Forage quality and beef cow preference is affected by wrap type of conventional and reduced-lignin alfalfa round bales stored outdoors

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ABSTRACT: Storing hay outdoors can result in detrimental changes in forage quality. Additionally, alfalfa (*Medicago sativa* L.) cultivar may influence dry matter intake (DMI) and hay waste when feeding livestock. The objectives were to determine the effects of conventional or reduced-lignin alfalfa round bales stored outdoors and wrapped with plastic twine, net wrap, or B-Wrap on forage quality, beef cow preference, and hay waste. Round bales made from reduced-lignin (n = 12) or conventional (n = 12) alfalfa cultivars were baled and stored outdoors for 16 mo. Within each cultivar, four bale replicates were bound with plastic twine, net wrap, or B-Wrap. After storage, bales were fed in a switchback design with period confounded with alfalfa cultivar to 18 lactating Angus cows (*Bos Taurus* L.). The pairs had ad libitum access to three round-bale feeders where bales of each wrap type were placed for eight 48 h periods. Position of round bale wrap type was rotated according to a Latin Square arrangement. Bales were weighed and waste surrounding each feeder was collected at 24 and 48 h to calculate DMI and hay waste. Statistical significance was set at $P < 0.05$. Alfalfa cultivar did not impact any of the response variables ($P > 0.05$). At feeding, round bales wrapped in net wrap had greater ($P < 0.015$) moisture content (16.4%) compared with those wrapped with B-Wrap (12.8%). Neutral detergent fiber was lower ($P = 0.03$) in bales wrapped in B-Wrap (46%) compared with twine-tied bales (49%) while net wrapped bales were not different. Total digestible nutrients ($P = 0.02$), and relative feed value ($P = 0.04$) were lower in twine-tied bales compared with B-Wrap while net wrapped bales were not different. Twine (7.1×10^6 colony forming units [CFU]/g) and net wrap (4.7×10^6 CFU/g) bales had greater ($P < 0.0001$) mold counts than B-Wrap bales (4.8×10^4 CFU/g), while concentrations of other forage components and yeast counts were not different among wrap types ($P > 0.05$). Total DMI, and DMI during the first 24 h, were greater ($P \leq 0.032$) for B-Wrap bales compared to twine-tied bales indicating preference for hay wrapped in B-Wrap; net wrapped bales were not different. Dry matter intake in the first 24 h was negatively associated with the mold count ($r = -0.52$; $P = 0.02$), and hay waste was not affected by wrap type ($P > 0.05$). These results confirm that wrap type affected forage quality and mold counts, which in turn influenced beef cattle preference of round bales stored outdoors.

Key words: alfalfa hay, B-Wrap, dry matter intake, mold, net wrap, plastic twine

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Received June 5, 2020.
Accepted September 7, 2020.

Transl. Anim. Sci. 2020.4:1-10
doi: 10.1093/tas/txaa167

INTRODUCTION

Round bales are a common way to harvest, store, and feed livestock throughout the United States. However, forage quality of round bales can deteriorate during outdoor storage, especially when left uncovered. Dry matter (DM) losses when round bales were stored outdoors without cover ranged from 7% to 49%, compared to only 2% to 6% when stored indoors (Harrigan and Rotz, 1994; Shinners et al., 2009). This deterioration is mostly confined to the outer layer, which is most exposed to weather (Belyea et al., 1985; Collins et al., 1987; Russell et al., 1990; Shinners et al., 2009, 2013) and subject to microbial activity (Harrigan and Rotz, 1994). Specifically, moisture from rainfall and snow can result in the loss of soluble nutrients, and an increase in concentration of insoluble plant fibers, mold growth, and repugnant odors (Collins et al., 1987; Russell et al., 1990; Scudamore and Livesey, 1998; Shinners et al., 2009). These factors can increase DM losses and reduce dry matter intake (DMI; Belyea et al., 1985; Russell et al., 1990; Undi and Wittenberg, 1996).

Several storage methods and bale wrap types have been studied to determine their impact on hay waste, DM losses, and DMI of livestock. Belyea et al. (1985) evaluated effects of storage on hay waste of round bales stored outdoors or covered. They found that cattle wasted 12% to 15% of round hay bales stored outdoors under cover, while hay waste from uncovered bales was 25%. Additionally, Russell et al. (1990) observed a 16% to 25% DMI increase by sheep (*Ovis aries* L.) fed outdoor stored round bales wrapped in net wrap compared to those fed round bales tied with twine. More recently, Shinners et al. (2013) evaluated cattle preference for shredded round bales that had been wrapped with a breathable film or net wrap. They found that shredded hay from round bales wrapped with the breathable film were equally preferred to hay from bales stored indoors, and both hays were preferred over net wrapped hay from bales stored outdoors.

While research by Shinners et al. (2013) provides some evidence of the impact of wrap type on livestock preference, bales are not usually shredded before feeding on many beef farms. Therefore, it is important to investigate the preference of feeding whole round bales, a practice routinely used on farms, bound in different wrap types after outdoor storage in order to maximize DMI and minimize hay waste. Historically, large round bales were tied with twine; however, net wrap use has grown due to a decrease in the time required to bind a bale, less DM loss, and a reduction of leaf loss during wrapping (Russell et al., 1990; Shinners et al., 2009). In an effort to further reduce DM and forage quality losses, B-Wrap (Ambraco Inc., Dubuque, IA) was recently developed. Reiter et al. (2019) found that DM losses were 7% for twine bales, 5% for net wrap bales, while B-Wrap bales maintained DM after 1 yr of outdoor storage. However, little is known about the interactive effects of round bale wrap type, alfalfa cultivar, and outdoor storage on livestock preference and hay waste during feeding. Reduced-lignin alfalfa is widely available, but no feeding trials have been conducted to explore beef cattle preference of reduced-lignin and conventional alfalfa hay. Beef cattle may prefer reduced-lignin alfalfa because it contains 8% to 24% less acid detergent lignin (ADL) and 10% to 26% greater neutral detergent fiber digestibility at 48 h (NDFD48) at harvest (Mertens and McCaslin, 2008; Li et al., 2015; Grev et al., 2017; Getachew et al., 2018). Reid et al. (1988) found a negative correlation between fiber concentrations and DMI in both cattle and sheep when grazing cool- and warm-season grasses. Crude protein and neutral detergent fiber (NDF) concentrations of reduced-lignin and conventional alfalfa have been similar at the time of harvest (Mertens and McCaslin, 2008; Li et al., 2015; Grev et al., 2017; Getachew et al., 2018). Differences in forage components of reduced-lignin and conventional alfalfa after long-term (>12 mo) outdoor storage have not been reported; however, Reiter et al. (2019) suggested that alfalfa cultivar had minimal effects on forage parameters after 1 yr of outdoor storage. Therefore, the objectives of this research were to determine the effects of conventional or reduced-lignin alfalfa round bales stored outdoors and wrapped with plastic twine, net wrap, or B-Wrap on forage quality, beef cow preference, and hay waste. We hypothesized that wrap type of round bales stored outdoors would impact forage quality, cow preference, and hay waste, but that alfalfa cultivar would have minimal effects on these variables.

MATERIALS AND METHODS

All experimental procedures were conducted according to those approved by the University of Minnesota Committee on Animal Use and Care (1808-36268A).

First cutting alfalfa hay was harvested on June 7, 2017 at the early bud stage (Kalu and Fick, 1981) in Otsego, MN. The alfalfa included two cultivars, reduced-lignin ("54HVX41," Forage Genetics, Napa, ID) and conventional ("WL355.RR," W-L Alfalfa, Ozark, MO). Each cultivar was replicated twice in 1.2 ha sized fields for a total area of 4.8 ha. Forage was cut, raked, and baled using best management practices designed to minimize leaf loss and optimize forage quality (Digman et al., 2011). Hay was baled into large round bales measuring 1.22 × 1.50 m (John Deere 459, Moline, IL). The cutting yielded 24 uniform bales, 6 bales from each field, for a total of 12 bales each of reduced-lignin and conventional alfalfa. Within each alfalfa cultivar, four round bales were wrapped with each wrap type including plastic twine (Case IH, Racine, WI), net wrap (Ambraco Inc.), and B-Wrap. All wrap types were applied according to manufacturer guidelines. Bales were stored outdoors in a row on wood pallets, on the rounded side, with approximately 13 cm between each bale. Bales were randomly placed in an east to west orientation (cut edges faced north and south), blocked by bale placement within the row, and arranged in a randomized complete block with stored bales as the experimental unit. Bales were stored through May 31, 2018, and during this time were utilized in a research trial investigating the effect of wrap type on DM loss and forage nutritive value of round bales in outdoor storage (Reiter et al., 2019). Upon completion of that trial, bales continued to be stored outdoors, and on September 1, 2018, were transported to the Rosemount Research and Outreach Center in Rosemount, MN, and stored outdoors until fed.

Starting on October 3, 2018, round bales were fed, following 16 mo in storage, to beef cow-calf pairs to determine the effect of wrap type and alfalfa cultivar on cattle preference and hay waste. The 16-mo storage period was chosen to simulate one of the longer hay storage periods likely found on farms. Immediately prior to feeding, round bales were weighed using axel weigh pads (Locosc, Ningbo, China) and randomly cored four times with a 46 cm hay probe with a 2.5 cm diameter (Penn State Forage Sampler, University Park, PA) to determine DM, forage quality, and mold and yeast counts. Hay core samples from individual bales were combined and dried in a forced-air oven at 60 °C for 48 h to determine DM. Samples were then ground through a 6-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ) followed by grinding in a Cyclotec (Foss, Eden Prairie, MN) equipped with a 1-mm screen. Ground samples were mixed thoroughly, and a subsample was analyzed using near-infrared reflectance spectroscopy (NIRS) to determine ether extract, crude fiber, and ash (Dairy One, Ithaca, NY). Total digestible nutrients (TDN) were then calculated (Weiss et al., 1992). Additionally, samples were scanned at the University of Minnesota (St. Paul, MN) using NIRS (Model DA 7200; Perten Instruments, Springfield, IL) with calibration equations developed in Minnesota to estimate crude protein (CP), NDF, acid detergent fiber (ADF), NDFD48, and ADL. The standard error of cross validation was 1.63, 3.08, 2.21, 2.64, and 1.98%, while the R^2 was 0.93, 0.95, 0.93, and 0.87 and, 0.98 for prediction of CP, NDF, ADF, NDFD48, and ADL, respectively. Relative forage quality (RFV) was then calculated (Rohweder et al., 1978).

Subsamples to determine mold and yeast counts were analyzed by a commercial laboratory (DHIA Laboratories, Sauk Centre, MN). In brief, mold and yeast counts were determined through pour-plate methodology using potato dextrose agar and peptone buffer. A total of 50 g of test material were diluted with 45 mL of peptone buffer. Serial dilutions were made to yield four dilutions, which were plated in peptone buffer. Plates were incubated in an upright position at 25 °C to 27 °C for 5 to 7 d. Mold and yeast colonies were then counted and expressed as CFU/g.

Eighteen Angus cow-calf pairs were housed in a 24 × 34 m cement pen, which included a 10 × 34 m covered area. Calves were approximately 33 ± 11 d old at the initiation of the trial. Throughout the trial, the pairs had ad libitum access to water and loose mineral (Rain and Wind All Season, Purina, St. Louis, MO). Individual cow bodyweight (BW) and body condition score (BCS; Spitzer, 1986) were recorded at the start and conclusion of the 17-d trial; BCS was determined by one trained individual. Immediately before feeding, all wrap types were removed from the round bales. Round bales were fed in a switchback design where periods were confounded with alfalfa cultivar. Within cultivar and period, bales were delivered to one of three identical 2.4 × 1.1 m skirted tombstone round bale feeders (Priefert, Mount Pleasant, TX) using a Latin Square arrangement that prevented immediate duplication of delivery location within wrap type treatment. All feeders were retrofitted with a welded solid bottom plate to facilitate moving and weighing of the bales once fed. Feeders were placed approximately 6.7 m apart in the covered area of the pen and cattle were allowed ad libitum access to all feeders. For each 48 h period (n = 8), three round bales, one from each wrap type within an alfalfa cultivar, were fed. The 48 h period was selected based on amount of hay available, estimated cow intake (Hibberd and Thrift, 1992), estimated hay waste (Buskirk et al., 2003), and to avoid complete consumption of hay for determination of cattle preference. At 24 and 48 h, the entire feeder was weighed using axel weigh pads (Locosc, Ningbo, China) to determine DMI. No other feedstuffs were offered during the 17 d trial; however, a bedding pack of chopped straw was maintained in the uncovered section of the pen.

Each day, hay waste was collected from the perimeter of the feeders. Hay waste was defined as hay on the ground outside of the feeders. After hay waste was removed, the area around each feeder was scraped clean by hand then power swept using a skid loader broom attachment (SE Series Hopper Broom, Spartan Equipment, Joppa, MD) to minimize contamination with manure, although some contamination was inevitable. Therefore, contaminated hay waste was rinsed with water to remove manure before drying. All hay waste was dried in a forced-air oven at 60 °C until a constant weight was achieved. After 48 h, hay remaining in the feeders (orts) was weighed, removed, and new bales were placed in feeders. Percent hay waste was calculated as the total amount of daily hay waste divided by the amount of hay fed, minus orts (Martinson et al., 2012). Dry matter intake was calculated as the amount of hay fed, minus orts and total hay waste, and was used to determine cow preference.

Forage quality, DMI, and hay waste data were analyzed using the MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC). Individual bales were the experimental unit, and statistical significance was set at $P \leq 0.05$. Forage quality response variables included bale moisture content, CP, NDF, ADF, ADL, NDFD48, TDN, RFV, and mold and yeast counts. Bale moisture content and mold and yeast counts were log transformed to meet analysis of variance assumptions; data were back transformed for presentation. Forage quality response variable models included alfalfa cultivar, wrap type, period, and alfalfa cultivar × wrap type interaction as fixed effects, while bale replicate was included as a random effect. The model for response variables hay waste and DMI included wrap type, feeder placement, and period as fixed effects at each collection time (e.g., 24 and 48 h). Initial bale DM was evaluated as a covariate for response variables associated with hay waste and remained in the model when significant. For categorical effects (e.g., wrap type), means separations were performed on significant effects using Tukey's HSD test. To assess the relationship between DMI and forage quality, partial Pearson correlation coefficients were calculated between DMI and the forage quality parameters for mold counts using the REG procedure of SAS (version 9.4; SAS Institute Inc.). Changes in animal BW and BCS over the experimental period were evaluated using a two-sample *t*-test using PROC TTEST in SAS (version 9.4; SAS Institute Inc.).

RESULTS AND DISCUSSION

Weather

Average daily temperatures and precipitation for the duration of the experiment are depicted in Fig. 1. Generally, daily average air temperatures were below the 30-yr average except on 3, 4, and 9 October. Although temperatures were below average, they were well above the lower critical temperature (<−20 °C) for cattle (Young et al., 1989). There were seven rainfall events during the experimental period. However, all bales were fed under cover, so rainfall events had minimal impact on results. Further, calves were provided a creep area undercover that was bedded with straw to lessen the impact of cooler, wet weather on calf health.

Alfalfa Cultivars

Alfalfa cultivar had no effect on bale moisture or forage quality response variables measured ($P > 0.05$). Therefore, cultivar was not included in models for DMI and hay waste, and all data were pooled across cultivars. The lack of differences between conventional and reduced-lignin cultivars baled as hay and stored outdoors for >12 mo has not been previously reported. However, Reiter et al. (2019) reported minimal differences in forage quality between reduced-lignin and conventional alfalfa hay when stored outdoors for 1 yr. No differences were expected between cultivars for CP, NDF, and ADF concentration based on similarities for these forage quality variables at the time of harvest (Mertens and McCaslin, 2008; Getachew et al., 2011; Li et al., 2015; Grev et al., 2017; Peterson et al., 2018). However, because of differences in lignin content at the time of harvest between cultivars, ADL and NDFD48 concentration were expected to differ. In previous studies focused on freshly harvested forage, reduced-lignin alfalfa had lower ADL and greater NDFD48 compared with conventional alfalfa (Mertens and McCaslin, 2008; Getachew et al., 2011; Li et al., 2015; Grev et al., 2017; Peterson et al., 2018). These results suggest that forage

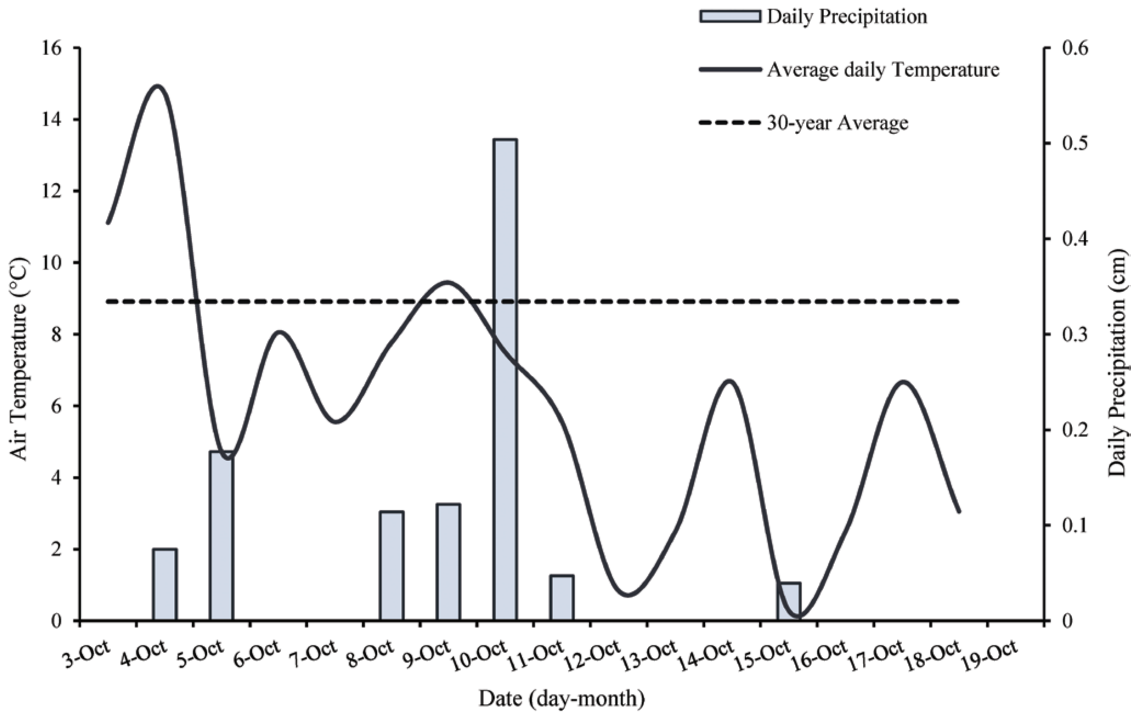

Figure 1. Daily and 30-yr average air temperature (°C) and daily precipitation (cm) from 3 to 19 October, 2018 in Rosemount, MN.

quality differences observed between reduced-lignin and conventional alfalfa at harvest may be lost after long-term, outdoor storage.

Bale Moisture

At feeding, bale moisture was different between the wrap types (P = 0.01; Table 1). Round bales wrapped in net wrap had a greater moisture content compared with those wrapped in B-Wrap; moisture content of bales tied in twine was not different from the other wrap types. Shinners et al. (2013) and Reiter et al. (2019) found that moisture concentrations of hay wrapped in B-Wrap were up to 66% less compared with net wrap and twine-tied bales stored outside. However, other researchers observed no differences in moisture content between twine and net wrapped bales (Taylor et al., 1995) after outdoor storage. These differences could be due to various factors including length of storage, weather during storage, and storage methods (e.g., stored on pallets or on the ground). Bale moisture during storage, an indicator of precipitation penetration, is an important consideration as it directly relates to the likelihood of mold formation (Martinson et al., 2011) and microbial activity (Harrigan and Rotz, 1994) that can increase the concentration of insoluble plant fibers (Collins et al., 1987; Russell et al., 1990; Scudamore and Livesey, 1998; Shinners et al., 2009) in hay. Martinson et al. (2011) found that round bales were prone to molding at relatively low moisture concentrations (17%), and confirmed that ≤15% moisture at the time of baling resulted in minimal risk of mold formation and deleterious changes in forage quality.

Bale Weight

After 16 mo of outdoor storage, bale weight (on a DM basis) was different between the wrap types (P = 0.007; Table 2). Bales wrapped in B-Wrap had a greater weight compared with those tied with twine, while the weight of net wrapped bales were not different from the other wrap types. At the start of the outdoor storage period (June 2017), all bales had a similar weight; however, DM losses were different between wrap types (Reiter et al., 2019). Therefore, differences in bale weight at the time of feeding were due to DM losses observed during the outdoor storage period. Many researchers have determined that twine-tied bales experience greater DM losses compared with net wrapped bales due to greater external moisture penetration (Russell et al., 1990; Shinners et al., 2009), while others have suggested B-Wrap is better able to repel moisture and conserve DM during outdoor storage (Shinners et al., 2013; Reiter et al., 2019). Specifically, Reiter et al. (2019) found that after 365 d in outdoor storage, DM losses were 7% for twine bales, 5% for net wrap bales, while B-Wrap bales maintained DM.

Table 1. Bale moisture, forage quality, and mold and yeast counts of alfalfa hay stored outdoors for 16 mo and wrapped in twine, net wrap, or B-Wrap

	Wrap type			
	Twine	Net wrap	B-Wrap	SEM
Moisture, %	15^{ab}	16^{a}	13^{b}	1.0
CP, % DM	14	15	15	0.3
NDF, % DM	49^{a}	48^{ab}	46^{b}	0.7
ADF, % DM	33	32	31	0.7
ADL, % DM	6	6	6	0.2
NDFD48, % NDF	45	46	47	0.8
TDN, % DM	61^{b}	62^{ab}	63^{a}	0.5
RFV	118^{b}	124^{ab}	130^{a}	2.8
Mold count, CFU/g	7.1×10^{6a}	4.7×10^{6a}	4.8×10^{4b}	0.8
Yeast count, CFU/g	1.5×10^{4}	6.0×10^{3}	2.6×10^{5}	1.2

^{ab}Means within quality parameter without common superscripts differ ($P < 0.05$).

Table 2. Bale weight (DM, kg) at feeding, hay waste (%), and dry matter intake (DMI, kg) of alfalfa hay stored outdoors for 16 mo, wrapped in twine, net or B-Wrap, and fed to beef cow calf pairs in Rosemount, MN

	Bale weight at feeding	Waste			DMI		
	Kg, DM	% DM offered			Kg/cow		
Wrap type		24 h	48 h	Total	24 h	48 h	Total
Twine	299^{a}	4.6	3.4	2.2	4.2^{b}	6.4	10.7^{b}
Net wrap	309^{ab}	4.5	2.8	2.9	5.8^{ab}	5.5	11.4^{ab}
B-Wrap	333^{b}	4.5	2.3	2.5	7.9^{a}	5.5	13.4^{a}
SEM	6.67	0.96	1.5	0.41	0.81	0.40	0.64

^{ab}Means within a column without common superscripts differ ($P < 0.05$).

Forage Quality

At the time of feeding, concentrations of CP, ADL, ADF, and NDFD48 were similar across wrap types ($P > 0.05$; Table 1). These results were expected for CP since other researchers have also found no differences in CP concentration between alfalfa hay stored outdoors in different wrap types (Russell et al., 1990; Harrigan and Rotz, 1994; Shinners et al., 2013; Reiter et al., 2019). The lack of differences in ADL and ADF between the wrap types was unexpected after the outdoor storage period since environmental moisture and microbial activity can result in the loss of soluble nutrients and an increase in the concentration of insoluble plant fibers (Collins et al., 1987; Russell et al., 1990; Harrigan and Rotz, 1994; Scudamore and Livesey, 1998; Shinners et al., 2009). Few researchers have reported ADL concentration in stored hay. Russell et al. (1990) found greater concentrations of ADL in twine-tied bales compared with net wrapped bales, while Reiter et al. (2019) found few differences in ADL concentration between twine, net wrap, and B-Wrap bales stored outdoors. Others found greater ADF concentrations in twine tied compared to net wrap bales (Russell et al., 1990; Shinners et al., 2009), while Reiter et al. (2019) found greater ADF concentrations in twine tied and net wrapped bales compared to B-Wrap bales after outdoor storage. Additionally, Reiter et al. (2019) found that NDFD48 was 24% and 35% greater in B-Wrap bales compared with net wrap or twine-tied bales, respectively, after 1 yr of storage. However, Shinners et al. (2013) found no differences in hay DM digestibility derived from bales stored outside and wrapped with net wrap or breathable film. The similarity in NDFD48 among wrap types in the current study is likely tied to the similarities observed in ADL. Lignification is a major factor impacting in vitro dry matter digestibility of whole plant forage (Jung et al., 2012).

At the time of feeding (16 mo postharvest), NDF, TDN, and RFV were impacted by wrap type (Table 1). Neutral detergent fiber was greatest ($P = 0.03$) in twine-tied bales compared with those wrapped in B-Wrap, while net wrap was not different from the other wrap types. Twine-tied bales were lower in both TDN ($P = 0.02$) and RFV ($P = 0.04$) compared to B-Wrap, while net wrapped bales were not different from the other wrap types. These results agree with the previous research, which has shown NDF values tend to be higher, or more concentrated, in twine tied and net wrap bales compared with B-Wrap after outdoor storage (Shinners et al., 2013; Reiter et al., 2019). Shinners et al. (2013) observed that net wrapped bales contained more NDF, while Reiter et al. (2019) found a 16% to 23% increase in NDF in net wrap and twine-tied bales compared with those wrapped in B-Wrap. The differences in NDF among wrap types are likely due to penetration of environmental moisture that can result in microbial activity and the loss of soluble nutrients which can increase the concentration of insoluble plant fibers (Collins et al., 1987; Russell et al., 1990; Harrigan and Rotz, 1994; Scudamore and Livesey, 1998; Shinners et al., 2009). Concentrations of NDF in hay are critical, as elevated values can limit DMI in cattle due to decreased palatability and increased rumen fill (Dado and Allen, 1995).

Shinners et al. (2013) found greater TDN in bales stored indoors and wrapped in breathable film and net wrap compared with net wrapped bales stored outdoors (Shinners et al., 2013). Even after 16 mo of outdoor storage, TDN reported in the present study should meet the energy requirement for beef cattle in early to mid-lactation (National Research Council [NRC], 2000). Similarly, Reiter et al. (2019) and Shinners et al. (2013) reported greater RFV in bales wrapped in B-Wrap compared to those tied in twine or net wrap. Additionally, RFV at the time of feeding remained similar to alfalfa harvested between early to late bloom (Dunham, 1988). The differences observed in RFV between B-Wrap and twine-tied bales are reflective of the differences observed in NDF since NDF is used to calculate RFV (Rohweder et al., 1978).

Mold counts differed among wrap type ($P < 0.0001$; Table 1). Twine tied and net wrap bales had higher mold counts compared with B-Wrap. Several researchers have reported visual observations of mold growth in round bales stored outside (Russell et al., 1990; Harrigan and Rotz, 1994; Shinners et al., 2009, 2010); however, this appears to be the first study to quantify the impact of wrap type on mold growth. Previously, Reiter et al. (2019) found that after 1 yr in outdoor storage, DM losses were 7% for twine bales, 5% for net wrap bales, while B-Wrap bales maintained DM. The loss in DM is an indicator that precipitation had penetrated the bales bound with twine and net wrap which is known to result in mold formation (Martinson et al., 2011), microbial activity (Harrigan and Rotz, 1994), and deleterious changes in forage quality (Collins et al., 1987; Russell et al., 1990; Scudamore and Livesey, 1998; Shinners et al., 2009). Although bale moisture for all wrap types was relatively low at the time of feeding (≤16.5%), Reiter et al. (2019) found that the moisture of bales wrapped with twine and net wrap were as high at 34% and 29%, respectively, during the 12-mo storage period, while bales bound with B-Wrap never exceeded 13% moisture.

Current recommendations for concentrations of mold in livestock rations indicate values of $<5 \times 10^5$ CFU/g are considered safe, 5×10^5 to 1×10^6 CFU/g are relatively safe, $>1 \times 10^6$ CFU/g should be fed with caution, and $> 5 \times 10^6$ CFU/g should not be fed to livestock (Adams et al., 1993). According to these recommendations, hay stored outside for 16 mo in B-Wrap was considered safe to feed livestock, hay wrapped in net wrap should have been fed with caution, while hay tied with twine should not have be fed. However, no illnesses or adverse health issues were observed in cow-calf pairs perhaps due to the relatively short experimental period (17 d). Future research should explore health impacts of outdoor stored hay bound with different wrap types when fed to beef cattle for long time periods.

Determining mold concentrations of outdoor stored hay is important as mold content can influence DMI. In this study, DMI during the first 24 h was negatively associated with the mold content of the hay ($r = -0.52$; $P = 0.02$). When moldy hay was fed to steers, it resulted in a lower DMI and decreased rumen function (Mohanty et al., 1969). Additionally, dairy calves preferred hay with low ($<2.0 \times 10^4$ CFU/g) amounts of mold compared with higher (1.4×10^5 CFU/g) and moderately moldy hays (8.5×10^4 CFU/g), and consumed 27% to 60% less hay from moderately and higher mold hays, respectively (Undi and Wittenberg, 1996).

There were no differences in yeast counts among wrap type ($P = 0.07$; Table 1). Yeast contamination is typically a concern in high moisture, fermented silage, and haylage but rarely in dried hay as moisture concentration tends to be too low to support yeast growth (Kung, 2001; Muck and Shinners, 2001). To our knowledge, there are no recommendations for the maximum inclusion of environmental yeast in ruminant diets. Although limited research has investigated the presence of yeast and the influence of hay contaminated with yeast on DMI, some yeast species (e.g., *Saccharomyces cerevisiae*) are being studied as direct-fed microbials in ruminant diets (Keyser et al., 2007; Oetzel et al., 2007; Malik and Bandla, 2010). However, yeast species identified as environmental yeast during hay making and storage may differ from those being tested as direct-fed microbials.

Cow Bodyweight and Body Condition

Cow BW and BCS did not differ throughout the trial ($P \geq 0.20$). On average, cows weighed 692 ± 46 kg at the start of the experiment (October 3, 2018) and 711 ± 46 kg 17 d later when the trial ended. Average cow BCS (Spitzer, 1986) was 6.4 ± 0.3 at the start of the trial and 6.7 ± 0.4 at the conclusion. Due to the relatively short duration of the trial, cows were not expected to have changes in BW or BCS. Finally, cows consumed 2.5% BW per day in forage which is consistent with expected forage intake of beef cows consuming average to high quality forage in early to mid-lactation (Hibberd and Thrift, 1992; NRC, 2000).

Dry Matter Intake and Cattle Preference

Wrap type affected total DMI and DMI measured at 24 h ($P \le 0.032$), but not at 48 h ($P = 0.22$; Table 2). Total DMI, and DMI at the end of 24 h, was greater from B-Wrap bales compared with twine bales. Intake from bales wrapped in net wrap was not different from the other wrap types. The absence of differences in DMI after 48 h is likely a result of cows consuming a majority of the hay they preferred in the first 24 h, then consuming the remaining hay more equally. The results observed at 24 h agree with previous findings of greater DMI of bales stored in a breathable film wrap similar to B-Wrap (Shinners et al., 2013). After 48 h, mean total hay consumed was 68, 68, and 67% for twine, net wrap, and B-Wrap, respectively. The amount is similar to Baxter et al. (1986) who found cows consumed an average of 70% of alfalfa-orchardgrass (*Dactylis glomerate* L.) round bales stored outside. However, it should be noted that the 48 h period in the current study was selected to avoid complete consumption of hay for determination of cattle preference.

It is important to note that livestock preference is only exhibited when a choice is given (Marten et al., 1978). Although each alfalfa cultivar was evaluated seperately, different wrap types allowed the cattle a choice. Based on 24 h and total DMI, cattle preferred round bales wrapped in B-Wrap compared to twine. While forage quality parameters measured in the laboratory were related to cattle preference, other factors affecting preference including taste, smell, stem to leaf ratio, and texture were not measured. However, a logical argument could be made that taste and smell are impacted by mold concentration and texture by plant fiber components (e.g., ADL, ADF, and NDF). Grev et al. (2020) showed that at the time of harvest, reduced-lignin and conventional alfalfa cultivars were not different in leaf to stem ratio; however, it is unclear how outdoor storage impacts this ratio and other sensory components of different cultivars of hay.

Hay Waste

There were no differences in hay waste collected at 24 h, 48 h, or total hay waste between the wrap types ($P = 0.55$; Table 2). Mean total hay waste was 2.2, 2.5, and 2.9% for hay bound in twine, net wrap and B-Wrap, respectively. Hay waste in the current study tended to be lower than previously reported. Other researchers reported hay waste ranged from 12% to 25% for round bales stored outdoors (Nelson, 1983; Belyea et al., 1985; Baxter et al., 1986). The lack of hay waste differences between wrap types could be a result of feeding under shelter, adding a bottom plate to the feeders, or the bale feeder itself. Other researchers found differences in hay waste between round bale feeder types (Buskirk et al., 2003; Sexten, 2011; Martinson et al., 2012; Moore and Sexten, 2015). These management strategies, combined with minimal forage quality differences among wrap type, could account for similarities in hay waste.

Interestingly, hay waste was different between the 24 and 48 h collection periods ($P = 0.03$). On average, hay waste in the first 24 h (4.6%) was greater compared with the average waste collected at 48 h (2.9%). Hay waste may have been greater in the first 24 h period because cattle were observed “lifting and flipping” the outer layer of weathered hay out of the feeder in order to reach the interior of the bale. Several researchers have determined that the weathered layer of an outdoor stored bale did not exceed 15 cm, regardless of wrap type (Shinners et al., 2009; Reiter et al., 2019). Additionally, researchers in the current study observed competition at the feeder containing the bale wrapped in B-Wrap during the first 24 h period. During this time, cattle would compete for the 12 head stalls at the feeder. Both observations are possible causes for the greater hay waste observed during the first 24 h and could be used to direct future behavior and hay waste research.

CONCLUSION

Alfalfa cultivar did not impact forage components after long-term outdoor storage; however, wrap type did. After 16 mo in outdoor storage, bales wrapped in B-Wrap had lower concentrations of NDF, greater concentrations of TDN and RFV, and lower counts of mold compared with twine-tied bales. Dry matter intake during the first 24 h was greater from feeders containing B-Wrap bales compared with those containing twine-tied bales indicating cattle preferred hay wrapped in B-Wrap. However, hay waste did not differ between wrap types. These results confirmed that wrap type influenced forage quality and mold counts in alfalfa round bales stored outdoors, which in turn impacted cattle preference during feeding.

ACKNOWLEDGMENTS

This project was funded in part by Midwest Forage Association, John Deere, and Tama Inc.

Conflict of interest statement: The authors report no conflicts of interest.

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