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ANIMAL PRODUCTION SCIENCE

Body weight and feed and water deprivation time predict cattle body weight loss from transportation

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ABSTRACT

Context. The body weight of cattle decreases during transport. The decrease in weight is associated with reduced gut fill, dehydration and weight loss. Cattle experience thirst and hunger during long journeys. To the best of the author's knowledge, a systematic review and meta-analysis of factors that contribute to weight loss during transport has not been previously published. A model that predicts body weight loss in cattle during transport may assist producers understand the key drivers of weight loss and identify opportunities where body weight loss can be reduced during the journey. **Aim.** The aim of this review is to identify factors associated with cattle live-weight loss during road transport and to develop a predictive model to assist industry stakeholders estimate weight loss. **Methods.** A systematic review of the literature found 26 studies suitable for inclusion in the meta-analysis, based on inclusion and exclusion criteria. Moderators were initially screened using univariable multilevel meta-regression analyses. A backward selection approach was used to construct the final multivariable model, with moderators sequentially removed based on statistical significance and model fit. **Key results.** Feed and water deprivation time ($P = 0.001$) and the initial body weight of the animal ($P = 0.001$) were significant modifiers of body weight loss. Treatment (transport or no transport) ($P = 0.3744$), genetic type ($P = 0.3417$), region ($P = 0.4501$), sex ($P = 0.6069$) and feed type ($P = 0.8101$) were not significant modifiers in the univariable analysis and were excluded from the final model. **Conclusions.** Initial body weight and the duration of feed and water deprivation are significant predictors of body weight loss. Road transportation was not a significant modifier of the relationship between feed and water deprivation and body weight loss. **Implications.** Reducing the total time that cattle are deprived of feed and water is likely to reduce weight loss during transportation. Therefore, providing cattle with *ad libitum* access to feed and water as close as possible to loading may help minimise weight loss. The predictive model, based on the results of the meta-analysis, can assist industry stakeholders predict cattle body weight loss for an intended journey.

Keywords: carcass, dehydration, fasting, lairage, meta-analysis, road, shrink, systematic review.

Background

Cattle undergoing transport experience a decrease in body weight (Self and Gay 1972; Parker *et al.* 2007). The loss of contents from the gastrointestinal tract (Self and Gay 1972), dehydration (Parker *et al.* 2007), and body tissue weight loss (Self and Gay 1972), contribute to weight loss during transport, often leading to animal welfare concerns that the cattle become fatigued, hungry and thirsty during the journey. Furthermore, body weight loss adds an economic cost to the seller (Coffey *et al.* 2001). The amount of body weight lost during transportation is variable with cited ranges of 0–16% of pre-transport body weight (Parker *et al.* 2007; Cernicchiaro *et al.* 2012). The total time cattle are deprived of feed and water is consistently cited as an important variable associated with body weight loss during an animal's journey (Wythes *et al.* 1981; Schwartzkopf-Genswein and Grandin 2014). However, other variables have been suggested to contribute to the decrease in body weight experienced by cattle during transport, such as pre-transport handling (Crookshank *et al.* 1979;

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Bravo *et al.* 2020) and diet (Phillips *et al.* 1985; Cole and Hutcheson 1987), distance traveled (Hoffman *et al.* 1998; da Silva *et al.* 2024), age (Marcato *et al.* 2022; Goetz *et al.* 2023), sex (Ishiwata *et al.* 2008; Abreu *et al.* 2024), genetic type (Levakhin *et al.* 2017; Minka and Ayo 2018), immune status (Earley *et al.* 2012; Brunel *et al.* 2018), environmental conditions (Fernandez *et al.* 1996; Goldhawk *et al.* 2015) and road conditions (Minka and Ayo 2018), with inconsistent results (Coffey *et al.* 2001; Fike and Spire 2006; Cernicchiaro *et al.* 2012).

Research syntheses that integrate empirical data of factors that contribute to cattle weight loss during transport are limited. To the best of current knowledge, a systematic review of the published literature on weight loss in transported cattle and meta-analysis of data from these studies has not been previously published. This study evaluates independent variables associated with body weight loss that occurs during road transportation of ruminant cattle. The aim of this study was to develop a model to assist beef cattle industry stakeholders in predicting weight loss of cattle during transport. The author hypothesized that as animal weight and time off feed and water increases, weight loss increases and that road transport increases the effect of these two variables. Other possible confounding factors, including the animal's sex and genetic type, global region (region) in which the study was conducted, and the type of feed offered to the animal prior to transport, were also assessed. The intended practical outcome of this work is a model that can predict body weight loss associated with transport.

Methods

Systematic literature review

The literature search was conducted using the Web of Science Core Collection (https://clarivate.com/academia-government/scientific-and-academic-research/research-discovery-and-referencing/web-of-science/web-of-science-core-collection/). Adjustments to the search strategy were tested to balance the sensitivity and specificity of the search, using several relevant studies identified *a priori* by the author. References from review articles were evaluated to ensure inclusion in the original literature search. The details of the final Boolean search are as follows.

Title: transport* OR transit OR fasting OR fast OR 'water deprivation' OR shipment OR 'feed deprivation' OR curfew

AND Title: cow* OR cattle OR beef OR dairy OR calf OR calves OR steer OR heifer OR bull OR carcass

AND Topic: liveweight OR weight OR age OR BCS OR 'body condition score' OR genotype OR 'bos taurus' OR 'bos indicus' OR 'cross bre*'

Studies written in English, found in journals (peer and non-peer reviewed), published abstracts, and gray literature (e.g. government/agency reports and news articles), published before January 20, 2026, and accessible via open access online sources, library resources or interlibrary loans, were included in the review. Studies were uploaded into Endnote 25 (Clarivate Analytics), and then into Covidence systematic review software (Veritas Health Innovation), for title and abstract screening, full text screening and data extraction. Duplicates were identified in Covidence and removed. Studies for inclusion in the meta-analysis were selected based on inclusion and exclusion criteria (Table 1).

Data was extracted on possible modifiers of the effect of feed and water deprivation on the amount (kg) of body weight lost during feed and water deprivation. A list of modifiers was developed during a meeting with beef producers and advisors in the livestock transport industry. The final list of modifiers included genetic type (*Bos indicus* (BI), *Bos taurus* (BT), *Bos javanicus* (JV), and cross bred (BI × BT)), region of origin, (Europe, North America, Other – Australia, Brazil, Chile, China, Tanzania, Indonesia), sex (bull, steer, female), feed type, (total mixed ration (TMR), hay, forage), treatment (transport or not transported), start weight, (body weight in kg immediately prior to feed and water deprivation), finish weight, (body weight in kg, immediately after feed and water deprivation), and time (the amount of time the animal was deprived of feed and water).

Although the inclusion of 'distance travelled' in the list of moderators was considered, industry experts advised that travel distance is weakly correlated with the amount of time the animal is being transported. Road type (highway or local roads), road condition (bitumen, dirt or gravel roads) and geography (flat, hilly or mountainous ± winding roads), driver expertise, and legislated rest stops in some countries, markedly influence the duration of transport and therefore

Table 1. Inclusion and exclusion criteria for selection of studies to include in the meta-analysis.

Inclusion criteria	- Cattle over 100 kg (ruminants). - Cattle deprived of feed and water while undergoing road transport (treatment). - Cattle deprived of feed and water without transport (control).
Exclusion criteria	- Studies that included cattle undergoing sea or rail transport or a combination of rail, sea and/or road transport. - Studies that did not report body weight at the time of loading (or at the start of fasting) AND body weight at the time of unloading (or at end of fasting). - Studies that did not include a measure of variance for body weight measurements. - Studies in which the cattle had access to feed and water during transportation. - Studies in which cattle had access to feed and water during rest stops.

time of feed and water deprivation. Therefore, travel distance was not included as a possible moderator.

The outcome of interest in this analysis was body weight loss, (start weight ± s.d. – finish weight ± s.d.), occurring between the start and finish of feed and water deprivation that may or may not be associated with road transport. This approach was selected to retain biologically meaningful information about the animal. Starting body weight reflects size and physiological maturity (Berg and Butterfield 1976), which influence gut fill, hydration status (Bailey 1986), and possible tissue loss during feed and water deprivation. In contrast, shrink, the percentage of body weight lost during feed and water deprivation, is often reported without a corresponding starting weight (Cernicchiaro *et al*. 2012; Browning and Leite-Browning 2013) and may obscure important differences between animals, as individuals of different sizes can exhibit similar proportional losses but different absolute weight changes. Shrink was therefore not chosen as the outcome of interest. The moderators included in the meta-analysis are listed and described in Table 2.

Meta-analysis

To assess the effect of moderators on body weight loss between the start and finish of feed and water deprivation, a meta-analysis was conducted using the metafor package (Viechtbauer 2010) in R (R Core Team 2021). Effect sizes were calculated using the 'escalc' function with the mean change (MC) metric, incorporating the within-group correlation to obtain the mean change in body weight (yi) and corresponding sampling variance (vi).

To account for non-independence of multiple treatment groups within studies, a multilevel meta-regression model was fitted using the rma.mv function with restricted maximum likelihood (REML) estimation. Two random effects were specified to model clustering of effect sizes within studies (effect sizes nested within studies). Between-study and within-study heterogeneity were quantified using variance components estimated in the multilevel model.

Moderators were initially screened using univariable multilevel meta-regression analyses. Moderators with *P*-values ≤ 0.10 were considered for inclusion in the multivariable model. A backward selection approach was used to construct the final multivariable model, with moderators sequentially removed based on statistical significance and model fit (Akaike Information Criterion, AIC), beginning with the least significant variable.

Model assumptions were evaluated graphically. Normality was assessed by visual inspection of Q–Q plots of standardized residuals, calculated as the difference between observed and predicted effect sizes divided by the square root of the corresponding sampling variance.

In addition to the primary additive meta-regression model, alternative model specifications were evaluated to assess potential non-linearity and effect modification. Non-linearity in the relationship between time and weight loss was examined by inclusion of a quadratic term in the model and by fitting restricted cubic spline and piecewise (knot) models. Comparisons between nested models differing in fixed effects were conducted using maximum likelihood (ML) estimation to permit valid likelihood ratio testing. Model fit was evaluated using likelihood ratio tests (LRT) and the AIC.

Potential effect modification was assessed by inclusion of an interaction term between starting weight and time. The interaction model was compared with the additive model using ML estimation, LRT, and AIC. As a sensitivity analysis, cluster-robust standard errors (CR2) were calculated using the *clubSandwich* (Pustejovsky 2026) package in R, allowing for correlation among effect sizes within studies. This approach provides small-sample corrections and a more conservative inference.

The final model specification was selected based on model fit, parsimony, biological plausibility, and robustness of inference across conventional and cluster-robust standard errors.

Table 2. Description of moderators included in the meta-analysis on cattle body weight loss.

Moderator	Description
Genetic type	*Bos indicus* (BI), *Bos taurus* (BT), *Bos javanicus* (JV), *and* crossbred (BI x BT).
Region	Region of origin (Europe, North America, Other – Australia, Brazil, Chile, China, Tanzania, Indonesia).
Sex	Bull, steer, female or mixed.
Feed	The type of feed fed in the week prior to feed and water deprivation – total mixed ration, hay, forage.
Treatment	Transported or not transported.
Start weight	Body weight in kg immediately prior to feed and water deprivation.
Time	The amount of time the animal was deprived of feed and water.

Results

The Boolean search identified 585 studies published between 1926 and January 2026. A further seven studies were identified via citation searching. Twenty-six (26) studies (Table 3) met the inclusion criteria for meta-analysis. Fig. 1 depicts the flow of information through the different phases of the systematic review. All 26 studies reported treatment, time, region, sex, genetic type, start weight and finish weight. The 26 studies included a total of 78 treatments involving 1896 head of cattle. Twenty-four studies reported feed type. Fourteen of the selected studies reported distance traveled, four of which reported approximate values only. Twelve of the selected studies reported shrink.

Table 3. Citations for the data collected from 26 research studies included in the meta-analysis.

Abreu *et al.* (2024)	Genther-Schroeder and Hansen (2015)
Arthington *et al.* (2003)	Goodchild (1985)
Beenken *et al.* (2021)	Heiderscheit *et al.* (2022)
Bravo *et al.* (2018)	Leo-Penu *et al.* (2016)
Buckham-Sporer *et al.* (2008)	Levakhin *et al.* (2017)[A]
Cole *et al* (1979)	Marques *et al.* (2012)
Cole *et al.* (1982)	Parker *et al.* (2007)
Cook *et al.* (2009)	Phillips *et al.* (1987)
Deng *et al.* (2017)	Phillips *et al.* (1991)
Dornbach *et al.* (2023)	Santosa *et al.* (2014)[A]
Earley *et al.* (2006)	Smith *et al.* (1982)
Fazio *et al.* (2025)	Werner *et al.* (2013)
Galyean *et al.* (1981)	Wu *et al.* (2020)

[A]Did not report feed type.

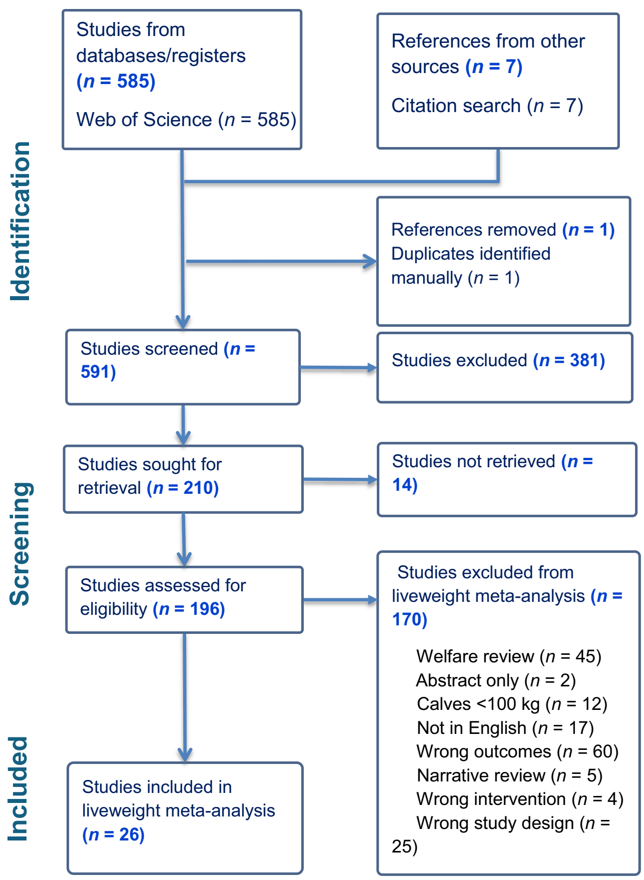

Fig. 1. PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) flow diagram for the systematic review of liveweight loss of cattle secondary to feed and water deprivation associated with road transport.

Moderators, treatment, region, sex, genetic type, start weight, feed type and time were included in the univariable analysis. Start weight ($P < 0.0001$) and time ($P < 0.0001$) were significant moderators of body weight loss. All other moderators were not significant (Table 4).

Pre-fasting body weight and total time fasting were included in the final multivariable model. Both moderators remained statistically significant (Table 5). The final model explained 75% of the between-study heterogeneity and 50% of the within-study heterogeneity relative to the base model without moderators (Table 6).

The plot of observed versus predicted liveweight loss demonstrated close agreement between model predictions and observed effect sizes (Fig. 2).

Visual inspection of the standardized residuals indicated tail deviation from normality; however, the majority of residuals followed the expected distribution (Fig. 3).

Table 4. Results of the univariable analysis to estimate the effect of moderators on body weight loss.

Moderator	*P*-value
Time	< 0.0001
Start weight	< 0.0001
Treatment	0.3744
Genetic type	0.3417
Region	0.4501
Sex	0.6069
Feed type	0.8101

Table 5. Final model including pre-fasting body weight and total time fasting.

	Estimate	*P*-value	95% confidence interval	
			Lower	Upper
Intercept	−9.2715	0.0079	−16.1161	−2.4270
Body weight pre-fasting (kg)	0.0808	< 0.0001	0.0617	0.1000
Total time fasting (h)	0.3642	< 0.0001	0.2390	0.4849

Table 6. Variance components for the base model without any predictors and the final model including time off feed and water and starting weight.

		N	Variance (kg^2)	$\sqrt{\text{variance}}$ (kg)
Base model	Between study	26	170.20	13.05
	Within studies	78	9.78	3.13
Final model	Between study	26	42.98	6.56
	Within studies	78	4.87	2.20

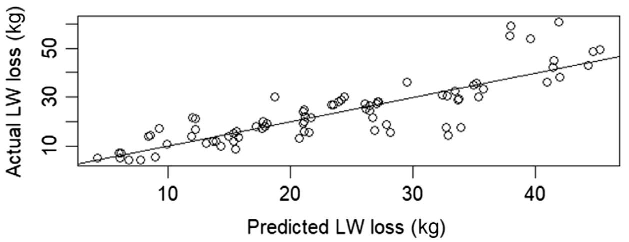

Fig. 2. The association between actual liveweight (LW) loss and model predicted liveweight loss.

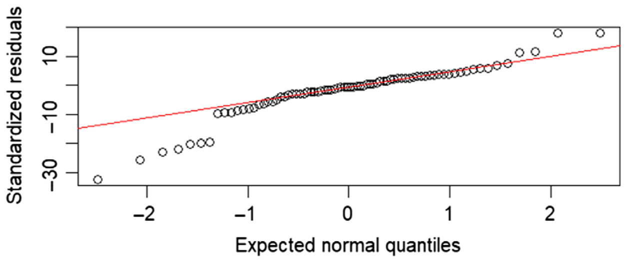

Fig. 3. Q–Q plot of standardized residuals of the final multilevel meta-regression model.

Potential non-linearity in the relationship between time off feed and water and weight loss was formally evaluated using alternative model specifications. Inclusion of a quadratic term did not improve model fit compared with the additive linear model (ML comparison: LRT = 0.53, $P = 0.47$; ΔAIC = +1.47). Similarly, restricted cubic spline models (*d.f.* = 3) did not improve model fit (LRT = 0.69, $P = 0.71$; ΔAIC = +3.31), nor did piecewise (knot) models (LRT = 0.05, $P = 0.82$; ΔAIC = +1.95). In all cases, the AIC increased relative to the linear specification. Therefore, time off feed and water was modeled as a linear predictor over the observed range.

Inclusion of an interaction term between starting weight and time modestly improved model fit under ML estimation. However, the effect was attenuated under cluster-robust standard errors. Therefore, the additive model was retained as the final specification.

The predictive equation for body weight loss is dependent on the body weight of the animal immediately before it is deprived of feed and water ($W1$) and the length of time the animal is deprived of feed and water (TFW) (Eqn 1).

$$\text{Weight loss} = -9.2715 + W1 \times 0.0808 + \text{TFW} \times 0.3642. \quad (1)$$

Discussion

This systematic review and meta-analysis found that the body weight of cattle immediately before the start of feed and water deprivation plus the total time of feed and water deprivation, predicted 75% of the variation in body weight loss between studies included in the analysis. Body weight reflects the anatomical and physiological maturity of the animal (Berg and Butterfield 1976). Throughout an animal's development, the tissues of the gastrointestinal tract (GIT) increase in weight, in a log linear pattern of development as the animal ages, until physiological maturity is reached (Bailey 1986). The developmental increase in the weight of the GIT tissue coincides with an increase in volume and weight of the digesta, such that the maximum weight of digesta is attained at physiological maturity for a given diet (Bailey 1986). The GIT digesta contributes to the total body water pool of an animal and loss of GIT content, without replacement, leads to dehydration, thirst and hunger (Parker *et al.* 2007). Faeces and urine are the main source of total body weight loss in the first 24 h of feed and water deprivation (Self and Gay 1972; Wythes *et al.* 1981; Parker *et al.* 2003, 2007). During feed and water deprivation immature animals have less weight to lose as the digesta weight in immature cattle is less than the weight of digesta in physiologically mature animals consuming the same diet (Berg and Butterfield 1976). This implies that immature animals undergoing periods of feed and water deprivation, with or without transport, have less GIT contents to lose and will start losing body tissue weight sooner than older mature cattle.

The time that cattle are deprived of feed and water is acknowledged as an important contributor to body weight loss during transportation. This analysis found that there is a linear relationship between the additive effect of time of feed and water deprivation (0–65 h) and starting body weight (146–530 kg). Minimizing the time cattle are deprived of feed and water reduces the loss of GIT contents, improves hydration status, minimizes thirst and hunger and improves overall animal welfare. While cattle producers may benefit from the sale of an animal with a greater body weight at slaughter, the effects of feed and water deprivation of ruminant animals may also have ongoing economic effects secondary to decreased dry matter intake and delays in body weight restoration (Galyean *et al.* 1981; Leo-Penu *et al.* 2018). Loss of appetite associated with feed and water deprivation is secondary to an increase in ruminal pH and a decrease in total bacteria and protozoa counts (Galyean *et al.* 1981). A study using rumen-canulated cattle found that after 72 h of feed and water deprivation, live bacteria and protozoa counts/mL were $0.8 \pm 0.0 \times 10^9$ and $2.4 \pm 0.9 \times 10^3$, compared to $23.7 \pm 1.8 \times 10^9$ and $551.2 \pm 53.3 \times 10^3$ in the ruminal fluid from control cattle (Leo-Penu *et al.* 2018). While live bacterial counts increased to control levels by day 4, ruminal gas production did not return to control levels until day 9 and protozoal counts were still not at control levels by day 9 (Leo-Penu *et al.* 2018). The decrease in dry matter intake can persist for up to 10 days following feed and water deprivation causing delays in body weight restoration (Leo-Penu *et al.* 2018).

During a journey, feed and water deprivation may start when cattle are moved from a paddock and placed in the yards and may continue after unloading if feed and water withdrawal continues on arrival at the destination. In the preparation of cattle for their intended journey, pre- and post-transportation periods are critical times, adding significantly to body weight loss during a journey, and are often overlooked. Therefore, minimizing the time cattle are deprived of feed and water throughout their journey is critical to reducing body weight loss (Wythes *et al.* 1981; Coffey *et al.* 1997). Coffey *et al.* (1997) found that during a 16 h period of feed and water deprivation, there was decreased shrinkage in cattle given time to graze pasture before mustering to handling facilities, compared to cattle that did not get extra grazing time. The benefits of reducing feed and water deprivation time have been demonstrated in studies on short duration lairage prior to harvest (6 h vs 22 h). For multiple market classes of cattle, decreased lairage time resulted in increases in hot standard carcass weight, cold carcass weight, and a reduction in dark cutting carcasses (George and George 2023; Alexander *et al.* 2025). To decrease weight loss associated with travel, cattle should be prepared for their intended journey by maintaining *ad libitum* intake of feed and water up to embarkation. If possible, it is also important that cattle return as soon as possible to *ad libitum* intake of feed and water after disembarkation.

Use of the predictive equation to estimate the body weight loss of cattle undergoing transportation can provide a starting point for price per animal negotiations between the seller and buyer for paddock sales, online auction systems and direct consignment of animals to harvest facilities. Furthermore, adoption of the body weight loss equation may incentivise producers to reduce the feed and water deprivation time prior to loading by providing hay in the yards up to the time of loading. Future work validating the equation with cattle undergoing transportation may be required to improve the rate of adoption with the cattle industries.

This study found no evidence to support the long-held belief that transportation of cattle modifies the effect of feed and water deprivation by increasing the rate of body weight loss, compared to feed and water deprivation in non-transported cattle (Warriss 1990; Knowles 1999; Fike and Spire 2006). The results of this study support others who have demonstrated no effect of transportation on body weight loss in cattle when compared to non-transported cattle (Galyean *et al.* 1981; Wythes *et al.* 1981; Parker *et al.* 2007). Furthermore, these results suggest that road transport can be eliminated from future studies attempting to test the effects of treatments on cattle body weight for journeys of up to 65 h. Rather than road transport, treatment effects could be assessed by housing cattle in pens while feed and water is deprived.

In the initial model, pre-transport dietary type characterized as hay, fresh forage, or a total mixed ration, was not a modifier in the model for predicting body weight loss. This categorization of pre-transport dietary type, however, was a generalization that did not account for organic matter digestibility, nutrient or energy availability or total dry matter intake of diets across studies because these variables are rarely reported in the methods of cattle transportation studies. There is evidence that forage diets create a greater weight of digesta within the GIT compared to concentrate diets in cattle (Bailey 1986; Warriss 1990). In addition, the digestibility of forage diets determines the retention rate within the rumen, such that differences in retention time have been reported from 17 h for ryegrass (*Lolium Perenne*) hay, to 36 h for speargrass (*Heteropogon contortus*) hay, and may influence GIT digesta weight (Panjaitan *et al.* 2010). I hypothesize that cattle consuming a diet with a digestibility that meets their daily net energy requirements prior to transportation, will minimize body weight loss during the journey. Further studies are recommended to understand if pre-transport diet can modify body weight loss.

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Data availability. Data used to generate the results in this manuscript are available.

Declaration of use of AI. AI was used to help find R code for the multilevel meta-regression analysis and R code for testing model assumptions (normality and linearity). AI was not used to analyze the data.

Conflicts of interest. The author declares that she has no conflicts of interest.

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