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Effects of meloxicam administration on physiological and performance responses of transported feeder cattle[1]

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ABSTRACT: This experiment evaluated the effects of meloxicam administration on physiological and performance responses of transported cattle during feedlot receiving. Eighty-four Angus × Hereford steers were ranked by BW on d –10 and assigned to 21 dry lot pens. From d –10 to 0, pens were fed alfalfa–grass hay ad libitum and 2.4 kg/steer daily (DM basis) of a corn-based concentrate. On d 0, pens were randomly assigned to 1) transport for 1,440 km in a livestock trailer and oral administration of meloxicam (1 mg/kg of BW) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving (MEL; $n = 7$); 2) the same transportation and treatment schedule of MEL but oral administration of lactose monohydrate (1 mg/kg of BW) instead of meloxicam (TRANS; $n = 7$); or 3) no transport and oral administration of lactose monohydrate (1 mg/kg of BW) concurrently with treatment administration to MEL and TRANS (CON; $n = 7$). Upon arrival (d 1), MEL and TRANS steers returned to their pens for a 21-d feedlot receiving with the same diet offered from d –10 to 0. Treatments were administered to steers via oral drench on d 0 and 1 or mixed daily with the concentrate from d 2 to 7. Full BW was recorded before (d –2, –1, and 0) treatment application and at the end of experiment (d 20, 21, and 22) for ADG calculation. Daily DMI was recorded from d 1 to 21. Blood samples were collected on d 0, 1, 3, 5, 7, 10, 14, and 21. During the initial 7 d of feedlot receiving, hay and total DMI were reduced ($P \leq 0.03$) in TRANS vs. CON and MEL and similar between CON and MEL ($P \geq 0.26$), whereas concentrate DMI did not differ ($P = 0.16$) among treatments. Mean ADG was reduced ($P \leq 0.03$) in TRANS vs. MEL and CON but similar ($P = 0.82$) between MEL and CON. Moreover, TRANS had reduced G:F vs. CON ($P = 0.01$) and MEL ($P = 0.05$), whereas G:F was similar ($P = 0.39$) between CON and MEL. Serum NEFA concentrations were greater ($P < 0.01$) for TRANS and MEL vs. CON on d 1. Plasma haptoglobin concentrations were greater ($P \leq 0.03$) for TRANS vs. CON and MEL on d 5 and greater ($P \leq 0.03$) for CON vs. TRANS on d 10. Plasma ceruloplasmin concentrations were greater ($P \leq 0.04$) for TRANS vs. CON on d 3, 5, 7, 10, and 14, greater ($P \leq 0.03$) for TRANS vs. MEL on d 5 and 7, and also greater ($P = 0.05$) for MEL vs. CON on d 3. In conclusion, meloxicam administration to feeder steers modulated the haptoglobin and ceruloplasmin responses and prevented the performance losses caused by long-distance transportation.

Key words: acute-phase proteins, beef cattle, feedlot receiving, meloxicam, transport

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INTRODUCTION

Road transport is one of the most stressful events encountered by feeder cattle during their productive lives (Arthington et al., 2003). Upon long-distance transportation and feedlot arrival, cattle experience inflammatory and acute-phase responses (Arthington et al., 2008; Cooke et al., 2011) that impact feedlot receiving performance by increasing basal metabolism and tissue catabolism and by reducing DMI and G:F (Johnson, 1997). Hence, strategies that lessen the

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acute-phase response during feedlot receiving, which can be monitored via acute-phase proteins such as haptoglobin and ceruloplasmin (Carroll and Forsberg, 2007), have been shown to improve productivity of transported cattle (Arthington et al., 2008).

Administration of flunixin meglumine, a nonsteroidal anti-inflammatory drug (**NSAID**), to steers before a 24-h road transport and at feedlot arrival alleviated the resultant acute-phase response but did not improve feedlot receiving performance (Cooke et al., 2013a). Perhaps the elimination half-life of flunixin meglumine (<8 h; Hardee et al., 1985) was insufficient to modulate the transport-elicited acute-phase response to an extent that resulted in enhanced cattle performance. Alternatively, meloxicam is another NSAID with an elimination half-life of 28 h (Coetzee et al., 2009) when orally administered to cattle at 1 mg/kg. Van Engen et al. (2014) reported that a single oral administration of meloxicam to cattle before a 16-h road transport reduced transport-induced inflammatory reactions, although the authors did not evaluate feedlot receiving performance. Based on this rationale, we hypothesized that oral meloxicam administration before transport and during feedlot receiving alleviates the acute-phase response and improves performance of feeder cattle. Hence, this experiment evaluated the effects of oral meloxicam administration on circulating concentrations of cortisol, NEFA, acute-phase proteins, and feedlot receiving performance of transported cattle.

MATERIALS AND METHODS

This experiment was conducted at the Oregon State University – Eastern Oregon Agricultural Research Center (Burns station) from October to November 2013. All animals used herein originated from the Eastern Oregon Agricultural Research Center (Burns station) research herd, born during the 2013 calving season and managed equally from birth until the beginning of the experiment. Moreover, all animals were cared for in accordance with acceptable practices and experimental protocols reviewed and approved by the Oregon State University Institutional Animal Care and Use Committee (number 4460).

Animals and Diets

Eighty-four Angus × Hereford steers, weaned 40 d before the beginning of the experiment (d –10), were used. On d –10, steers were ranked by BW (252 ± 3 kg; initial age of 214 ± 2 d) and randomly allocated to 21 dry lot pens (4 steers/pen; 7 by 15 m) in a manner in which all pens had equivalent average BW. From d –10 to 0, all pens were fed alfalfa–grass hay ad libitum and 2.4 kg/steer daily (DM basis) of a concentrate containing (as-fed basis) 84% cracked corn, 14% soybean meal, and 2% mineral mix, which was offered separately from hay at 0800 h. On d 0, pens were randomly assigned to 1 of 3 treatments: 1) transport for 1,440 km in a commercial livestock trailer and oral administration of meloxicam (1 mg/kg of BW; Carlsbad Technologies, Inc., Carlsbad, CA) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving (**MEL**; $n = 7$ pens/treatment); 2) transport for 1,440 km in a commercial livestock trailer and oral administration of lactose monohydrate (1 mg/kg of BW; excipient used in the manufacture of meloxicam tablets; Avantor Performance Materials, Center Valley, PA) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving (**TRANS**; $n = 7$ pens/treatment); or 3) no transport and oral administration of lactose monohydrate (1 mg/kg of BW; Avantor Performance Materials) concurrently with treatment administration to MEL and TRANS steers (**CON**; $n = 7$ pens/treatment).

On d 0 of the experiment, MEL and TRANS steers were commingled and transported at the same time and in the same double-deck commercial livestock trailer (Legend 50′ Cattle Liner; Barrett LLC., Purcell, OK), while CON steers remained in their respective drylot pens with ad libitum access to alfalfa–grass hay and 2.4 kg/steer (DM basis) of the aforementioned concentrate. Within the livestock trailer, MEL and TRANS steers were randomly accommodated into two 2.1 by 7.2 m compartments to allow a minimum space of 1 m^2 per steer. During transport, the driver stopped every 6 h to rest for 60 min but cattle remained in the truck at all times, and total transport time was 24 h. Transport length and duration were selected to elicit the stress challenges of a long haul (Arthington et al., 2008). Minimum, maximum, and average environmental temperatures during transport were –3, 16, and 7°C, respectively, whereas average humidity was 56% and no precipitation was observed. Upon arrival (d 1), MEL and TRANS steers returned to their original pens for a 21-d feedlot receiving. All pens were fed alfalfa–grass hay ad libitum and 2.4 kg/steer daily (DM basis) of the aforementioned corn-based concentrate during the receiving period, which was offered separately from hay at 0800 h. Water was offered for ad libitum consumption from d –10 to 28, except to MEL and TRANS cattle during transport.

The meloxicam dose adopted herein was based on the oral administration used by Coetzee et al. (2012) and Repenning et al. (2013) to weaned beef cattle and the same dose used by Van Engen et al. (2014) for transported feeder steers. Meloxicam was originally presented in 15 mg tablets, which were ground daily using a commercial food processor (Soho Food Processor; West Bend Housewares, West Bend, WI) to ensure that MEL steers received their exact dose. Lactose monohydrate was administered to TRANS and CON steers to account for potential placebo effects, whereas the CON treatment was

included as a nontransport positive control for physiological and performance measurements. On d 0 and 1, meloxicam or lactose monohydrate was manually mixed with 50 mL of 0.9% saline and administered individually to steers via oral drench during handling of MEL and TRANS steers for truck loading (d 0) or feedlot arrival (d 1). Treatments were mixed with saline within 30 s before administration in 60 mL sterile syringes (Monoject Covidien Animal Health, Mansfield, MA), and 1 syringe was used per animal. From d 2 to 7, treatments were manually mixed daily with the corn-based concentrate according to the total BW of each pen.

Samples of hay and concentrate ingredients were collected weekly, pooled across all weeks, and analyzed for nutrient content by a commercial laboratory (Dairy One Forage Laboratory, Ithaca, NY). All samples were analyzed by wet chemistry procedures for concentrations of CP (method 984.13; AOAC, 2006), ADF (method 973.18 modified for use in an Ankom 200 fiber analyzer; Ankom Technology Corp., Fairport, NY; AOAC, 2006), and NDF (Van Soest et al., 1991; modified for use in an Ankom 200 fiber analyzer; Ankom Technology Corp.). Calculations for TDN used the equation proposed by Weiss et al. (1992), whereas NEm and NEg were calculated with the equations proposed by the NRC (1996). Hay nutritional profile was (DM basis) 60% TDN, 39% NDF, 28% ADF, 1.27 Mcal/kg of NEm, 0.70 Mcal/kg of NEg, and 19.0% CP. Based on the nutritional analysis of ingredients, concentrate nutritional profile was (DM basis) 85% TDN, 9.0% NDF, 4.6% ADF, 2.12 Mcal/kg of NEm, 1.46 Mcal/kg of NEg, and 14.5% CP. The mineral mix (Cattleman's Choice; Performix Nutrition Systems, Nampa, ID), contained 14% Ca, 10% P, 16% NaCl, 1.5% Mg, 3,200 mg/kg of Cu, 65 mg/kg of I, 900 mg/kg of Mn, 140 mg/kg of Se, 6,000 mg/kg of Zn, 136,000 IU/kg of vitamin A, 13,000 IU/kg of vitamin D3, and 50 IU/kg of vitamin E.

All cattle were vaccinated against clostridial diseases (Clostrishield 7; Novartis Animal Health, Bucyrus, KS) and bovine virus diarrhea complex (Virashield 6 + Somnus; Novartis Animal Health) at approximately 30 d of age. At weaning (d –40), cattle were vaccinated against clostridial diseases and *Mannheimia haemolytica* (One Shot Ultra 7; Zoetis, Florham Park, NJ), infectious bovine rhinotracheitis, bovine viral diarrhea complex, and pneumonia (Bovi-Shield Gold 5 and TSV-2; Zoetis) and administered an anthelmintic (Dectomax; Zoetis). No incidences of mortality or morbidity were observed during the entire experiment.

Sampling

Individual full BW was recorded and averaged over 3 consecutive days before treatment application (d –2, –1, and 0) and at the end of experiment (d 20, 21, and 22) for ADG calculation. Furthermore, BW was collected before concentrate and hay feeding of the day. Average BW of d –2, –1, and 0 was used to determine meloxicam and lactose monohydrate doses. Individual BW was also collected on d 1, immediately before treatment application, to evaluate BW shrink as percentage change from the average BW recorded on d –2, –1, and 0. Concentrate, hay, and total DMI were evaluated daily from d –10 to 21 from each pen by collecting and weighing refusals daily. Feed intake on d 0 was not included into DMI evaluation given that only CON steers were fed. Samples of the offered and nonconsumed feed were collected daily from each pen and dried for 96 h at 50°C in forced-air ovens for DM calculation. Hay, concentrate, and total daily DMI of each pen were divided by the number of steers within each pen and expressed as kilograms per steer per day. Total BW gain and DMI of each pen from d 1 to 21 were used for feedlot receiving G:F calculation.

Blood samples were collected on d 0 and 1 immediately before treatment application and on d 3, 5, 7, 10, 14, and 21 via jugular venipuncture into commercial blood collection tubes (Vacutainer, 10 mL; Becton Dickinson, Franklin Lakes, NJ) with or without 158 United States Pharmacopeia units of freeze-dried sodium heparin for plasma and serum collection, respectively. Blood samples were collected before concentrate and hay feeding, except for d 0 when MEL and TRANS cattle were transported after blood collection. All blood samples were placed immediately on ice, centrifuged (2,500 × *g* for 30 min at 4°C) for plasma or serum harvest, and stored at –80°C on the same day of collection. Plasma concentrations of cortisol were determined using a chemiluminescent enzyme immunoassay (Immulite 1000; Siemens Medical Solutions Diagnostics, Los Angeles, CA). Plasma concentrations of ceruloplasmin and haptoglobin were determined according to colorimetric procedures previously described (Demetriou et al., 1974; Cooke and Arthington, 2013). Serum concentrations of NEFA were determined in samples collected from d 0 to 7 using a colorimetric commercial kit (HR Series NEFA–2; Wako Pure Chemical Industries Ltd. USA, Richmond, VA) with the modifications described by Pescara et al. (2010). Serum NEFA concentrations were only evaluated in samples collected from d 0 to 7 because NEFA returns to pretransport levels within 7 d following the transportation model adopted herein (Francisco et al., 2012; Marques et al., 2012; Cooke et al., 2013a). The intra- and interassay CV were, respectively, 3.8 and 3.4% for cortisol, 4.3 and 6.5% for NEFA, 9.1 and 9.0% for ceruloplasmin, and 6.9 and 7.9% for haptoglobin.

Statistical Analyses

Data were analyzed using pen as the experimental unit with the PROC MIXED procedure of SAS (SAS Inst., Inc.,

Cary, NC) and Satterthwaite approximation to determine the denominator degrees of freedom for the tests of fixed effects. The model statement used for BW shrink from d 0 to 1 and ADG contained the effect of treatment. Data were analyzed using pen(treatment) and steer(pen) as random variables. The model statement used for DMI and G:F contained the effects of treatment, in addition to day, the treatment × day interaction, and average feed intake from d –10 to –1 as covariate for DMI only. Data were analyzed using pen(treatment) as the random variable because DMI was recorded for each pen. Moreover, DMI was also analyzed within each week of the experiment (d 1 to 7, d 8 to 14, and d 15 to 21) using the previously described model, given that DMI is mainly impacted by transport and feed yard entry during the first week of feedlot receiving (Hutcheson and Cole, 1986; Araujo et al., 2010). The model statement used for blood variables contained the effects of treatment, day, the treatment × day interaction, and values obtained on d 0 as covariate. Data were analyzed using steer(pen) and pen(treatment) as random variables. The specified term for the repeated statements was day, with pen(treatment) or steer(pen) as subject for DMI or blood variables, respectively. The covariance structure used was first-order autoregressive, which provided the smallest Akaike information criterion and hence the best fit for all variables analyzed. Results are reported as least square means as well as covariately adjusted least square means for DMI and blood variables and were separated using PDIFF. Significance was set at $P \leq 0.05$ and tendencies were determined if $P > 0.05$ and $P \leq 0.10$. Results are reported according to main treatment effect if no interactions were significant or according to the highest-order interaction detected that contained the effect of treatment.

Table 1. Feedlot receiving performance (21 d) of steers transported for 1,440 km and receiving meloxicam (MEL; 1 mg/kg of BW daily; $n = 7$) or lactose monohydrate (TRANS; 1 mg/kg of BW daily; $n = 7$) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving or nontransported steers that concurrently received lactose monohydrate (CON; 1 mg/kg of BW daily; $n = 7$)[1]

Item	CON	MEL	TRANS	SEM	*P*-value
BW,[2] kg					
Initial	259.9	260.4	260.3	4.9	0.99
Final	291.5	292.9	287.7	5.5	0.78
Shrink,[3] %	–0.71[a]	9.07[b]	9.83[b]	0.35	<0.01
ADG,[4] kg/d	1.50[a]	1.48[a]	1.26[b]	0.07	0.03
DMI,[5] kg/d					
Hay	5.90	5.98	5.75	0.09	0.19
Concentrate	2.39	2.38	2.38	0.01	0.18
Total	8.33	8.34	8.10	0.09	0.13
G:F,[6] g/kg	185[a]	177[a]	153[b]	8	0.03

[a,b]Within rows, values with different superscripts differ ($P \leq 0.05$).

[1]Steers assigned to MEL and TRANS were transported at the same time and in the same double-deck commercial livestock trailer (Legend 50′ Cattle Liner; Barrett LLC., Purcell, OK), while CON steers remained in drylot pens (4 steers/pen; 7 by 15 m) with access to feed and water. At loading (d 0) and unloading (d 1), meloxicam and lactose monohydrate were diluted in 50 mL of 0.9% saline and administered individually to steers via oral drench during handling of MEL and TRANS for truck loading or feedlot arrival. From d 2 to 7 of the experiment, meloxicam and lactose monohydrate were manually mixed with a corn-based concentrate.

[2]Initial BW = average of BW recorded on d –2, –1, and 0; final BW = average of BW recorded on d 20, 21, and 22.

[3]Based on BW loss from d 1 to initial BW.

[4]Calculated using initial and final BW.

[5]Calculated from each pen but divided by the number of steers within each pen and expressed as kilograms per steer per day. Average hay, concentrate, and total DMI from d –10 to –1 of the experiment served as covariate for each respective analysis.

[6]Calculated using total DMI and BW gain of each pen d 0 to d 21.

RESULTS AND DISCUSSION

A treatment effect was detected ($P < 0.01$) for BW shrink from d 0 to 1. As expected, BW shrink was greater ($P < 0.01$) for both TRANS and MEL compared with CON steers and similar ($P = 0.14$) between TRANS and MEL steers (Table 1). Accordingly, previous research from our group reported equivalent BW shrink in feeder cattle exposed to the same transportation schedule adopted herein (Marques et al., 2012; Cooke et al., 2013a,b). No treatment effects were detected ($P \geq 0.13$) on hay, concentrate, and total DMI during the 21-d feedlot receiving (Table 1). When DMI was analyzed within each week of the experiment, TRANS had reduced hay and total DMI during the initial week of feedlot receiving compared with CON ($P \leq 0.03$) and MEL ($P \leq 0.01$) steers (Table 2), which were similar between MEL and CON steers ($P \geq 0.26$). No treatment effects were detected for concentrate intake during the initial week of feedlot receiving ($P = 0.15$) as well as hay, concentrate, and total DMI during the second ($P \geq 0.42$) and third ($P \geq 0.28$) weeks of feedlot receiving (Table 2). These results indicate that all pens readily consumed their daily concentrate allocation and hence their designed meloxicam and lactose monohydrate dose during the initial 7 d of feedlot receiving. These results also suggest that oral meloxicam administration prevented the decrease in feed intake often observed in transported cattle during the first week of feedlot receiving, which directly impairs initial receiving ADG (Hutcheson and Cole, 1986; Araujo et al., 2010).

A treatment effect was detected ($P = 0.03$) for ADG during the 21-d feedlot receiving (Table 1). Steers assigned to TRANS had reduced ADG compared with MEL ($P = 0.03$) and CON ($P = 0.01$) steers, whereas ADG was similar between ($P = 0.82$) CON and MEL steers. However, treatment effects detected on ADG were not sufficient to impact ($P = 0.78$) cattle BW at the end of the 21-d feedlot receiving (Table 1). Nevertheless, a treatment effect was detected ($P = 0.03$) for G:F during

Table 2. Intake parameters (kg/d) within each week of feedlot receiving (21 d) in steers transported for 1,440 km and receiving meloxicam (MEL; 1 mg/kg of BW daily; $n = 7$) or lactose monohydrate (TRANS; 1 mg/kg of BW daily; $n = 7$) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving or nontransported steers that concurrently received lactose monohydrate (CON; 1 mg/kg of BW daily; $n = 7$)[1,2]

Item	CON	MEL	TRANS	SEM	*P*-value
First week (d 1 to7)					
Hay	5.43[a]	5.35[a]	5.05[b]	0.09	0.02
Concentrate	2.38	2.37	2.37	0.01	0.15
Total	7.85[a]	7.70[a]	7.39[b]	0.09	0.01
Second week (d 8 to 14)					
Hay	5.71	5.74	5.55	0.11	0.44
Concentrate	2.40	2.39	2.38	0.01	0.56
Total	8.12	8.12	7.93	0.11	0.42
Third week (d 15 to 21)					
Hay	6.55	6.83	6.63	0.12	0.28
Concentrate	2.39	2.39	2.39	0.01	0.76
Total	9.00	9.20	9.01	0.12	0.35

[a,b]Within rows, values with different superscripts differ ($P \leq 0.05$).

[1]Steers assigned to MEL and TRANS were transported at the same time and in the same double-deck commercial livestock trailer (Legend 50′ Cattle Liner; Barrett LLC., Purcell, OK), while CON steers remained in drylot pens (4 steers/pen; 7 by 15 m) with access to feed and water. At loading (d 0) and unloading (d 1), meloxicam and lactose monohydrate were diluted in 50 mL of 0.9% saline and administered individually to steers via oral drench during handling of MEL and TRANS for truck loading or feedlot arrival. From d 2 to 7 of the experiment, meloxicam and lactose monohydrate were manually mixed with a corn-based concentrate.

[2]Calculated from each pen, but divided by the number of steers within each pen and expressed as kilograms per steer per day. Average hay, concentrate, and total DMI from d –10 to –1 of the experiment served as covariate for each respective analysis.

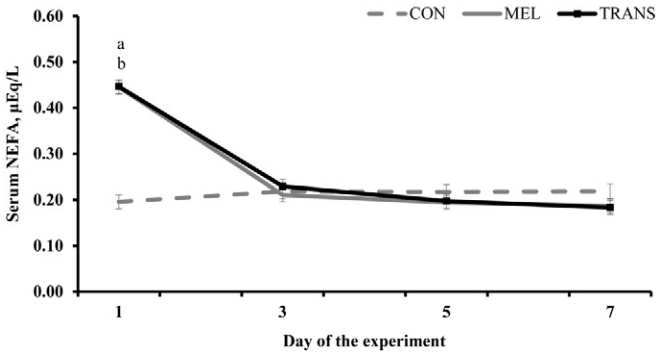

Figure 1. Serum NEFA concentration in steers transported for 1,440 km and receiving meloxicam (MEL; 1 mg/kg of BW daily; $n = 7$) or lactose monohydrate (TRANS; 1 mg/kg of BW daily; $n = 7$) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving or nontransported steers that concurrently received lactose monohydrate (CON; 1 mg/kg of BW daily; $n = 7$). At loading (d 0) and unloading (d 1), meloxicam and lactose monohydrate were diluted in 50 mL of 0.9% saline and administered individually to steers via oral drench during handling of MEL and TRANS for truck loading or feedlot arrival. From d 2 to 7 of the experiment, meloxicam and lactose monohydrate were manually mixed with a corn-based concentrate. Values obtained before treatment application (d 0) served as covariate ($P < 0.01$) but did not differ ($P = 0.47$) among treatments (0.204, 0.229, and 0.215 μEq/L for CON, MEL, and TRANS, respectively; SEM = 0.014). A treatment × day interaction was detected ($P < 0.01$). Within days, letters indicate the following treatment differences: a = TRANS vs. CON ($P < 0.01$) and b = MEL vs. CON ($P < 0.01$).

the 21-d feedlot receiving because TRANS had reduced G:F compared with MEL ($P = 0.05$) and CON steers ($P = 0.01$), whereas G:F was similar ($P = 0.39$) between MEL and CON steers (Table 1). Hence, feedlot receiving performance of MEL was similar to CON and greater than TRANS steers, indicating that oral meloxicam administration prevented the performance losses typically observed in cattle transported for long distances (Hutcheson and Cole, 1986; Marques et al., 2012; Cooke et al., 2013b)

No treatment effect was detected ($P = 0.89$) for plasma cortisol concentrations during the 21-d feedlot receiving (21.1, 20.6, and 20.4 ng/mL for CON, MEL, and TRANS, respectively; SEM = 1.0). The impact of long-distance transportation on cortisol has been variable, with research studies reporting increased (Crookshank et al., 1979; Tarrant et al., 1992; Knowles et al., 1999) or unaltered (Cole et al., 1988; Arthington et al., 2003; Van Engen et al., 2014) circulating cortisol concentrations following transport. However, previous research from our group reported increased plasma cortisol concentrations during feedlot receiving in cattle exposed to the same transportation schedule adopted herein (Marques et al., 2012; Cooke et al., 2013a,b). Hence, the lack of treatment effects on plasma cortisol in the present experiment, particularly between CON and TRANS steers, was unexpected and may have hindered proper assessment of meloxicam effects on transport-induced plasma cortisol response. Nevertheless, Van Engen et al. (2014) also did not detect significant differences in plasma cortisol concentrations during feedlot receiving between steers transported for 16 h and orally administered meloxicam or a whey protein placebo before transport.

A treatment × day interaction was detected for serum NEFA ($P < 0.01$; Fig. 1), given that NEFA concentrations were greater ($P < 0.01$) for TRANS and MEL compared with CON steers on d 1 of feedlot receiving. These results corroborate that stress due to long-distance transport stimulates fat tissue mobilization and increases circulating NEFA concentration in cattle (Earley and O'Riordan, 2006; Marques et al., 2012), whereas oral meloxicam administration did not alleviate this outcome. To the best of our knowledge, Newby et al. (2013) is the only research study available in the literature that evaluated circulating NEFA in cattle following meloxicam administration. These authors administered meloxicam (0.5 mg/kg of BW) subcutaneously to Holstein cows approximately 24 h after parturition and reported that serum NEFA concentrations during the initial 12 d of lactation were similar compared with cohorts receiving saline. Hence, meloxicam administration appears not to modulate lipid mobilization and metabolism in cattle on stress and nutritional challenges.

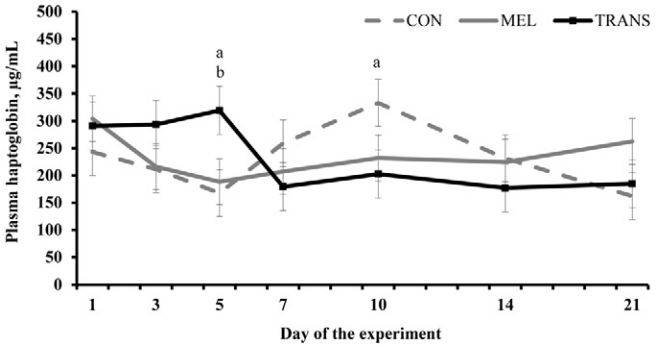

Figure 2. Plasma haptoglobin concentration in steers transported for 1,440 km and receiving meloxicam (MEL; 1 mg/kg of BW daily; $n = 7$) or lactose monohydrate (TRANS; 1 mg/kg of BW daily; $n = 7$) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving, or nontransported steers that concurrently received lactose monohydrate (CON; 1 mg/kg of BW daily; $n = 7$). At loading (d 0) and unloading (d 1), meloxicam and lactose monohydrate were diluted in 50 mL of 0.9% saline and administered individually to steers via oral drench during handling of MEL and TRANS for truck loading or feedlot arrival. From d 2 to 7 of the experiment, meloxicam and lactose monohydrate were manually mixed with a corn-based concentrate. Values obtained before treatment application (d 0) were not significant covariates ($P = 0.43$) and hence did not differ ($P = 0.14$) among treatments (274, 254, and 190 µg/mL for CON, MEL, and TRANS, respectively; SEM = 30). A treatment × day interaction was detected ($P < 0.01$). Within days, letters indicate the following treatment differences: a = TRANS vs. CON ($P \leq 0.03$) and b = TRANS vs. MEL ($P = 0.03$).

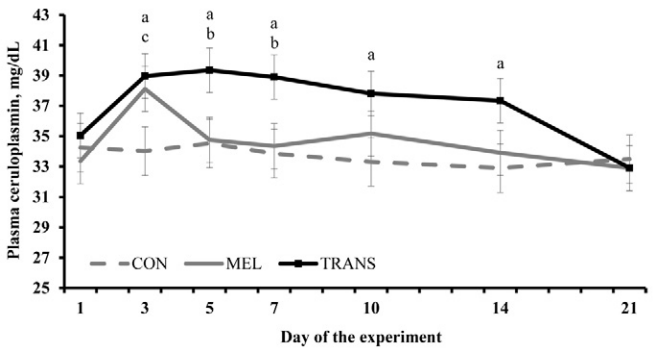

Figure 3. Plasma ceruloplasmin concentration in steers transported for 1,440 km and receiving meloxicam (MEL; 1 mg/kg of BW daily; $n = 7$) or lactose monohydrate (TRANS; 1 mg/kg of BW daily; $n = 7$) at loading (d 0), unloading (d 1), and daily from d 2 to 7 of feedlot receiving or nontransported steers that concurrently received lactose monohydrate (CON; 1 mg/kg of BW daily; $n = 7$). At loading (d 0) and unloading (d 1), meloxicam and lactose monohydrate were diluted in 50 mL of 0.9% saline and administered individually to steers via oral drench during handling of MEL and TRANS for truck loading or feedlot arrival. From d 2 to 7 of the experiment, meloxicam and lactose monohydrate were manually mixed with a corn-based concentrate. Values obtained before treatment application (d 0) were significant covariates ($P < 0.01$) but did not differ ($P = 0.70$) among treatments (35.2, 35.7, and 33.7 mg/dL for CON, MEL, and TRANS, respectively; SEM = 1.8). A tendency for treatment × day interaction was detected ($P = 0.09$). Within days, letters indicate the following treatment differences: a = TRANS vs. CON ($P \leq 0.04$), b = TRANS vs. MEL ($P \leq 0.03$), and c = MEL vs. CON ($P = 0.05$).

A treatment × day interaction was detected for plasma haptoglobin ($P < 0.01$; Fig. 2), whereas a tendency ($P = 0.09$; Fig. 3) for the same interaction was detected for plasma ceruloplasmin. Plasma haptoglobin concentrations were greater ($P \leq 0.03$) for TRANS compared with CON and MEL steers on d 5 and greater ($P \leq 0.03$) for CON compared with TRANS steers on d 10. Plasma ceruloplasmin concentrations were greater ($P \leq 0.04$) for TRANS compared with CON steers on d 3, 5, 7, 10, and 14, greater ($P \leq 0.03$) for TRANS compared with MEL steers on d 5 and 7, and also greater ($P = 0.05$) for MEL compared with CON steers on d 3. Corroborating the ADG, DMI, G:F, and physiological differences detected between TRANS and CON steers, previous research from our group also reported that 24-h road transport elicited an acute-phase response that reduced feedlot receiving performance of feeder cattle (Cooke et al., 2012, 2013b; Marques et al., 2012). Accordingly, circulating concentrations of acute-phase proteins in transported cattle have been negatively associated with receiving ADG (Berry et al., 2004; Qiu et al., 2007; Araujo et al., 2010), and such outcome can be attributed to altered basal metabolism, increased tissue catabolism, and reduced feed intake and efficiency during an acute-phase response (Johnson, 1997). The reason why plasma haptoglobin concentrations increased on d 10 of feedlot receiving in CON but not MEL and TRANS steers is unknown. A similar response was not detected for plasma ceruloplasmin, whereas circulating concentrations of acute-phase proteins are typically correlated (Cooke et al., 2009; Araujo et al., 2010). Haptoglobin is also positively associated with morbidity in feeder cattle (Carter et al., 2002; Berry et al., 2004; Petersen et al., 2004), but no incidence of morbidity or mortality was detected during feedlot receiving. In addition, hay, concentrate, and total DMI of CON were similar ($P \geq 0.42$) compared with MEL and TRANS steers during the second week of feedlot receiving, whereas an inflammatory-induced haptoglobin response is usually accompanied by reduced feed intake (Johnson, 1997; Araujo et al., 2010).

Supporting our hypothesis, meloxicam administration modulated the acute-phase protein response elicited by 24-h transport based on differences detected for plasma haptoglobin and ceruloplasmin between TRANS and MEL steers. Meloxicam inhibits cyclooxygenase, an enzyme that regulates synthesis of inflammatory eicosanoids associated with the acute-phase response such as PGE_2 (Lees et al., 2004). Accordingly, Van Engen et al. (2014) administered a single oral dose of meloxicam or a whey protein placebo at approximately 1 mg/kg of BW to steers before a 16-h road transport. These authors reported that steers receiving meloxicam had reduced circulating concentrations of biomarkers of stress and inflammation compared with cohorts receiving placebo, including stress-induced neutrophilia as well as monocyte and lymphocyte counts. However, Van Engen et al. (2014) did not evaluate production parameters to determine if the immunological benefits of oral meloxicam administration to transported cattle would result in enhanced

feedlot receiving performance. In the present experiment, feedlot receiving performance of MEL steers was similar compared with CON and greater compared with TRANS. These results indicate that oral meloxicam administration effectively prevented the performance losses caused by road transport, likely by inhibiting the changes in metabolism and feed intake regulated by inflammatory eicosanoids during an acute-phase response (Johnson, 1997; Klasing and Korver, 1997; Lees et al., 2004).

It is important to note that meloxicam was administered on d 0 with the purpose of modulating stress-induced inflammatory reactions elicited during road transport (Cooke et al., 2012; Marques et al., 2012) and administered from d 1 to 7 of feedlot receiving to modulate residual and novel inflammatory reactions elicited by unloading and feedlot entry (Duff and Galyean, 2007). Given the substantial half-life and bioavailability of meloxicam (Coetzee et al., 2009, 2011), which may remain in circulation for several days following a single oral administration (Van Engen et al., 2014), perhaps meloxicam can be administered to transported cattle with less frequency or dosage as used herein while maintaining the same physiological and performance benefits. In addition, steer morbidity or mortality was not detected in the present experiment. The magnitude of the transport-elicited acute-phase reaction, including the plasma haptoglobin response, has been positively associated with health issues in feeder cattle (Carter et al., 2002; Berry et al., 2004). Hence, additional research is warranted to determine if the immune benefits of meloxicam administration reported herein translate into decreased incidence of sickness during feedlot receiving (Snowder et al., 2006).

In conclusion, meloxicam administration to feeder steers before road transport, at feedlot arrival, and during the initial week of feedlot receiving (1 mg/kg of BW per administration) modulated the haptoglobin and ceruloplasmin responses and increased ADG, DMI, and G:F during feedlot receiving. Hence, meloxicam administration may be a viable strategy to mitigate inflammatory reactions and performance losses elicited by long-distance transportation. Nevertheless, research is still warranted to properly determine optimal dosage and length of meloxicam administration and assess additional health and performance responses of transported cattle.

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