allen, 2000). Propionate is the signal of energy satiety in ruminants, and it can limit the animal's DMI in diets where physical limitation does not occur (Allen, 2020).

The daily variation of the feed intake during the feedlot period is used to identify subacute acidosis (Bevans et al., 2005). Despite the difference in DMI across treatments, there was no significant daily variation in DMI. Fluctuations in intake are better detected in animals fed individually (Owens et al., 1998), which did not occur on this trial, since the animals were in collective pens. Owens et al. (1998) explain that when animals are fed in groups, daily variations in intake may not be detected, unless all animals experience acidosis at the same time.

The impact of WPCS processing on beef cattle performance is inconsistent in the literature. Although there was no interaction between the type of harvester and the forage inclusion level, ADG was higher (1.585 kg/d) in cattle fed a diet of 33% WPCS harvested with SPFH. The lower ADG for animals consuming a diet with 15% WPCS, may be due to an incidence of subacute digestive disorders in these animals, reducing the gain (Gentry et al., 2016). As in this study, Rojas-Bourrillon et al. (1987) evaluating the harvest of WPCS with a self-propelled with or without (silage control) kernel processor on the performance of steers fed high (60% DM of corn silage), medium (90% DM of corn silage) and low energy (65% DM of corn silage and 25% DM of alfalfa-bromegrass hay), observed higher DMI (7.07 vs. 6.02 vs. 5.95 kg DM/d) and ADG (0.98 vs. 0.72 vs. 0.71 kg/d) for animals fed high energy diets with no effect of forage processing during WPCS harvest.

Rumination and chewing time increased when the diet 15% WPCS was compared with 33% WPCS, which is important to stimulate saliva production, buffer the rumen and increase the flow of rumen fluid, to prevent digestive disorders and maintain adequate rumen pH (Galyean and Hubbert, 2014). Likewise, Goulart et al. (2020) observed a progressive increase in rumination time (230.8 vs. 407.5 min/d) and chewing time (427.5 vs. 631.0 min/d) for Nellore bulls fed diets with 19.9% and 39.8% of WPCS, respectively.

Animals preferred (> 100%) particles larger than 8 mm when inclusion was 15% WPCS harvested with SPFH. The WPCS particles harvested with SPFH proved to be more uniform and in a higher percentage on the 8 mm sieve, which may have induced the animals to make this choice. Beauchemin (2018) reported that higher intakes of medium particles (4-19 mm) affect rumination time. Animals are able to make choices that meet their metabolic or physiological requirements, and not just their nutritional requirements, since they can judge what will be best for their organism and keep it comfortable during feeding and rumination activities (Ferreira, 2003).

Although there is no significant difference, animal selected against (< 100%) fine particles associated with the concentrate, and this pattern was a visible and recurrent behavior in this study. Studies show that dairy cows reject long particles and prefer smaller particles from the typical 50:50 diets (Leonardi and Armentano, 2003). However, feedlot beef cattle with 80:20 diet appear to have an opposite selection behavior compared to dairy cows (Custodio et al., 2016). Comparing Nellore and crossbred animals, Rodrigues et al. (2020) observed that crossbred animals had higher DMI and preference for smaller feed particles, which is compatible with the higher nutritional demand of this genetic group.

The increase in blood oxygen saturation (sO_2) and pressure (pO_2) in animals fed a diet with 15% WPCS, may be indicative of metabolic acidosis. High energy diets with reduced peNDF (~4.05% $peNDF_{>8}$), increase acid production and decrease saliva production, reducing ruminal buffering and increasing blood bicarbonate demand. Therefore, the lungs exert a compensatory effect in order to replace the bicarbonate removed from the blood, stimulating hyperventilation. Blood pH may not decrease during acidosis, as occurred in this study, due to the degree of bicarbonate compensation (Owens et al., 1998).

The values of forage NDF, indicate that the inclusion of 15% of WPCS can be considered unsafe, as demonstrated in the study by Goulart et al. (2020), where diets with only 10% NDF from WPCS should be used with caution in Brazilian feedlots, due to the decrease in rumen mat consistency, shorter chewing time and, consequently, lower ruminal pH values close to 5.8. Zebeli et al. (2014) considered subacute acidosis when the pH remains between 5.2 and 5.8 for a period of up to 5 h. In this study, ruminal pH was not measured, therefore, it is not possible to confirm that cattle on the 15% WPCS diet had been under subacute acidosis. However, blood parameters profile indicates a potential acidotic state. Fox and Tedeschi (2002) recommend minimum levels of 7% of $peNDF_{>1.18}$ in the diet to ensure an appropriate environment for digestion and keep the pH close to 5.7. Based on the equation by Pitt et al. (1996), diets with 15% WPCS, which had an average of 4.05% of $peNDF_{>8}$, resulted in a pH of 5.6, indicating a possible risk of acidosis.

The lower fecal pH in animals that consumed a diet with 15% WPCS compared to a diet with 33% WPCS, also suggests that more fermentable carbohydrates reached the large intestine, stimulating the organic acids formation. The decreased utilization of starch in the rumen results in an increase in starch reaching the large intestine, but the intestinal digestion of starch is limited in cattle (Huntington, 1997), and normally does not result in optimal performance in the feedlot (Galyean and Hubbert, 2014).

2.5. Conclusions

The higher inclusion of WPCS increased the performance of finishing cattle compared to a lower inclusion, regardless of the forage harvester type. The diet with 33% WPCS can be considered safe in relation to feeding behavior, blood parameters and animal performance.

The type of equipment used during the WPCS harvesting did not influence the performance of the beef cattle in diets with inclusion up to 33% of DM. It seems, therefore, that such processing has a small effect on the nutritional value and animal performance with corn silage harvest containing less than 30% of DM. Possible other advantages of processing, such as increased particle uniformity and greater speed of harvesting, should be considered when evaluating its usefulness.

Literature cited

Alhadas, H. M., S. C. Valadares Filho, F. F. Silva, F. A. S. Silva, P. Pucetti, M. V. C. Pacheco, L. O. Silva, and L. O. Tedeschi. 2021. Effects of including physically effective fiber from sugarcane in whole corn grain diets on the ingestive, digestive, and ruminal parameters of growing beef bulls. Livest. Sci. 248:104508. doi:10.1016/j.livsci.2021.104508.

Allen, M. S. 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. J. Dairy Sci. 80:1447–1462. doi:10.3168/jds.S0022-0302(97)76074-0.

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598–1624. doi:10.3168/jds.S0022-0302(00)75030-2.

Allen, M. S. 2020. Review: Control of feed intake by hepatic oxidation in ruminant animals: integration of homeostasis and homeorhesis. Animal, 14(S1):55–64. doi:10.1017/S1751731119003215.

Andrae, J. G., C. W. Hunt, G. T. Pritchard, L. R. Kennington, J. H. Harrison, W. Kezar, and W. Mahanna. 2001. Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. J. Anim. Sci. 79:2268–2275. doi:10.2527/2001.7992268x.

AOAC. 1990. Official methods of analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOAC. 2006. Official methods of analysis, 18th ed. Assoc. Off. Anal. Chem., Washington, DC.

Baker, S., and T. Herrman. 2002. Evaluating particle size. Bulletin No. MF-2051. Manhattan (KS): Feed Manufacturing, Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University.

Beauchemin, K. A. 2018. Invited review: Current perspectives on eating and rumination activity in dairy cows. J. Dairy Sci. 101:4762–4784. doi:10.3168/jds.2017-13706.

Bernardes, T. F. 2012. Levantamento das práticas de produção e uso de silagens em fazendas leiteiras no Brasil. 17f. E-book, Universidade Federal de Lavras, Lavras.

Bernardes, T. F., J. L. P. Daniel, A. T. Adesogan, T. A. McAllister, P. Drouin, L. G. Nussio, P. Huhtanen, G. F. Tremblay, G. Bélanger, and Y. Cai. 2018. Silage review: Unique challenges of silages made in hot and cold regions. J. Dairy Sci. 101:4001–4019. doi:10.3168/jds.2017-13703.

Bernardes, T. F., and A. C. do Rêgo. 2014. Study on the practices of silage production and utilization on Brazilian dairy farms. J. Dairy Sci. 97:1852–1861. doi:10.3168/jds.2013-7181.

Bevans, D. W., K. A. Beauchemin, K. S. Schwartzkopf-Genswein, J. J. Mckinnon, and T. A. McAllister. 2005. Effect of rapid or gradual grain adaptation on sub acute acidosis and feed intake by feedlot cattle. J. Anim. Sci. 83:1116–1132. doi:10.2527/2005.8351116x.

Carbonare, M. S. D. 2020. Processamento de grãos (KPS) da silagem de milho e aproveitamento do amido por vacas em lactação em fazendas comerciais. Thesis (PhD in Animal Science) – Federal University of Paraná, Curitiba. p. 1–205.

Custodio, S. A. S., F. L. Claudio, E. M. Alves, G. Calgaro Júnior, T. P. Paim, and E. R Carvalho. 2016. Seleção de partículas da dieta de bovinos de corte em confinamento alimentados com diferentes forragens e alojados em baias individuais ou coletivas. J. Anim. Behav. Biometeorol. 4:55–64. doi:10.14269/2318-1265/jabb.v4n2p55-64.

Dias Junior, G. S., L. F. Ferraretto, G. G. S. Salvati, L. C. de Resende, P. C. Hoffman, M. N. Pereira, and R. D. Shaver. 2016. Relationship between processing score and kernel fraction particle size in whole-plant corn silage. J. Dairy Sci. 99:2719–2729. doi:10.3168/jds.2015-10411.

Ferraretto, L. F., and Shaver, R. D. 2012. Meta-analysis: Impact of corn silage harvest practices on intake, digestion and milk production by dairy cows. Prof. Anim. Sci. 28:141–149. doi:10.15232/S1080-7446(15)30334-X.

Ferraretto, L. F., R. D. Shaver, and B. D. Luck. 2018. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J. Dairy Sci. 101:3937–3951. doi:10.3168/jds.2017-13728.

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 São Paulo, Pirassununga, p. 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. doi:10.3168/jds.S0022-0302(05)73128-3.

Fox, D. G., and L. O. Tedeschi. 2002. Application of physically effective fiber in diets for feedlot cattle. In: Proc. Plains Nutr. Counc. Spring Conf., San Antonio, TX. AREC 02- 20. p. 67–81.

Frisch, J. E., and J. E. Vercoe. 1977. Food intake, eating rate, weight gains, metabolic rate and efficiency utilization in Bos taurus and Bos indicus crossbreed catte. Anim. Sci. 25:343–358. doi:10.1017/S0003356100016755.

Galyean, M. L., and P.J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 81:E8–E16. doi:10.2527/2003.8114.

Galyean, M. L., and M. E. Hubbert. 2014. Review: Traditional and alternative sources of fiber – Roughage values, effectiveness, and levels in starting and finishing diets. Prof. Anim. Sci. 30:571–584. doi:10.15232/pas.2014-01329.

Galyean, M. L., and M. E. Hubbert. 2012. Traditional and alternative sources of fiber–roughage values, effectiveness, and concentrations in starting and finishing diets. In: Proc. Plains Nutrition Counc., San Antonio, TX. p. 75–97.

Gentry, W. W., C. P. Weiss, C. M. Meredith, F. T. McCollum, N. A. Cole, and J. S. Jennings. 2016. Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers. J. Anim. Sci. 94:4759–4770. doi:10.2527/jam2016-1406.

Goulart, R.S., R. A. M. Vieira, J. L. P. Daniel, R. C. Amaral, V. P. Santos, S. G. Toledo Filho, and L. G. Nussio. 2020. Effects of source and concentration of neutral detergent fiber from roughage in beef cattle diets on feed intake, ingestive behavior, and ruminal kinetics. J. Anim. Sci. 98:1–15. doi:10.1093/jas/skaa107.

Guyader, J., V. Baron, and K. Beauchemin. 2018. Corn forage yield and quality for silage in short growing season areas of the Canadian prairies. Agron. 8:164–176. doi:10.3390/agronomy8090164.

Hall, M. B. 2000. Neutral detergent-soluble carbohydrates nutritional relevance and analysis. Bulletin 339. University of Florida, Gainesville, FL.

Hall, M. B. 2009. Determination of starch, including maltooligosaccharides, in animal feeds: comparison of methods and a method recommended for AOAC collaborative study. J. AOAC Int. 92:42–49.

Huntington, G. B. 1997. Starch utilization by ruminants: From basics to the bunk. J. Anim. Sci. 75:852–867. doi:10.2527/1997.753852x.

Huhtanen, P., K. Kaustell, and S. Jaakkola. 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. doi:10.1016/0377-8401(94)90173-2.

Jennings, J. S., C. L. Lockard, and L. O. Tedeschi. 2019. Determining the appropriate inclusion of physically effective fiber for finishing beef cattle diets. In: Teixeira, I. A .M. A., B. Biagioli, L. Hauschild, and N. K. Sakomura, editors. Proc. of the 9th Workshop on Modelling Nutrient Digestion and Utilization in Farm Animals (MODNUT), September 14 to 17, 2019; Ubatuba, SP (Brazil): Cambridge University Press; p. 317.

Johnson, L. M., J. H. Harrison, D. Davidson, W. C. Mahanna, and K. Shinners. 2003. Corn silage management: Effects of hybrid, chop length, and mechanical processing on digestion and energy content. J. Dairy Sci. 86:208–231. doi:10.3168/jds.S0022-0302(03)73601-7.

Johnson, L. M., J. H. Harrison, D. Davidson, J. L. Robutti, M. Swift, W. C. Mahanna, and K. Shinners. 2002. Corn silage management I: Effects of hybrid, maturity, and mechanical processing on chemical and physical characteristics. J. Dairy Sci. 85:833–853. doi:10.3168/jds.S0022-0302(02)74143-X.

Kononoff, P. J., A. J. Heinrichs, and D. R. Buckmaster. 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. doi:10.3168/jds.S0022-0302(03)73773-4.

Krehbiel, C. R., J. J. Cranston, and M. P. McCurdy. 2006. An upper limit for caloric density of finishing diets. J. Anim. Sci. 84:34–49. doi:10.2527/2006.8413_supplE34x.

Kung, L. Jr., R. D. Shaver, R. J. Grant, and R. J. Schmidt. 2018. Silage Review: Interpretation of chemical, microbial, and organoleptic components of silage. J. Dairy Sci. 101:4020–4033. doi:10.3168/jds.2017-13909.

Lammers, B., D. R. Buckmaster, and A. J. Heinrichs. 1996. A simple method for the analysis of particle sizes of forage and total mixed rations. J. Dairy Sci. 79:922–928. doi:10.3168/jds.S0022-0302(96)76442-1.

Leonardi, C., and L. E. Armentano. 2003. Effect of quantify, quality, and length of alfalfa hay on selective consumption by dairy cows. J. Dairy Sci. 86:557–564. doi:10.3168/jds.S0022-0302(03)73634-0.

Maekawa, M., K. A. Beauchemin, and D. A. Christensen. 2002. Chewing activity, saliva production and ruminal pH of primiparous and multiparous lactating dairy cows. J. Dairy Sci. 85:1176–1182. doi:10.3168/jds.S0022-0302(02)74180-5.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80:1463–1481. doi:10.3168/jds.S0022-0302(97)76075-2.

Mertens, D. R. 2002. Gravimetric determination of amylase treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: collaborative study. J. AOAC Int., 85:1217–1240.

McDonald, P., A. R. Henderson, and S. J. E. Heron. 1991. The Biochemistry of Silage, 2nd Edn. Marlow: Chalcombe Publications.

Muck, R. E., L. E. Moser, and R. E. Pitt. 2003. Postharvest factors affecting ensiling. Sil. Sci. Techn. 42:251–304. doi:10.2134/agronmonogr42.c6.

Nagaraja, T. G., and E. C. Titgemeyer. 2007. Ruminal acidosis in beef cattle: the current microbiological and nutritional outlook. J. Dairy Sci. 90:17–38. doi:10.3168/jds.2006-478.

National Academies of Sciences, Engineering, and Medicine (NASEM), 2016. Nutrient requirements of beef cattle. Eighth Revised Edition. Washington, DC: The National Academies Press. doi:10.17226/19014.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: a review. J. Anim. Sci. 75:868–879. doi:10.2527/1997.753868x.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: a review. J. Anim. Sci. 76:275–286. doi:10.2527/1998.761275x.

Pitt, R. E., J. S. Van Kessel, D. G. Fox, A. N. Pell, M. C. Barry, and P. J. Van Soest. 1996. Prediction of ruminal volatile fatty acids and pH within the net carbohydrate and protein system. J. Anim. Sci. 74:226–244. doi:10.2527/1996.741226x.

Pryce, J. D. 1969. A modification of Barker-Summerson method for determination of lactic acid. Analyst. 94:1151–1152. doi:10.1039/AN9699401151.

Rodrigues, M. S., R. T. Santos, L. M. Oliveira, I. S. Silva, F. A. Vargas, and J. L. F. Lourenço. 2020. Intake pattern and feed sorting of two beef cattle genetic groups fed different nutritional strategies. Braz. J. of Develop. 6:91804–91818. doi:10.34117/bjdv6n11-550.

Rojas-Bourrillon, A., J. R. Russell, A. Trenkle, and A. D. McGilliard. 1987. Effects of rolling on the composition and utilization by growing steers of whole-plant corn silage. J. Anim. Sci. 64:303–311. doi:10.2527/jas1987.641303x.

Salinas-Chavira, J., E. Alvarez, M. F. Montaño, and R. A. Zinn. 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. 183:106–115. doi:10.1016/j.anifeedsci.2013.05.004.

Salvati, G. G. S., W. P. Santos, J. M. Silveira, V. C. Gritti, B. A. V. Arthur, P. A. R. Salvo, L. Fachin, A. P. Ribeiro, N. N. Morais Junior, L. F. Ferraretto, J. L. P. Daniel, K. A. Beauchemin, F. A. P. Santos, and L. G. Nussio. 2020. Effect of kernel processing and particle size of whole-plant corn silage with vitreous endosperm on dairy cow performance. J. Dairy Sci. 104:1794–1810. doi:10.3168/jds.2020-19428.

Savoie, P., K. J. Shinners, and B. N. Binversie. 2004. Hydrodynamic separation of kernel and stover components in corn silage. Appl. Biochem. Biotechnol. 113-116:41–54. doi:10.1385/ABAB:113:1-3:041.

Shinners, K. J., and B. J. Holmes. 2013. Making sure your kernel processor is doing its job. Focus on forage, 15:1-3. Accessed January 10, 2021. http://fyi .uwex .edu/forage/files/2014/01/KernelProcessing-FOF.pdf.

Shinners, K. J., A. G. Jirovec, R. D. Shaver, and M. Bal. 2000. Processing whole-plant corn silage with crop processing rolls on a pull-type forage harvester. Appl. Eng. Agric. 16:323–331. doi:10.13031/2013.5214.

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. doi:10.37496/rbz5020200189.

Sova, A. D., S. J. LeBlanc, B. W. McBride, and T. J. DeVries. 2013. Associations between herd-level feeding management practices, feed sorting, and milk production in freestall dairy farms. J. Dairy Sci. 96:4759–4770. doi:10.3168/jds.2013-6679.

Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990. Effects of grain type, roughage level and monensin level on finishing cattle performance J. Anim. Sci., 68:3441–3455. doi:10.2527/1990.68103441x.

Stone, W. C. 2004. Nutritional Approaches to Minimize Subacute Ruminal Acidosis and Laminitis in Dairy Cattle. J. Dairy Sci. 87:13–26. doi:10.3168/jds.s0022-0302(04)70057-0.

Turgeon, O. A., J. I. Szasz, W. C. Koers, M. S. Davis, and K. J. Vander Pol. 2010. Manipulating grain processing method and roughage level to improve feed efficiency in feedlot cattle. J. Anim. Sci. 88:284–295. doi:10.2527/jas.2009-1859.

Upton, W. H., K. A. Donoghue, H. U. Graser, and D. J. Johnston. 1999. Ultrasound proficiency testing. Proc. Assoc. Adv. Anim. Breed. Genet. 13:341–344.

Weissbach, F. 2009. Correction of dry matter content of silages used as substrate for biogas production. In: G. A. Broderick, A. T. Adesogan, L. W. Bocher, K. K. Bolsen, F. E. Contreras- Govea, J. H. Harrison, R. E. Muck, editor, Proceedings XV International Silage Conference, Madison, WI. p. 483–484.

Zebeli, Q., B. U. Metzler-Zebeli, and B. N. Ametaj. 2012. Meta-analysis reveals threshold level of rapidly fermentable dietary concentrate that triggers systemic inflammation in cattle. J. Dairy Sci. 95:2662–2672. doi:10.3168/jds.2011-5080.

Zinn, R. A., and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J. Anim. Sci. 76:1280–1289. doi:10.2527/1998.7651280x.

Zotti C. A., A. P. Silva, R. Carvalho, C. T. Marino, P. H. M. Rodrigues, L. F. P. Silva, T. A. McAllister, and P. R. Leme. 2017. Monensin and a blend of castor oil and cashew nut shell liquid used in a high-concentrate diet abruptly fed to Nellore cattle. J. Anim. Sci. 95:4124–4138. doi:10.2527/jas2017.1580.

3. SEALING STRATEGIES ON CONSERVATION OF WHOLE-PLANT CORN SILAGE FOR FINISHING BEEF CATTLE

Abstract

The study compared the performance of beef cattle fed diets based on whole-plant corn silage (WPCS) sealed with thin films, with or without oxygen barrier (OB), protected with an anti-ultraviolet (anti-UV) cover or double-sided polyethylene (PE) film. The WPCS was harvested at 32% dry matter (DM) and packed in four duplicate silos (total of eight silos) simultaneously. The silos were divided transversally, and four treatments were applied to each one, as follows: 45 µm OB film protected with anti-UV cover (anti-UV+OB); 45 µm OB film protected with 120 µm double-sided PE film (PE120+OB); 50 µm PE film protected with anti-UV cover (anti-UV+PE50); 50 µm PE film protected with 120 µm double-sided PE film (PE120+PE50). The storage time of the first four silos was 300 days and the other four, 347 days. Silage samples were taken from the external surface of the silo to determine silage composition, fermentation products, microbial count, temperature, pH and dry matter loss. Sixty-four Nellore bulls (456 ± 42.8 kg) were blocked by initial shrunk body weight (SBW) and allotted in individual pens for 103 days (13 days of adaptation to facilities + 90 days of feeding trial). The experimental diets contained (on a DM basis) 70% concentrate and 30% corn silage from the different sealing strategies. Dry matter intake (DMI) was measured daily, while SBW and other animal variables were measured at the beginning, middle and end of the feeding trial period. Silage and animal performance data were analyzed as a complete randomized block design. The silages stored under OB film showed higher mold counts. Losses during silage feed-out were higher for films protected with PE120. The anti-UV cover showed temperatures 9.60°C higher at 11:00 am and 4.22°C higher at 4:00 pm, during storage, compared to PE120. The highest silage temperatures were verified in the upper layer, and the highest densities, in the bottom layer of the silo. Animals fed a diet with silage from the PE120+OB treatment showed greater daily variation in DMI. The DMI, average daily gain and other carcass characteristics were similar between treatments. In conclusion, the protection of both thin films with an anti-UV or PE120 coating attenuated the influence of silo covering film on animal performance.

Keywords: animal performance, silo cover, plastic film

3.1. Introduction

Whole-plant corn silage (WPCS) is currently the most common forage source in Brazilian beef cattle feedlot systems (Silvestre and Millen, 2021) and dairy cattle in the world (Ferraretto et al., 2018). The management of conservation process is important to achieve high quality and nutritional value of the silage (Wilkinson and Fenlon, 2013). During the ensiling process, sealing is a limiting step as it contributes to the maintenance of an anaerobic environment inside the silo, favoring the development of lactic acid bacteria and reducing the presence of spoilage microorganisms (Pahlow et al., 2003; Borreani and Tabacco, 2014, 2017).

The physical-chemical characteristics of the plastic film and the lining placement the silo have a great effect on reducing losses by deterioration (Borreani et al., 2007; Bernardes, 2016). Among the plastic films, polyethylene (PE) is the most used; however, has high oxygen permeability, resulting in nutrient loss and lower hygienic quality, especially in the peripheral zones of the silo (Bolsen et al., 1993; Borreani et al., 2018). The production of new films allowed the extrusion of polymers with low oxygen permeability with mechanical resistance, which, in turn, contributes to improve the quality of the silage (Borreani et al., 2007; Borreani et al., 2011; Borreani and Tabacco, 2014; Wilkinson and Fenlon, 2013).

The films with a thickness of 40-50 μm are fragile and need to be protected with other materials or with another plastic film (2-step cover system) to prevent damage during storage and protect against ultraviolet radiation (Borreani et al., 2018). The use of sealing strategies reduces yeast and clostridial counts silage (Machado, 2019), increases recovery of digestible nutrients and, consequently, improves the productive efficiency of lactating dairy cows (Amaral et al., 2014) and weight gain in dairy heifers (Parra et al., 2021).

Losses generated by inefficiency in the sealing system are an important factor to be considered in order to succeed in production systems, especially when WPCS is the main roughage. Deteriorated silages decrease dry matter intake (DMI) and, consequently, animal performance due to the lack of nutrients and high costly diets (Tabacco et al., 2011). Machado (2019) reported that when comparing PE and OB films, both covered with anti-UV protective on nutritive value of maize silage for feedlot cattle, the silage sealed with OB showed lower yeast and clostridial counts, but no difference in animal performance. A hypothesis raised is that the combination of the OB film with other sealing strategies may improve the physico-chemical characteristics of the forage, consequently, its fermentation, reduce aerobic deterioration and limit the growth of undesirable microorganisms, resulting in higher performance of finishing cattle. In addition, there are no studies with large-scale silo replications to evaluate the performance of finishing beef cattle. Therefore, the aim of this study was to compare the nutritional value and the performance of finishing beef cattle fed WPCS from horizontal silos sealed with thin films, with or without oxygen barrier (OB), protected with an anti-ultraviolet (anti-UV) cover or a double-sided polyethylene (PE) film.

3.2. Materials and Methods

3.2.1. Ensiling and treatments

The experiment was conducted at the Department of Animal Science, University of São Paulo, Faculty of Animal Science and Food Engineering, Pirassununga, São Paulo, Brazil. Corn hybrid BM709PRO3 (Biomatrix Seeds, Brazil), was planted in November 2018, with 50 cm spacing between rows. A fertilizer containing N, P and K (10-20-10) was applied at 430 kg/ha in-furrow with the seed. After 25 d of planting, a fertilizer containing N, P and K (30-0-10) was applied.

Corn plants were harvested with approximately 32% DM, with a pull-type forage harvester (Nogueira Máquinas Agrícolas, São João da Boa Vista, Brazil) set for chopping a theoretical length of cut of 8 mm and with a kernel processor device. The forage was stored without additive, into four horizontal silo with approximately 6 m wide, 1 m high and 10 m long. The four silos were replicated twice totalizing eight silos with approximately 36 tons each. The silos were transversely divided (2 m wide for each panel) into four sections, each receiving one of the four sealing strategies: 1) 45 μm OB film (ethylene-vinyl alcohol copolymer film, orange Silostop, Lallemand Animal Nutrition, Brazil) protected with anti-UV cover (Silostop, Lallemand Animal Nutrition, Brazil) (anti-UV+OB); 2) 45 μm OB film protected with 120 μm double-sided PE film (Pacifil Brazil, Sapiranga, RS) (PE120+OB); 3) 50 μm PE film protected with anti-UV cover (anti-UV+PE50); 4) 50 μm PE film protected with 120 μm double-sided PE film (PE120+PE50). Gravel bags were placed around the edges, in transversal lines and in rows across the silo.

During silage storage, the temperature of the covers (anti-UV and PE120) was measured approximately 15 cm on top of the silo using a digital thermometer, at 11:00 am and 4:00 pm of the day. The feed-out phase was initiated at day 300 after sealing for the first set of four silos and at day 347 for the second set of four silos. The four silos were opened at the same time from the side (silo length) and the silage removed daily from the center of each sealing strategy.

3.2.2. Silage sampling

Dry matter losses (DM loss) during silage storage were determined by using the buried bags technique (Borreani et al., 2018). At ensiling, nylon bags containing approximately 500 g of fresh forage were buried 30 cm deep from the upper surface, totaling two bags per sealing strategy.

During the feed trial, the exposed silo feed-out face was sampled. The silage density (kg as fed/m^3) was estimated using a cylindrical probe at the top, middle and bottom of the silo panel. The radius of the cylinder and the depth of the mass removed were measured to calculate the sampled volume, and the silage sample was weighed. The panel temperature was measured at the same locations sampled for density, using a bulb thermometer inserted 20 cm into the panel face.

Silage samples were collected at a depth of 30 cm from the upper surface and aqueous extracts were prepared (25 g + 225 g of deionized water). The pH was measured (DM 20 pH meter, Digimed Analitica, São Paulo, Brazil), fermentation end products were determined by a gas chromatograph with a mass detector (GCMS QP 2010 plus, Shimadzu, Kyoto, Japan), using a capillary column (Stabilwax, Restek, Bellefonte, PA; 60 m, 0.25-mm, i.d., 0.25 90 m), lactic acid was measured by colorimetry (Pryce, 1969) and microbial counts (molds, yeasts, lactic acid bacteria, clostridia and aerobic spores) were made by pour plating serial dilutions of aqueous extracts in selective media.

Samples of silages visually classified as well preserved were collected according to treatment to obtain dry matter (DM) values in a forced air circulation oven at 55°C for 72 h and ground to pass a 1-mm screen using a Wiley type mill (Marconi MA340, Piracicaba, Brazil). The absolute DM was obtained by oven-drying at 105°C (method 934.01; AOAC, 1990). Ash concentration was determined by complete combustion in a muffle furnace at 600°C for 4 h (method 924.05; AOAC, 1990), concentration of crude protein (CP) was determined as N x 6.25 after analysis with a N analyzer (Leco 2000, Leco Instruments Inc.) by the Dumas method (method 990.03; AOAC, 2006). The ether extract was determined (EE) according to AOAC (1990) (method 920.39). Neutral detergent fiber (NDF) was assayed with sodium sulphite and a heat stable amylase and expressed as free of residual ash (Mertens, 2002). The content of non-fiber carbohydrate (NFC) was calculated as NFC = 100 - (CP + NDF + EE + ash). Silage DM content was corrected for volatile compounds (DMcorr) was calculated according to Weissbach (2009): DMcorr (% as fed) = DM (% as fed) + acetone (% as fed) + esters (% as fed) + n-alcohols (% as fed) + isopropanol (% as fed) + 2-butanol (% as fed) + 2,3-butanediol (% as fed) + 0.95 × volatile fatty acids (% as fed) + 0.77 × 1,2-propanediol (% as fed) + 0.08 × lactic acid (% as fed).

The aerobic stability was defined as the time elapsed until silage temperature increases 2°C above the room temperature (O'Kiely, 1993). Samples (3 kg) were weighed into plastic buckets and exposed to air for 10 d in a room with controlled temperature. Temperature of samples and room was recorded every 15 minutes using dataloggers (iMini, Impac, São Paulo, Brazil).

The particle size distribution of the silage was determined using the Penn State particle separator (Kononoff et al., 2003). The kernel and stover fractions were separated by a hydrodynamic procedure based on differences in buoyancy (Savoie et al., 2004). After separation, the kernel fraction was transferred to aluminum plates, re-dried at 60°C for 48 h in a forced-air circulation oven and dry-sieved using a Tyler Ro-Tap Shaker (model RX-29, Tyler, Mentor, OH) with a set of sieves with nominal square apertures of 9.52, 6.70, 4.75, 2.36, 1.18, 0.59 mm plus the bottom pan. The geometrical mean particle size (GMPS; µm) and surface area (cm²/g) were calculated using a log normal distribution (Baker and Herrman, 2002) as described by Dias Junior et al. (2016). The physical characterization of the silages is presented in Table 7.

Table 7. Particle distribution, mean particle length (MPL)[1] and geometrical mean particle size (GMPS)[2] of roughage.

Item	Mean
>19-mm, %	7.9
8-mm, %	56.1
1.18-mm, %	25.8
Pan, %	10.1
MPL, mm	7.4
GMPS, mm	2.6

[1] Particle size distribution was measured using the Penn State particle size separator as described by Kononnoff et al. (2003).
[2] Measured using a Tyler Ro-Tap Shaker with set of sieves.

3.2.3. Animals and experimental diets

Animal care and handling procedures were approved by the Ethics Committee for Animal Use of the University of São Paulo, Faculty of Animal Science and Food Engineering, Pirassununga, São Paulo, Brazil (protocol number 8354020320 – CEUA/FZEA).

Sixty-four Nellore bulls (456 ± 42.8 kg) were housed in individual pens with concrete floor, individual feed bunk and waterer. The feeding period lasted 103 days, being the first 13 days for adaptation and the last 90 days for the feeding trial. At the end of the adaptation period, animals were weighed, blocked according to initial body weight (initial BW), and assigned to the treatments (16 blocks with 4 animals in each block).

The treatments consisted of total mixed rations (TMR) containing 70% of concentrates and 30% of whole-plant corn silage from the silos with different sealing strategies (Table 8). Diets were formulated according to NASEM (2016) recommendations. Every morning, silages were judged according to appearance as edible or inedible, unloaded manually using a fork and weighed. Only the silage from the central region (1m wide) of each panel was fed to the animals, to exclude a possible intervention between treatments. The TMR was offered once a day, and feed orts were collected and weighed daily to determine feed intake before the morning feeding. Diet ingredients samples were analyzed for DM, ash, CP, EE and NDF.

Table 8. Ingredients and chemical composition of the experimental diets.

Item	Treatment[1]			
	PE120		anti-UV	
	OB	PE50	OB	PE50
	Ingredients			
Corn silage PE120+OB, %	30.00	-	-	-
Corn silage PE120+PE50, %	-	30.00	-	-
Corn silage anti-UV+OB, %	-	-	30.00	-
Corn silage anti-UV+PE50, %	-	-	-	30.00
Corn kernel, ground %	63.00	63.00	63.00	63.00
Soybean meal, %	3.90	3.90	3.90	3.90
Limestone, %	0.55	0.55	0.55	0.55
Urea, %	1.30	1.30	1.30	1.30
Salt, %	0.50	0.50	0.50	0.50
Mineral premix[2], %	0.75	0.75	0.75	0.75
	Nutrients			
DM, %	57.60	58.79	57.80	57.19
CP, % DM	12.35	12.32	12.38	12.33
NDF, % DM	25.25	25.29	24.93	25.40
EE, % DM	2.78	2.75	2.78	2.73
Ash, % DM	2.30	2.25	2.29	2.26
NFC, % DM	57.31	57.39	57.62	57.27

[1] PE120+OB: silo covered with oxygen barrier film (45 µm) and protected with double-sided polyethylene (120 µm). PE120+PE50: silo covered with polyethylene film (50 µm) and protected with double-sided polyethylene (120 µm). anti-UV+OB: silo covered with an oxygen barrier film (45 µm) and protected with an anti-UV cover. anti-UV+PE50: silo covered with polyethylene film (50 µm) and protected with an anti-UV cover. [2] Composition per kg: 200 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 e 4000 mg of monensin sodium.

Particle size distribution of total mixed rations was determined using a Penn State particle separator (Kononoff et al., 2003). Offered ration and orts were sampled three times during the feeding trial, with 30-days intervals. The sorting index was calculated by the observed intake of each fraction retained in each sieve expressed as a percentage of the predicted intake (as fed basis). Values < 100% indicate refusal, values > 100% indicate preference and values = 100% indicate no sorting (Leonardi and Armentano, 2003).

Feeding behavior was evaluated during the feeding trial and animals were monitored every 10 min during 24 h (Maekawa et al., 2002). Chewing activity was obtained by the sum of eating and rumination activities. The number of meals per day, meal size, meal length, meal interval, rate of intake and duration of the first meal were also recorded.

The shrunk body weight (SBW) was recorded at the beginning, middle and end of the feeding trial period. The average daily gain (ADG) was determined as the slope of the SBW linear regression over time. Feed efficiency was computed as ADG/DMI. Total-tract apparent digestibility was determined by using indigestible NDF as an internal marker (Huhtanen et al., 1994). From the individual DMI and ADG data, diet net energy was estimated using the equations proposed by Zinn and Shen (1998).

Carcass traits were evaluated through ultrasound and images were collected using a 17 cm, 3.5 MHz probe. Ribeye area and rib fat thickness were measured between the 12th and 13th rib transversally to the longissimus muscle. Marbling score (1 to 10) was recorded from the 11th to 13th rib longitudinally to the longissimus muscle. Biceps femoris fat thickness was also recorded (Upton et al., 1999). The images were analyzed using a software. Bulls were slaughtered after an 18-hour fast according to animal welfare and pre-slaughter practices established by the local sanitary inspection. The hot carcass weight was recorded, and dressing was calculated as hot carcass weight/SBW.

3.2.4. Statistical analysis

Silage data were analyzed as a randomized complete block design, with the silos being the blocks, four treatments (sealing strategies) and four replicates per treatment (panel as experimental unit). The silage data were compared through a model including the random effect of period and block, fixed effect of cover (PE120 and anti-UV) and film (OB and PE50), and interaction of cover x film.

Animal performance data were analyzed as a randomized complete block design, with four treatments (sealing strategies) and sixteen replicates per treatment (animal as the experimental unit). The model included fixed effects of cover, film, and interaction between cover x film, and the block was considered as a random effect. Means were compared by Tukey's test ($\alpha = 0.05$), using the PDIFF option in the LSMEANS statement, of Mixed procedure of SAS (v 9.4). Differences were declared significant if $P \leq 0.05$, and trends were indicated if $0.05 < P \leq 0.10$.

3.3. Results

The silage characteristics are shown in Table 9. The values of nutrients and fermentation profile were similar ($P > 0.05$). The means (% DM) for CP, EE, NDF and pH were 7.65, 1.91, 47.98 and 3.87, respectively. Silage DMcorr tended ($P = 0.07$) to be higher (32.5%) for the treatment with PE120+PE50 and lower (30.9%) for anti-UV+PE50. Silages with OB film ($P < 0.01$) and films covered with PE120 ($P = 0.04$) had higher mold counts. There was a trend ($P = 0.08$) of greater losses during storage for treatments with anti-UV compared to PE120 (~7.1 vs. 6.35% DM). Losses during silage feed-out were increased ($P < 0.01$) for films covered with PE120.

Table 9. Characteristics of corn silages under sealing strategies[1].

Item	Treatment[2]				SEM[3]	*P*-value[4]		
	PE120		anti-UV					
	OB	PE50	OB	PE50		C	F	C*F
	Chemical composition							
DMcorr[2], % as fed	31.3	32.5	31.5	30.9	0.98	0.14	0.51	0.07
CP, % DM	7.78	7.19	7.90	7.75	0.242	0.76	0.65	0.87
EE, % DM	1.99	1.87	1.96	1.82	0.064	0.51	0.12	0.89
NDF, % DM	47.16	47.35	46.07	47.77	0.554	0.58	0.14	0.22
Ash, % DM	4.12	3.94	4.09	4.03	0.087	0.78	0.23	0.51
	Fermentation profile							
pH	3.84	3.87	3.90	3.89	0.028	0.17	0.74	0.58
Lactic acid, % DMcorr	4.29	4.15	4.00	4.66	0.331	0.83	0.42	0.18
Acetic acid, % DMcorr	1.44	1.48	1.42	1.33	0.120	0.56	0.72	0.66
Ethanol, % DMcorr	0.18	0.14	0.19	0.17	0.027	0.28	0.13	0.60
Butyric acid, mg/kg DMcorr	25.67	25.33	27.99	33.11	5.02	0.20	0.54	0.48
	Microbial profile							
Lactic acid bacteria, log cfu/g	5.52	5.75	5.76	5.71	0.821	0.77	0.79	0.68
Yeasts, log cfu/g	6.00	5.39	6.10	5.91	0.731	0.68	0.59	0.78
Moulds, log cfu/g	4.92	3.86	4.50	3.30	0.145	0.04	<0.01	0.66
Aerobic spores, log cfu/g	4.66	3.87	4.41	4.39	0.480	0.73	0.31	0.34
Clostridia, log cfu/g	3.09	2.83	2.91	2.45	0.302	0.38	0.27	0.73
	Losses							
Storage DM loss[5], % DM	6.6	6.1	7.5	6.7	1.98	0.08	0.53	0.88
Loss during feed-out[7], % as fed	2.5	3.2	1.1	1.3	0.28	<0.01	0.17	0.48
Aerobic stability, h	29.7	35.3	26.1	28.2	6.61	0.37	0.51	0.77

[1] Measured at 30 cm depth from the upper surface.[2] PE120+OB: silo covered with oxygen barrier film (45 µm) and protected with double-sided polyethylene (120 µm). PE120+PE50: silo covered with polyethylene film (50 µm) and protected with double-sided polyethylene (120 µm). anti-UV+OB: silo covered with an oxygen barrier film (45 µm) and protected with an anti-UV cover. anti-UV+PE50: silo covered with polyethylene film (50 µm) and protected with an anti-UV cover.[3] SEM: standard error of the mean. [4] C: cover. F: film. C*F: interaction between cover*film. [5] Measured by using buried bags. [7] Amount of spoiled silage visually identified separated and quantified daily.

The type of cover influenced ($P < 0.01$) the heat absorption during the silage storage at the two evaluated times. The anti-UV cover showed an increase of 9.60°C (53.4 vs. 43.8°C) at 11:00 am and of 4.22°C (33.78 vs. 29.56°C) at 4:00 pm in relation to the PE120. There was a trend ($P = 0.07$) for higher temperature at the surface for the PE50 film (~32.16 vs. 31.18°C) (Table 10).

Table 10. Surface temperature of the silo cover (PE120 vs. anti-UV) during storage at two times of the day (11:00 am and 4:00 pm).

Hour	Treatment[1]				SEM[2]	*P*-value[3]		
	PE120		anti-UV					
	OB	PE50	OB	PE50		C	F	C*F
11:00 am	43.83	43.77	54.10	52.70	2.308	<0.01	0.65	0.68
4:00 pm	28.95	30.17	33.41	34.15	0.542	<0.01	0.07	0.65

[1] PE120+OB: silo covered with oxygen barrier film (45 µm) and protected with double-sided polyethylene (120 µm). PE120+PE50: silo covered with polyethylene film (50 µm) and protected with double-sided polyethylene (120 µm). anti-UV+OB: silo covered with an oxygen barrier film (45 µm) and protected with an anti-UV cover. anti-UV+PE50: silo covered with polyethylene film (50 µm) and protected with an anti-UV cover. [2] SEM: standard error of the mean. [3] C: cover. F: film. C*F: interaction between cover*film.

The silage temperature was higher ($P < 0.01$) at the top for the both cover (PE120 = 35.9°C; anti-UV = 35.1°C), the temperature of the middle with anti-UV coating was similar to the top (34.9 vs. 35.1°C) and the lowest temperature was for the bottom of the silage with PE120 cover (PE120 = 32.4°C; anti-UV = 34.0°C). For the films, the highest temperatures were being observed in the upper surface (top = 35.5°C; middle = 34.5°C; bottom =

33.2°C) of silages. Density was affected by the silo layer ($P < 0.01$), the highest densities were to the bottom surface and the lowest to the top (Table 11).

Table 11. Silage temperature and density under cover (PE120 or anti-UV) and films (OB or PE50) in different silo layers.

	Layer[1]									
	Top	Middle	Bottom	Top	Middle	Bottom				
	Cover[2]							*P-value*[4]		
Item	PE120			anti-UV			SEM[3]	C	L	C*L
Temperature, °C	35.9^{a}	34.2^{dc}	32.4^{e}	35.1^{ab}	34.9^{bc}	34.0^{d}	0.35	0.04	<0.01	<0.01
Density, kg as fed/m^3	406	549	621	392	532	622	10.1	0.21	<0.01	0.59
	Films[5]							*P-value*[4]		
Item	OB			PE50			SEM[3]	C	L	C*L
Temperature, °C	35.1	34.4	32.9	35.9	34.7	33.5	0.44	0.12	<0.01	0.81
Density, kg as fed/m^3	408	540	617	390	541	625	9.94	0.66	<0.01	0.36

[1]Top: 15 cm depth from upper surface. Middle: 45 cm depth from upper surface. Bottom: 60 cm depth from upper surface. [2]PE120: silo protected with double-sided polyethylene (120 μm). anti-UV: silo protected with an anti-UV cover. [3]SEM: standard error of the mean. [4]C: cover. L: layer. C*L: interaction between cover*layer. [5]OB: silo covered with oxygen barrier film (45 μm). PE50: silo covered with polyethylene film (50 μm). [a,b,c]Different superscripts indicate significant differences between means within a row ($P < 0.05$).

The DMI (~11.35 kg DM/d) of the animals was not affected by cover or film type ($P = 0.46$). However, animals fed a diet containing PE120+OB silage showed greater daily variation in DMI ($P = 0.01$). The ADG (~1.512 kg/d), carcass gain (~1.229 kg/d), feed efficiency (~0.133 kg/kg), dressing (~56.9%) and other carcass characteristics were similar between treatments (Table 12).

Table 12. Effect of whole-plant corn silage sealing strategies on the performance of Nellore cattle.

	Treatment[1]							
Item	PE120		anti-UV		SEM[2]	*P*-value[3]		
	OB	PE50	OB	PE50		C	F	C*F
	Performance							
DMI, kg/d	11.00	11.22	11.25	11.95	0.432	0.11	0.13	0.46
Daily DMI variation, %	7.65^{a}	6.00^{b}	6.48^{b}	6.26^{b}	0.270	0.09	<0.01	0.01
Initial SBW, kg	458	455	456	458	22.8	0.87	0.98	0.55
Final SBW, kg	597	589	588	607	25.5	0.62	0.51	0.12
ADG, kg/d	1.517	1.494	1.470	1.570	0.063	0.81	0.54	0.32
Carcass gain, kg/d	1.205	1.235	1.198	1.278	0.072	0.69	0.23	0.59
Feed efficiency (ADG/DMI)	0.137	0.133	0.129	0.133	0.003	0.37	0.91	0.29
	Carcass traits							
Hot carcass weight, kg	337	338	336	344	16.9	0.68	0.32	0.46
Dressing, %	56.5	57.6	57.0	56.8	0.52	0.73	0.23	0.13
Backfat thickness at 12th-rib, mm	6.07	6.54	6.40	5.89	0.519	0.75	0.96	0.34
Biceps femoris fat thickness, mm	7.64	7.52	7.14	7.51	0.632	0.68	0.84	0.69
Longissimus muscle area at 12th-rib, cm^2	97.67	95.76	96.70	98.93	2.325	0.18	0.35	0.11

[1]PE120+OB: silo covered with oxygen barrier film (45 μm) and protected with double-sided polyethylene (120 μm). PE120+PE50: silo covered with polyethylene film (50 μm) and protected with double-sided polyethylene (120 μm). anti-UV+OB: silo covered with an oxygen barrier film (45 μm) and protected with an anti-UV cover. anti-UV+PE50: silo covered with polyethylene film (50 μm) and protected with an anti-UV cover. [2]SEM: standard error of the mean. [3]C: cover. F: film. C*F: interaction between cover*film. [a,b,c]Different superscripts indicate significant differences between means within a row ($P < 0.05$).

The sealing strategies did not affect the variables of feeding behavior (Table 13). The average ruminating time was 303 min/d, chewing time was 490 min/d and number of meals was 7.4 meals/d. There was no significant in particle sorting index, but the values indicate that the animals selected in favor (> 100%) of particles with sizes of 8 mm and 19 mm.

Table 13. Feeding behavior and particle sorting index in cattle fed diets containing whole-plant corn silage under different sealing strategies.

Item	Treatment[1]				SEM[2]	*P*-value[3]		
	PE120		anti-UV					
	OB	PE50	OB	PE50		C	F	C*F
	Feeding behavior							
Eating, min/d	189	190	181	188	10.9	0.63	0.70	0.76
Ruminating, min/d	305	291	303	314	18.0	0.43	0.88	0.33
Chewing, min/d	495	481	484	502	19.7	0.77	0.90	0.37
Chewing/DMI, min/kg DM	44.9	42.9	42.9	41.5	1.67	0.31	0.30	0.85
Meals, /d	7.5	7.3	7.3	7.6	0.39	0.87	0.87	0.57
Meal size, g DM/meal	1482	1644	1614	1728	112.6	0.27	0.16	0.80
Meal length, min/meal	25.5	26.5	25.2	25.7	1.51	0.70	0.60	0.85
Intermeal interval, min	180	183	182	176	12.8	0.84	0.90	0.73
Intake rate, g DM/min	61.1	62.8	69.7	70.1	6.38	0.12	0.84	0.89
Duration of first meal, min	49.4	56.9	51.9	55.9	4.72	0.86	0.22	0.71
	Índice de seleção de partículas							
>19-mm, %	106	102	104	100	4.9	0.45	0.17	0.87
8-mm, %	102	100	101	100	4.9	0.37	0.19	0.94
1.18-mm, %	99	94	96	93	4.9	0.26	0.11	0.99
Pan, %	85	82	84	80	4.2	0.57	0.15	0.87

[1]PE120+OB: silo covered with oxygen barrier film (45 µm) and protected with double-sided polyethylene (120 µm). PE120+PE50: silo covered with polyethylene film (50 µm) and protected with double-sided polyethylene (120 µm). anti-UV+OB: silo covered with an oxygen barrier film (45 µm) and protected with an anti-UV cover. anti-UV+PE50: silo covered with polyethylene film (50 µm) and protected with an anti-UV cover. [2]SEM: standard error of the mean. [3]C: cover. F: film. C*F: interaction between cover*film.

The net energy values of diets containing corn silages were similar (P > 0.05) as shown in Table 14. The diet had an average NEg of 1.18 Mcal/kg DM and TDN of 76.4%, the silage had NEg of 0.81 and TDN of 57.1%.

Table 14. Net energy values of diets containing corn silages under different sealing strategies for finishing beef cattle.

Item	Treatment[1]				SEM[2]	*P*-value[3]		
	PE120		anti-UV					
	OB	PE50	OB	PE50		C	F	C*F
	Diet and silage energy[4]							
Diet NEm[5], Mcal/kg DM	1.86	1.82	1.79	1.81	0.035	0.15	0.69	0.27
Diet NEg[6], Mcal/kg DM	1.22	1.19	1.16	1.18	0.030	0.15	0.74	0.25
Diet TDN[7], %	77.8	76.4	75.3	76.1	1.15	0.15	0.74	0.26
Silage NEm, Mcal/kg DM	1.42	1.31	1.23	1.29	0.079	0.15	0.74	0.27
Silage NEg, Mcal/kg DM	0.90	0.81	0.73	0.79	0.078	0.15	0.74	0.26
Silage TDN, %	60.5	57.1	54.4	56.3	2.87	0.15	0.74	0.26

[1]PE120+OB: silo covered with oxygen barrier film (45 µm) and protected with double-sided polyethylene (120 µm). PE120+PE50: silo covered with polyethylene film (50 µm) and protected with double-sided polyethylene (120 µm). anti-UV+OB: silo covered with an oxygen barrier film (45 µm) and protected with an anti-UV cover. anti-UV+PE50: silo covered with polyethylene film (50 µm) and protected with an anti-UV cover. [2]SEM: standard error of the mean. [3]C: cover. F: film. C*F: interaction between cover*film. [4]Calculated from animal performance data according to Owens et al. (1997), Zinn and Shen (1998). [5]Net energy for maintenance. [6]Net energy for gain. [7]Total digestible nutrients.

3.4. Discussion

The chemical composition of the silage suggest that the corn was well preserved and is in agreement with studies similar to this (Robinson and Swanepoel, 2016; Wang et al., 2017). The DM content of WPCS was approximate to ideal DM (30–35%) for satisfactory silage (Guyader et al., 2018). Kung et al. (2018) indicated pH values less than 4.5 and lactic acid from 3 to 6% DM. In the present study, the average pH was less than 4.0 and lactic acid was of 4.27% DM. Also, low concentration of butyric acid indicated that clostridia was suppressed during silage fermentation (Kung et al., 2018).

Differences in chemical characteristics and nutritional quality of the silages were numerically small and reflected the fact that all silo treatment were covered with two layers, a film below and a cover above as a strategy. Robinson and Swanepoel (2016) also observed that use of a underlay film with or without OB properties had no impact on silage fermentation parameters the outer 25.4 cm of the silage pile, or in 25.4 to 50.8 cm depth below the surface of closed silage piles. The literature reports that films with OB properties reduce the development of undesirable microorganisms and decrease DM losses in silage (Borreani et al., 2007; Borreani and Tabacco, 2008; Bernardes et al., 2012; Borreani et al., 2013; Wilkinson and Fenlon, 2013). However, the findings of this study demonstrate the opposite for the OB film. Robinson and Swanepoel (2016) suggested that several studies have indicated the benefits of OB film for silage, but probably they did not compare inner films with or without OB properties, the benefits were due to a “silage cover system” and not just the OB film.

The lower DM content (30.9% DM) for anti-UV+PE50 film, can be associated with nutrients consumed by microorganisms during fermentation (Hu et al., 2009). Already the higher mold count for silage sealed with OB was not expected this film has typical lower oxygen permeability (Borreani et al., 2018) and decreases deterioration losses (Wilkinson and Fenlon, 2013). Oxygen permeability or water condensation/absorption by the OB film were not evaluated, but a possible explanation is that the ethylene-vinyl alcohol copolymer film (EVOH) used as an oxygen barrier in this study has polar groups in its composition, and therefore, the capacity to form hydrogen bonds, absorbing moisture and losing its impermeability to oxygen and mechanical properties (Aucejo et al., 1999; Mokwena and Tang, 2012).

The colour of the material used for the seal exerts a highly significant influence on its temperature (Snell et al., 2002). The present study confirms the finding. The green anti-UV cover absorbed 22% more heat than white PE120 at the hottest time of day, and the silage below presented a thin layer darken, which may be linked to the Maillard reaction, which involves the condensation of sugars with amino groups of the amino acids, making the nitrogen terminal unavailable (Muck et al., 2003). Snell et al (2002) demonstrates that the green and black coloured films showing a very similar thermal behavior (33.2°C and 32.9°C, for black and green film, respectively), with highest values of temperatures reached at midday, but with absence of differences in silage quality. However, the authors evaluated the effect of the films in mini-silos, which may have reduced the heat exchange, resulted in relatively homogeneous conditions.

Despite the higher surface temperature of the anti-UV, the coverage reduced loss during feed-out silage, therefore, covering the films with anti-UV might have helped in ultraviolet reduce and prevented the material from disintegrating under sunlight, resulting in lower air infiltration (Wilkinson et al., 2003). Likewise, Machado (2019) observed that the protection of films OB and PE (40 μm) with an anti-UV cover might have might have helped in preserving the film properties and reduced the differences in silage composition.

Studies similar to this one also evaluated the effect of thin films with or without OB, both protected with double-sided PE film (Robinson and Swanepoel, 2016; Wang et al., 2017). The results showed only difference in the pH (OB = 3.73 vs. PE = 3.76) and lactic acid (OB = 5.85 vs. PE = 5.63% DM) (Wang et al., 2017) and without evidence of deterioration in silage, because the pH, fermentation products, microorganism count, temperature and nutrients, were similar (Robinson and Swanepoel, 2016). However, the studies did not evaluate different coverage and the separate effects of film and coverage. In this present trial mold counts were 12% higher for silage with coverage with PE120 than for anti-UV (~4.39 vs. 3.90 log cfu/g), which demonstrates that there were differences in the transmission of oxygen through the covering materials which favored the development of molds. The presence of molds in silage can indicate the existence of mycotoxins, produced by filamentous fungi (Storm et al., 2008), these compounds are highly toxic and can affect to feed intake, growth rate, animal performance or to the immune system (Pereyra et al., 2008; Ogunade et al., 2018).

The high temperature on the silage surface is linked to the lower density of this layer, as the increase in porosity and oxygen exchanges (Pitt and Muck, 1993) favors the development of yeasts, resulting in the production of heat and increase in the temperature of the mass (Woolford, 1990). Development of yeasts in the first 15 cm of the silo was not studied in this trial, but data indicates that the heating of the silage was due to the presence of oxygen in this layer and it favored the appearance of these microorganisms.

Although there was no difference in performance, the animals presented an ADG (average of 1.512 kg/d) within the calculated by NASEM (2016). The cattle showed hot carcass weight and final body weight consistent with those required by most slaughterhouses in Brazil, of at minimum 180 kg and 500 kg, respectively. The average carcass dressing percentages were superior to Nellore standards, where 52% carcass dressing is considered normal for Nellore cattle slaughtered at 24 months of age (Farias et al., 2012). The averaging of backfat thickness was 6.22 mm. This value is adequate, the backfat thicker than 3 mm is desirable, as preventing the muscle fibers from shortening due to cold and does not compromise the tenderness of meat (Rezende et al., 2019). The cattle displayed normal feeding behavior, and similar with other study (Machado, 2019). It is common for Nellore bulls sort particles in favor of roughage, especially when the diets have higher contents of concentrates (Caetano et al., 2015). This may explain the animals select in favor of particles between 19 and 8 mm.

The greater losses during feed-out for the films covered with PE120 combined with the enhanced growth of molds for the OB film resulted in the worst strategy of sealing the silage, which was identified by the animals, resulting in a greater daily variation of DMI for cattle fed TMR containing silage from this treatment. The DMI variation may be a result of the low preference for spoiled silages and lower intake when animals have a choice for different feeds silage sources (Gerlach et al., 2013).

In this study, the spoiled silage was disposal before inclusion in the livestock feed. Windle and Kung (2013) fed a fresh and spoiling TMR containing corn silage to heifers, the animals fed the spoiling TMR ate about 12% less DM. Bernardes and Rêgo (2014) carried out a study on silage production and utilization in Brazil, reported that a total of 88.8% of the farmers did not discard silage with a deteriorated appearance before providing it to the animals. Several studies in cattle (Wichert et al., 1998; Whitlock et al., 2000) demonstrated that the offer of deteriorated silage, even in small quantities, has a strong negative effect on the animals DMI and the nutritional value of the diet.

Silage sealing can improve the DMI and, consequently, the performance of categories of animals fed a high dietary proportion of silage (Parra et al., 2021). Parra et al. (2021) observed an increase in the DMI of diets containing 80% WPCS under OB sealing, which resulted in 8% more digestible energy intake and 12% more ADG in dairy heifers. In the present study, the inclusion of 30% of WPCS associated with the few differences found in the silages and the spoiled silage discard before inclusion in the diet, may have resulted in the absence of changes in the DMI and other variables related to the performance of finishing cattle.

3.5. Conclusion

Our results suggest that sealing strategy with thin plastic underlay film with OB properties versus without OB properties for whole-plant corn silage has the potential to reduce losses during storage for up to at least 11 months, without altering the chemical composition and fermentation quality. The double silage sealing combined with the inclusion of 30% of silage in the diet were not enough to change the performance of finishing beef cattle.

Literature Cited

Amaral, R. C., M. C. Santos, J. L. P. Daniel, A. S. Neto, A. W., Bispo, E. H. Cabezas-Garcia, T. F. Bernardes, and L. G. Nussio. 2014. The influence of covering methods on the nutritive value of corn silage for lactating dairy cows. R. Bras. Zootec. 43:471–478. doi:10.1590/S1516-35982014000900003.

AOAC. 1990. Official methods of analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOAC. 2006. Official methods of analysis, 18th ed. Assoc. Off. Anal. Chem., Washington, DC.

Aucejo, S., C. Marco, and R. Gavara. 1999. Water effect on the morphology of EVOH copolymers. J. App. Poly. Sci. 74:1201–1206. doi:10.1002/(SICI)1097-4628(19991031)74:5<1201::AID-APP17>3.0.CO;2-8

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

Bernardes, T. F. 2016. Advances in Silage Sealing. In: Da Silva, T., E.M. Santos, editor, Advances in Silage Production and Utilization. InTech Open, Rijeka, Croatia. p. 53–62. doi:10.5772/65445.

Bernardes, T. F., and A. C. Rêgo. 2014. Study on the practices of silage production and utilization on Brazilian dairy farms. J. Dairy Sci. 97:1852–1861. doi: 10.3168/jds.2013-7181.

Bernardes, T. F., L. G. Nussio, and R. C. Amaral. 2012. Top spoilage losses in maize silage sealed with plastic films with different permeabilities to oxygen. Grass Forage Sci. 67:34–42. doi:10.1111/j.1365-2494.2011.00823.x.

Bolsen, K. K., J. T. Dickerson, B. E. Brent, R. N. Sonon Jr, B. S. Dalke, C. Lin, and J. E. Boyer Jr. 1993. Rate and extent of top spoilage losses in horizontal silos. J. Dairy Sci. 76:2940–2962. doi:10.3168/jds.S0022-0302(93)77634-1.

Borreani, G., P. Dolci, E. Tabacco, and L. Cocolin. 2013. Aerobic deterioration stimulates outgrowth of spore-forming *Paenibacillus* in corn silage stored under oxygen-barrier or polyethylene films. J. Dairy Sci. 96:5206–5216. doi:10.3168/jds.2013-6649.

Borreani, G., and E. Tabacco. 2008. Low permeability to oxygen of a new barrier film prevents butyric acid bacteria spore formation in farm maize silage. J. Dairy Sci. 91:4272–4281. doi:10.3168/jds.2008-1151.

Borreani, G., and E. Tabacco. 2014. Improving corn silage quality in the top layer of farm bunker silos through the use of a next-generation barrier film with high impermeability to oxygen. J. Dairy Sci. 97:2415–2426. 10.3168/jds.2013-7632.

Borreani, G., and E. Tabacco. 2017. Chapter 9: Plastics in animal production, In: Orzolek, M. (Ed.), A Guide to the Manufacture, Performance, and Potential of Plastics in Agriculture. Elsevier Ltd., Amsterdam, p. 145–185. doi:10.1016/B978-0-08-102170-5.00009-9.

Borreani, G., E. Tabacco, and de Angelis, D. 2011. Special EVOH: based films improve quality and sanity of farm corn silage. In: Proc. Int. Conf. Agri. Hort. Film Ind. Applied Market Information Ltd., Barcelona, Spain, p. 1–15.

Borreani, G., E. Tabacco, and L. Cavallarin. 2007. A new oxygen barrier film reduces aerobic deterioration in farm-scale corn silage. J. Dairy Sci. 90:4701–4706. doi:10.3168/jds.2007-0310.

Borreani, G., E. Tabacco, R. J. Schmidt, B. J. Holmes, and R. E. Muck. 2018. Silage review: Factors affecting dry matter and quality losses in silages. J. Dairy Sci. 101:3952-3979. doi:10.3168/jds.2017-13837.

Caetano, M., R. S. Goulart, S. L. Silva, J. S. Drouillard, P. R. Leme, and D. P. Lanna. 2015. Effect of flint corn processing method and roughage level on finishing performance of Nellore-based cattle. J. Anim. Sci. 93:4023–4033. doi:10.2527/jas.2015-9051.

Dias Junior, G. S., L. F. Ferraretto, G. G. S. Salvati, L. C. de Resende, P. C. Hoffman, M. N. Pereira, and R. D. Shaver. 2016. Relationship between processing score and kernel fraction particle size in whole-plant corn silage. J. Dairy Sci. 99:2719-2729. doi:10.3168/jds.2015-10411.

Degano, L., 1999. Improvement of silage quality by innovative covering system. In: Proc. XII Int. Silage Conf., Uppsala Sweden, p. 296–297.

Farias, M. S., I. N. Prado, M. V. Valero, F. Zawadzki, R. R. Silva, C. E. Eiras, D. C. Rivaroli, and B. S. Lima. 2012. Níveis de glicerina para novilhas suplementadas em pastagens: desempenho, ingestão, eficiência alimentar e digestibilidade. Semina, 33:1177–1188. doi:10.5433/1679-0359.2012v33n3p1177.

Ferraretto, L. F., R. D. Shaver, and B. D. Luck. 2018. Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. J. Dairy Sci. 101:3937–3951. doi:10.3168/jds.2017-13728.

Gerlach, K., F. Roß, K. Weiß, W. Büscher, and K. H. Südekum. 2013. Changes in maize silage fermentation products during aerobic deterioration and effects on dry matter intake by goats. Agric. Food Sci. 22:168–181. doi:10.23986/afsci.6739.

Guyader, J., V. Baron, and K. Beauchemin. 2018. Corn forage yield and quality for silage in short growing season areas of the Canadian prairies. Agron. 8:164–176. doi:10.3390/agronomy8090164.

Hu, W., R. J. Schmidt, E. E. Mcdonell, C. M. Klingerman, and L. Kung Jr. 2009. The effect of Lactobacillus buchneri 40788 or Lactobacillus plantarum MTD1 on the fermentation and aerobic stability of corn silages ensiled at two dry matter contents. J. Dairy Sci. 92:3907–3914. doi:10.3168/jds.2008-1788.

Huhtanen, P., K. Kaustell, and S. Jaakkola. 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. doi:10.1016/0377-8401(94)90173-2.

Kononoff, P. J., A. J. Heinrichs, and D. R. Buckmaster. 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. doi:10.3168/jds.S0022-0302(03)73773-4.

Kung, L. Jr., R. D. Shaver, R. J. Grant, and R. J. Schmidt. 2018. Silage Review: Interpretation of chemical, microbial, and organoleptic components of silage. J. Dairy Sci. 101:4020–4033. doi:10.3168/jds.2017-13909.

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. doi:10.3168/jds.S0022-0302(03)73634-0.

Machado, J., 2019. Filmes de vedação na conservação de silagem de milho para bovinos de corte em terminação. Masters dissertation. Department of Animal Science, State University of Maringá, Maringá.

Maekawa, M., K. A. Beauchemin, and D. A. Christensen. 2002. Chewing activity, saliva production and ruminal pH of primiparous and multiparous lactating dairy cows. J. Dairy Sci. 85:1176–1182. doi:10.3168/jds.S0022-0302(02)74180-5.

Mertens, D. R., 2002. Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: collaborative study. J. AOAC Int. 85:1217–1240.

Mokwena, K. K., and J. Tang. 2012. Ethylene Vinyl Alcohol: A Review of Barrier Properties for Packaging. Crit. Rev. Food Sci. Nutr. 52:640–650. doi:10.1080/10408398.2010.504903.

Muck, R. E., L. E. Moser, and R. E. Pitt. 2003. Postharvest factors affecting ensiling. In Silage Science and Technology. Vol. 42. D. R. Buxton, R. E. Muck, and J. H. Harrison, ed. Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI, p. 251–304.

National Academies of Sciences, Engineering, and Medicine (NASEM), 2016. Nutrient requirements of beef cattle. Eighth Revised Edition. Washington, DC: The National Academies Press. doi:10.17226/19014.

Ogunade I. M., C. Martinez-Tuppia, O. C. M. Queiroz, Y. Jiang, P. Drouin, F. Wu, D. Vyas, and A. T.Adesogan. 2018. Silage review: Mycotoxins in silage: Occurrence, effects, prevention, and mitigation. J. Dairy Sci. 101:4034–4059. doi:10.3168/jds.2017-13788.

O'Kiely, P. 1993. Influence of a partially neutralized blend of aliphatic organic acids on fermentation, effluent production and aerobic stability of autumn-grass silage. Ir. J. Agric. Food Res. 32:13–26.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: a review. J. Anim. Sci. 75:868–879. doi:10.2527/1997.753868x.

Pahlow, G., R. E. Muck, F. Driehuis, S. J. W. H. Oud Elferink, and S. F. Spoelstra. 2003. Microbiology of ensiling. Chapter 2. In: Buxton, D. R., R. E. Muck, and J. H. Harrison, editors. Silage science and technology. Madison (WI): American Society of Agronomy; p. 31–93.

Parra, C. S., J. M. Bragatto, F. A. Piran Filho, S. M. S. Silva, B. F. Tuzzi, C. C. Jobim, and J. L. P. Daniel. 2021. Effect of sealing strategy on the feeding value of corn silage for growing dairy heifers. J. Dairy Sci. 104:6792–6802. doi:10.3168/jds.2020-19895.

Pereyra, M. L. G., V. A. Alonso, R. Sager, M. B. Morlaco, C. E. Magnoli, A. L. Astoreca, C. A. R. Rosa, S. M. Chiacchiera, A. M. Dalcero, and L. R. Cavaglieri. 2008. Fungi and selected mycotoxins from pre- and postfermented corn silage. J. Appl. Microbiol. 104:1034–1041. doi:10.1111/j.1365-2672.2007.03634.x.

Pitt, R. E., and R. E. Muck. 1993. A diffusion model of aerobic deterioration at the exposed face of bunker silos. J. Agric. Eng. Res. 55:11–26. doi:10.1006/jaer.1993.1029.

Pryce, J. D. 1969. A modification of Barker-Summerson method for determination of lactic acid. Analyst. 94:1151–1152. doi:10.1039/an9699401151.

Rezende P. L. P., Restle J., U. O. Bilego, J. J. R. Fernandes, R. L. Missio, and T. P. Guimarães. 2019. Carcass characteristics of feedlot-finished Nellore heifers slaughtered at different weights. Acta Sci., Anim. Sci. 41: e44826. doi:10.4025/actascianimsci.v41i1.44826.

Robinson, P. H., and N. Swanepoel. 2016. Impacts of a polyethylene silage pile underlay plastic with or without enhanced oxygen barrier (EOB) characteristics on preservation of whole crop maize silage, as well as a short investigation of peripheral deterioration on exposed silage faces. Anim. Feed Sci. Technol. 215:13–24. doi:10.1016/j.anifeedsci.2016.02.001.

Savoie, P., K. J. Shinners, and B. N. Binversie. 2004. Hydrodynamic separation of kernel and stover components in corn silage. Appl. Biochem. Biotechnol. 113–116:41–54. doi:10.1385/ABAB:113:1-3:041.

Silvestre, A. M., and D. D. Millen. 2021. The 2019 Brazilian survey on nutritional practices provided by feedlot cattle consulting nutritionists. R. Bras. Zootec. 1–25. doi:10.37496/rbz5020200189.

Snell, H. G. J., C. Oberndorfer., W. Lücke, and H. F. A. Van den Weghe. 2002. Effects of the colour and thickness of polyethylene film on ensiling conditions and silage quality of chopped maize, as investigated under ambient conditions and in mini-silos. Grass and Forage Sci. 57:342–350. doi:10.1046/j.1365-2494.2002.00334.x.

Tabacco, E., F. Righi, A. Quarantelli, and G. Borreani.2011. Dry matter and nutritional losses during aerobic deterioration of corn and sorghum silages as influenced by different lactic acid bacteria inocula. J. Dairy Sci. 94:1409–1419. doi:10.3168/jds.2010-3538.

Upton, W. H., K. A. Donoghue, H. U. Graser, and D. J. Johnston. 1999. Ultrasound proficiency testing. Proc. Assoc. Adv. Anim. Breed. Genet. 13:341–344.

Wang, K.; M. E. Uriarte, S. C. Li, K. Rich, C. Banchero, D. P. Bu, J. M. Wilkinson, and K. K. Bolsen. 2017. Effect of type of underlay film on fermentation profile, nutritional quality and estimated loss of organic matter in the outer layer of whole-plant maize ensiled in large bunker silos. Grass Forage Sci. 72:772–776. doi:10.1111/gfs.12283.

Weissbach, F. 2009. Correction of dry matter content of silages used as substrate for biogas production. In: G. A. Broderick, A. T. Adesogan, L. W. Bocher, K. K. Bolsen, F. E. Contreras- Govea, J. H. Harrison, R. E. Muck, editor, Proc. XV Int. Silage Conf., Madison, WI. p. 483–484.

Whitlock, L. A., M. K. Siefers, R. S. Pope, B. E. Brent, and K. K. Bolsen. 2000. Effect of surface spoiled silage on the nutritive value of corn silage-based rations. In: Kansas State University Agricultural Experimental Station Report of Progress 861. p. 36–38.

Wichert, B., E. Kienzle, and J. Baufr. 1998. Palatability and intake of silage in dairy cows, in relation to hygienic quality. J. Anim. Physiol. Anim. Nutr. (Berl.) 80:253–259. doi:10.1111/j.1439-0396.1998.tb00538.x.

Wilkinson, J. M., K. K. Bolsen, and C. J. Lin. 2003. History of silage. in: Silage Science and Technology (Agronomy Series No. 42). Buxton D. R., R. E. Muck, and H. J. Harrison, ed. American Society of Agronomy, Madison, WI. pp. 1−30.

Wilkinson, J. M., and J. S. Fenlon. 2013. A meta-analysis comparing standard polyethylene and oxygen barrier film in terms of losses during storage and aerobic stability of silage. Grass Forage Sci. 69:385–392. doi:10.1111/gfs.12087.

Windle, M. C., and L. Kung Jr. 2013. The effect of a feed additive on the feeding value of a silage-based TMR exposed to air. J. Dairy Sci. 96(E-Suppl. 1):16.

Woolford, M. K. 1990. The detrimental effect of air on silage. J. Appl. Bacteriol. 68:101–116. doi:10.1111/j.1365-2672.1990.tb02554.x.

Zinn, R. A., and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J. Anim. Sci. 76:1280–1289. doi:10.2527/1998.7651280x.