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Effects of organic trace mineral supplementation on the prevalence of digital dermatitis in beef feedlot cattle

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ABSTRACT

Objective: The aim of the study was to evaluate the effects of organic trace mineral (OTM) supplementation (Availa Plus, Zinpro Corporation) on the prevalence of digital dermatitis (DD) and growth performance in feedlot beef cattle.

Materials and Methods: A blinded, randomized, controlled field study in a commercial beef cattle feedlot was performed for 11 mo. The study was conducted in 2 phases: the adaptation phase comprised the initial 60 d of feeding the control (CON) and OTM supplements, and the postadaptation phase continued until cattle were sent to slaughter. A total of 1,120 beef heifers were enrolled in the study distributed over 8 pens. The CON and OTM supplements were fed in their respective TMR.

Results and Discussion: Regression analysis at the animal level indicated that during the postadaptation phase, there was a significantly lower rate of increase in DD lesions in the OTM group compared with the CON group. However, the pen-level analysis revealed that there were no statistically significant differences in DD lesions between the CON and OTM groups during the postadaptation phase.

The analysis of hot carcass weight, centered around the mean, revealed that the OTM supplementation was significantly associated with an increase of 9.7 kg (2.9–16.5 95% CI) above the centered hot carcass weight per head at slaughter compared with cattle fed the CON diet. Centering around the mean was performed by subtracting the mean hot carcass weight from each hot carcass weight value in the data set.

Implications and Applications: The OTM supplementation may help prevent DD and increase performance of beef feedlot cattle.

Key words: beef cattle, digital dermatitis, organic trace minerals, lameness

INTRODUCTION

Bovine digital dermatitis (**DD**) is an infectious disease of cattle characterized by circumscribed ulcerative lesions of the skin near the heel-horn border of the foot (Blowey and Sharp, 1988; Read and Walker, 1998). Digital dermatitis is the leading cause of lameness in the cattle industry worldwide, with significant economic and welfare consequences. However, the pathogenesis of DD in beef cattle has not been widely reported or studied. Kulow et al. (2017) recently reported that severe outbreaks of lameness are caused by DD in finishing beef cattle resulting in reduced feed efficiency and compromises to cattle well-being. The awareness and detection of DD lesions in beef cattle has increased considerably in the last 15 yr (Plummer and Krull, 2017).

Information regarding prevention and control of DD in beef cattle is limited, and beef producers are increasingly becoming aware of the need for DD management and mitigation strategies. The current DD control and treatment strategies in lactating dairy cattle involve chemical footbaths and frequent monitoring in the parlor or pen to identify active lesions requiring treatment with topical antibiotics (Shearer et al., 2015; Solano et al., 2015). These mitigation strategies usually require repeated applications and are difficult to implement in a feedlot setting. Likewise, the agents typically used in these strategies are also problematic to the environment and worker safety (carcinogenic chemicals and antimicrobial resistance) (Salam and El-Fadel, 2008; Doane and Sarenbo, 2014; Orsel et al., 2018). Producers, nutritionists, feed manufactures, veterinarians, and scientists have shown a strong interest in

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the role of trace minerals in animal production. Adequate trace mineral intake and absorption are essential for numerous metabolic functions including pathogenic challenge immune response, reproduction, and growth (Bortoluzzi et al., 2020; Gombart et al., 2020; Harvey et al., 2021). Recently, there has been significant focus on the importance of trace mineral supplementation in improving skin integrity and optimizing the animal's immune response to DD (Gomez et al., 2014; Zhao et al., 2015; Spears and Engle, 2016). Trace mineral supplementation is an adaptable approach that could be used to aid in the prevention of DD on beef feedlots.

The aim of this study was to evaluate the efficacy of an organic trace mineral (**OTM**) supplement on the prevalence and severity of DD lesions in feedlot cattle and its effects on growth performance and carcass yield. We hypothesized that supplementing the diet with OTM would significantly reduce the occurrence of DD lesions and increase performance parameters upon slaughtering of feedlot cattle.

MATERIALS AND METHODS

Test Animal Description and Management

The trial was authorized by the University of Wisconsin–Madison Animal Care and Use Committee, protocol V01525. The randomized controlled field trail was conducted on a commercial feedlot in the upper Midwest of the United States for 11 mo from December 2014 to November 2015. Cattle used in the study were predominantly black-hided heifers that had been purchased from auction markets in Manitoba, Canada, and shipped to the study site during November 2014. Cattle were received and processed according to standard procedures used by the feedlot, which included vaccination for respiratory and clostridial disease (Bovi-Shield GOLD IFR/BVD, Zoetis; Inforce3, Zoetis; Somubac, Zoetis) and administration of an endectocide (Dectomax, Zoetis; Panacur, Merck Animal Health). During the initial 4 wk following arrival, heifers were fed starting diets of increasing dietary energy as they were transitioned to the finishing diets.

Study animals were enrolled in the study following transition to the finishing diets, approximately 30 d on feed (**DOF**) following arrival. Before enrollment, both control and OTM groups were fed the control supplement. At study initiation, heifers were evaluated based on cattle type, source, health status, and BW. Heifers were individually weighed after morning feeding in a weigh box and, based on initial BW, divided into 2 relative weight groups of light (mean BW = 272 kg, SD 24.3 kg) and heavy (mean BW = 282 kg, SD 23.8 kg) animals. Within each weight group, heifers were randomly allotted to either CON or OTM pens. A total of 1,120 beef heifers were distributed over the 8 pens (4 CON and 4 OTM supplement pens) with each pen housing approximately 140 cattle (Table 1). Cattle were housed in open soil lots with access to feed bunks on 2 sides of each pen, with approximately 45 cm of bunk space per head and 2 water troughs per pen. Cattle were offered fresh study diet feed as a TMR twice per day. Animal data collected for each individual animal included DD lesion presence, origin, coat color, production parameters, health records, and carcass information. The study was conducted in 2 phases: the adaptation phase (**APh**) comprised the initial 60 d of feeding the control and OTM supplements, and the postadaptation phase (**PAPh**) continued until cattle were sent to slaughter. Cattle were slaughtered after the last evaluation date by pen based on finished BW. Antimicrobial footbaths with 3% formalin solutions were implemented monthly, starting 2 mo after arrival. Implants were administered at 70 DOF using Revalor-IH (Merck Animal Health) in addition to vaccination with Bovi-Shield Gold IBR/BVD (Zoetis) and Vision 7 with Spur (Merck Animal Health) and Bovi-Shield Gold IBR/BVD (Zoetis) and Vision CD (Merck Animal Health) at 190 DOF.

Description of Diets and Feeding Procedures

Beginning on d 0, each set of paired feedlot pens was fed either the control (**CON**) or OTM treatment diets. The ingredient and analyzed chemical composition of the TMR diets are listed in Table 2. Formulated dietary levels for primary trace minerals as defined by their chemical source are shown in Table 3. In both treatment diets, trace minerals, vitamins, and monensin (987 mg/kg) were fed in a suspension-type liquid supplement. The OTM supplement provided AA complexed sources of copper, manganese, and zinc; cobalt glucoheptonate; and potassium iodide (Availa Plus, Zinpro Performance Minerals), which were co-supplemented with inorganic sources of these trace minerals together with a source of selenium and iodine (ethylenediamine dihydroiodide, EDDI) to formulate a DD premix (**DDP**) (Table 3). The OTM group was supplemented with Availa Plus for the entire duration of the trial. Target intake of the DDP from the OTM supplement was 28.2 mg/kg of BW guided by previous research primarily with dairy cows and heifers (Gomez et al., 2014). Dietary inclusion rate of the OTM supplement was periodically adjusted throughout the study to maintain the target DDP dose for an estimated 80% of the animals in a pen based on computer-projected BW as described in the following. The initial dose of DDP was set based on the heaviest cattle to ensure that all pens received a minimum level of 28.2 mg/kg of BW. A supplement feeding rate of approximately 3.52% of dietary DM to provide 0.50 kg·head^{-1} per day was targeted. Cattle mean BW for each pen was estimated throughout the trial using a commercial cattle management software program (CattleXpert Cattle Management Software, CattleXpert) using equations for predicting ADG (NASEM, 1984) based on calculated dietary NE_m and NE_g values. At approximate 2-wk intervals, average feed consumption of each pen was evaluated by and compared with the actual

Table 1. Pen distribution, coat color, and initial weight parameter frequencies of heifers supplemented with or without organic trace mineral[1] (n = 1,120)

Variable[2]	Control group	OTM group
No. of heifers	555	565
Pen 1 CON, no. of heifers	141	—
Pen 2 CON, no. of heifers	139	—
Pen 3 CON, no. of heifers	138	—
Pen 4 CON, no. of heifers	137	—
Pen 5 OTM, no. of heifers	—	140
Pen 6 OTM, no. of heifers	—	144
Pen 7 OTM, no. of heifers	—	140
Pen 8 OTM, no. of heifers	—	141
Coat color black, no. of heifers	282	273
Coat color other, no. of heifers	273	292
Initial weight, kg (SD)	276.7 (23.9)	276.6 (24.2)
Initial weight centered, kg (SD)	0.02 (23.9)	−0.06 (24.2)

[1]Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide.

[2]Pen = identification number of the 8 enrolled pens of cattle (CON = control pen; OTM = supplement pen); Coat color = black or other; Initial weight = initial BW at enrollment; Initial weight centered = initial BW at enrollment centered around the mean.

or computer-projected BW of each pen. Diets were formulated to exceed minimum nutrient requirements (NASEM, 2000). As DMI and BW increased with DOF, inclusion rate for DDP into the supplement was periodically increased to maintain a constant feeding rate of 28.2 mg/kg of BW. Monensin (Rumensin; Elanco Animal Health) was fed to all cattle in compliance with approved uses and at levels consistent between each treatment (33.6 mg/kg of BW). Approximately, 30 d before shipping, all heifers were fed ractopamine hydrochloride (Optaflexx; Elanco Animal Health) to provide 300 mg of ractopamine per animal per day. Control and OTM study diets were sampled monthly throughout the study and sent to a commercial analytical laboratory (ServiTech Laboratory) for nutrient concentration analysis.

Evaluation of Prevalence and Severity of DD Lesions

Cattle were evaluated for DD lesions at 4 time points during the study period, either with a restraint chute or in a sorting alley during so-called alley checks. Investigators responsible for evaluation of lesions were blinded to pens assigned to the CON and OTM supplement groups. During alley checks, groups of 3 to 5 heifers were herded into an alleyway allowing for visual observation and scoring of the hind feet by a single trained investigator. The DD lesions were scored based on DD lesion type using the M-stage DD classification system described by Döpfer et al. (1997) and Berry et al. (2012). The M-stages were used together with signs of chronicity compiled into the following stages: M0, M4H, M4P, M2 and M2P. The M-stage DD classification system is as follows: cattle with normal digital skin were classified as **M0**; chronic lesions characterized by a thickened epithelium (hyperkeratosis) were classified as **M4H**; chronic lesions characterized by proliferative growth of the epithelium were classified as **M4P**; active ulcerative or granulomatous lesions $\geq$20 mm in diameter were classified as **M2**; and active ulcerative or granulomatous lesions with proliferative growth were classifieds as **M2P** (Figure 1). The letter H represents hyperkeratotic, and the letter P represents the proliferative aspect of the lesion surfaces. The most severe DD score per heifers' 2 hind feet and evaluation day was recorded using the following severity hierarchy of M-stages: M0 $<$ M4H $<$ M4P $<$ M2 $<$ M2P. Cattle were also categorized into a cattle type group based on the recurrence of M2 lesions as follows: cattle type 1—heifers that never developed M2 lesions; cattle type 2—heifers that developed M2 lesions only once during the study period; and cattle type 3—heifers that developed M2 lesions repeatedly during the study period (Döpfer et al., 2004; Holzhauer et al., 2008).

Statistical Analysis for DD Outcomes

The performance of bivariable and multivariable analyses were used to analyze the outcomes at the animal level and evaluate the study phase (APh or PAPh) comparisons. Pen-level analysis was also performed using bivariable and multivariable analyses for the PAPh phase. Statistical analyses were conducted using R version 4.0.5 (R Core Team, 2021). Backward stepwise elimination was used to select covariates for the multivariable logistic regression models for predicting the DD lesion outcomes

Table 2. Ingredient and analyzed composition of the TMR study diets fed to the control (CON) and organic trace mineral (OTM[1]) groups

Item	Diet 1	Diet 2	Diet 3	Diet 4
Days fed	3	82	134	121
Ingredient, % of DM				
High-moisture corn	17.7	23.4	46.3	55.7
Suspension supplement[2]	3.4	3.4	3.4	3.5
Steep liquor	10.6	16.4	16.3	16.2
Glycerin	3.1	4.6	—	—
Oat hulls	22.6	16.4	6.3	—
Ground corn stalks	14.8	13.7	13.1	12.4
Wet distillers grains with solubles	11.3	6.2	4.4	9.0
Wet corn gluten feed	16.5	15.9	10.2	3.2
Total	100.0	100.00	100.0	100.0
Analyzed nutrient values[3]	CON		OTM	
DM, %	58.0 ± 2.6		58.3 ± 3.0	
CP, %	13.8 ± 1.0		13.9 ± 0.9	
ADF, %	14.5 ± 4.3		14.9 ± 4.0	
Calcium, %	0.7 ± 0.1		0.7 ± 0.1	
Phosphorus, %	0.6 ± 0.1		0.6 ± 0.1	
Magnesium, %	0.26 ± 0.03		0.26 ± 0.02	
Potassium, %	1.2 ± 0.1		1.3 ± 0.1	
Sodium, %	0.37 ± 0.08		0.39 ± 0.07	
Sulfur, %	0.4 ± 0.1		0.3 ± 0.1	
Copper, mg/kg	20.0 ± 3.0		19.0 ± 2.0	
Iron, mg/kg	421.0 ± 106.0		519.0 ± 135.0	
Manganese, mg/kg	62.0 ± 9.0		102.0 ± 9.0	
Zinc, mg/kg	97.0 ± 16.0		124.0 ± 11.0	

[1]Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide.

[2]The CON and OTM diets provided on average 3,587 IU/kg vitamin A; 359 IU/kg vitamin D; 10.3 IU/kg vitamin E; 25.2 mg/kg thiamine mononitrate; and 33.6 mg/kg monensin sodium.

[3]Values are overall mean ± SD of analytical values from approximately 33 feed samples for the CON and OTM groups collected and submitted throughout the study.

with the statistical significance at the 95% CI. The variable **M2M4** was created by joining findings of lesion and chronicity (M2, M2P, M4H, and M4P) into one category to contrast with the M0 reference group. The M2M4 variable was positive if an animal was observed to have any type of DD lesion (M2, M2P, M4H, and M4P) and was negative if an animal was never observed to have any type of DD lesion during the study phases. The initial model equation (Equation 1) for the multiple variable logistic regressions for the M2M4 outcome compared with the reference level is as follows:

$$\begin{aligned} \text{M2M4} &= \text{intercept} + \text{Phase} + \text{Group} + \text{CattleType} \\ &+ \text{EvalDOF} + \text{InitialWTc} + \text{CoatColor} + \text{ADG} + \text{Pen} \\ &+ \text{Group} \times \text{CattleType} + \text{Phase} \times \text{Group} \\ &+ \text{Group} \times \text{EvalDOF} + \text{Group} \times \text{InitialWTc} \\ &+ \text{Phase} \times \text{EvalDOF} + \text{error}, \end{aligned} \quad [1]$$

where M2M4 = M2 and M4 lesions; Phase = APh or PAPh, Group = OTM or CON; CattleType = assigned based on history of M2 lesions (type 1 = no M2 lesions; type 2 = 1× M2 lesions; type 3 = multiple M2 lesions during trial period); EvalDOF = days on feed at evaluation date; InitialWTc = initial BW at enrollment centered around the mean; CoatColor = color of coat (where coat color is black or other); Pen = identification number of the 8 enrolled pens of cattle. The variable Pen was included in Equation 1 as a fixed effect compared with a random effects term. A log likelihood ratio test indicated that the random Pen effect did not improve the goodness of fit of the models significantly; therefore, the fixed Pen effect was preferred to the random effects model as shown in Equation 1. Centering around the mean was performed by subtracting the mean from each value of the initial BW variable in the data set. Interaction terms between Phase and Group, Phase and EvalDOF, Group and CattleType, Group and EvalDOF, and Group and InitialWTc were

Table 3. Formulated levels of added trace minerals by source (DM basis; CON = control diet; OTM = treatment diet[1])

Trace mineral level by source	Diet 1	Diet 2	Diet 3	Diet 4
CON				
Copper, mg/kg				
Inorganic source—copper sulfate	8.9	8.9	8.9	9.2
AA complex[2]	7.0	7.0	7.0	7.3
Total	15.9	15.9	15.9	16.5
Manganese, mg/kg				
Inorganic source—manganese sulfate	30.8	30.7	30.7	31.9
Zinc, mg/kg				
Inorganic source—zinc sulfate	51.8	51.6	51.7	53.7
Polysaccharide complex	18.6	18.5	18.6	19.3
Total, mg/kg	70.4	70.1	70.3	73.0
Cobalt,[3] mg/kg	0.1	0.1	0.1	0.1
Iodine,[4] mg/kg	3.7	3.7	3.7	3.8
Sodium selenium, mg/kg	0.2	0.2	0.2	0.2
OTM				
Copper, mg/kg				
Inorganic source—copper sulfate	2.1	2.2	2.6	2.8
AA complex	9.7	10.0	12.6	13.7
Total	11.8	12.2	15.2	16.5
Manganese, mg/kg				
Inorganic source—manganese sulfate	37.7	38.8	48.8	53.2
AA complex	19.3	19.9	25.2	27.5
Total	57.0	58.7	74.0	80.7
Zinc, mg/kg				
Inorganic source—zinc sulfate	31.3	32.2	40.5	44.1
AA complex	57.9	59.7	75.5	82.5
Total	89.2	91.9	116.0	126.6
Cobalt,[3] mg/kg	1.0	1.0	1.3	1.4
Iodine,[4] mg/kg	7.4	5.5	4.9	5.3
Sodium selenium, mg/kg	0.3	0.3	0.4	0.5

[1]Availa Plus (Zinpro Corporation) providing 6.0% zinc, 2.0% manganese, and 1.0% copper as AA complexes with 0.10% cobalt from cobalt glucoheptonate and 0.13% iodine from potassium iodide.

[2]The source for CON diets was Availa Cu 100 (Zinpro Corporation).

[3]Cobalt carbonate for CON diets and cobalt carbonate and cobalt glucoheptonate for OTM diets.

[4]Supplemental iodine provided from potassium iodine for the CON diets and ethylenediamine dihydroiodide (EDDI) in OTM diets.

introduced to the initial model and were eliminated if not significant. The fit of the final fixed effect models was assessed based on Akaike information criterion. The final models for the M2M4 lesion outcome for the PAPh only and APh and PAPh were as follows, respectively:

Equation [2] PAPh only:

$$\text{M2M4} = \text{intercept} + \text{Group} + \text{CattleType} + \text{EvalDOF} + \text{InitialWTc} + \text{Pen} + \text{Group} \times \text{EvalDOF} + \text{Group} \times \text{InitialWTc} + \text{Pen} + \text{error}, \quad [2]$$

Equation [3] APh and PAPh:

$$\text{M2M4} = \text{intercept} + \text{Phase} + \text{Group} + \text{Pen} + \text{CattleType} + \text{InitialWTc} + \text{Phase} \times \text{Group} + \text{Group} \times \text{EvalDOF} + \text{Group} \times \text{InitialWTc} + \text{Phase} \times \text{EvalDOF} + \text{error}. \quad [3]$$

Odds ratios (**OR**) were determined by exponentiation of the estimates for main effects.

Pen-level analysis was performed using logistic regression for the data summarized from the PAPh phase using the following equation.

Equation [4] pen-level PAPh only:

$$\text{M2M4} = \text{intercept} + \text{Group} + (1|\text{Pen}) + \text{error}. \quad [4]$$

The regression model was fitted at the pen level as a unit of observation using glmmPQL package in R. Logistic regression for rates of DD lesions at the pen level for the PAPh phase were weighted by the number of observations, and pen was fitted as a random effect on the intercept.

Statistical Analysis for Production Data

Analysis of the production data of hot carcass weight centered (**HCWc**) was performed to determine association with DD and other potential risk factors. Statistical analyses were conducted using R version 4.0.5 (R Core Team, 2021). Centering around the mean was performed by subtracting the mean hot carcass weight from each hot carcass weight value in the data set. Centering around the mean was also performed for the initial weight variable. A backward stepwise elimination process was used to select covariates of the final linear regression model for predicting the production parameter, HCWc, and the statistical significance was declared at the 95% confidence level. Goodness-of-fit evaluation was accomplished using decreasing Akaike information criterion values during backward stepwise elimination. The initial linear model equation for the production data HCWc was as follows:

$$\text{HCWc} = \text{intercept} + \text{M2M4} + \text{Group} + \text{DOF} + \text{InitialWTc} + \text{CattleType} + \text{CoatColor} + \text{ADG} + \text{Pen} + \text{Group} \times \text{InitialWTc} + \text{error}, \quad [5]$$

where HCWc = hot carcass weight centered around the mean; M2M4 = M2 lesions or M4 lesions as opposed to M0; Group = OTM or CON; DOF = days on feed; InitialWTc = initial BW at enrollment centered around the mean; CattleType = assigned based on history of M2 lesions (type 1 = no M2 lesions, reference; type 2 = 1× M2 lesions; type 3 = multiple M2 lesions during trial period); CoatColor = color of coat (where coat color is black or other); and Pen = identification number of the enrolled pens of cattle used as fixed effect. The interaction terms of the model equation were between Lesion and InitialWTc, Lesion and DOF, and DOF and InitialWTc. The final model for the HCWc outcome is listed as follows:

$$\text{HCWc} = \text{intercept} + \text{M2M4} + \text{Group} + \text{InitialWTc} + \text{CattleType} + \text{Pen} + \text{Group} \times \text{InitialWTc} + \text{error}. \quad [6]$$

RESULTS AND DISCUSSION

A total of 1,120 heifers from a commercial beef cattle feedlot were enrolled in the study. During the study period, 9 heifers died from respiratory disease, for reasons unrelated to treatment (6, APh and 3, PAPh). There was no difference in mortality attributable to treatment group. The cattle (n = 1,111) were evaluated for DD lesions at 4 time points during the study period resulting in 4,295 observations for analysis. Table 4 displays the frequencies and relative percentages of M-stage lesions during the APh and PAPh phases by intervention group. The associations were explored using relative risks. The APh prevalence for M2M4 lesions in the CON and OTM groups was 1.8 and 2.3%, respectively. There was no statistically significant difference in the frequency of M2M4 lesions in the CON and OTM groups during the APh phase, as tested using a bivariate analysis ($P = 0.42$). The prevalence for M2M4 lesions during PAPh in the CON and OTM groups was 13.4 and 11.3%, respectively. The relative risk for developing M2M4 lesions versus no lesions in the PAPh was 6.12 (4.90–7.64 95% CI) times greater ($P < 0.05$) compared with the APh, indicating that there was an overall significant increase in M2M4 lesions in both groups from the APh to the PAPh. There were relatively fewer M2M4 lesions in the OTM group ($P < 0.05$) compared with the

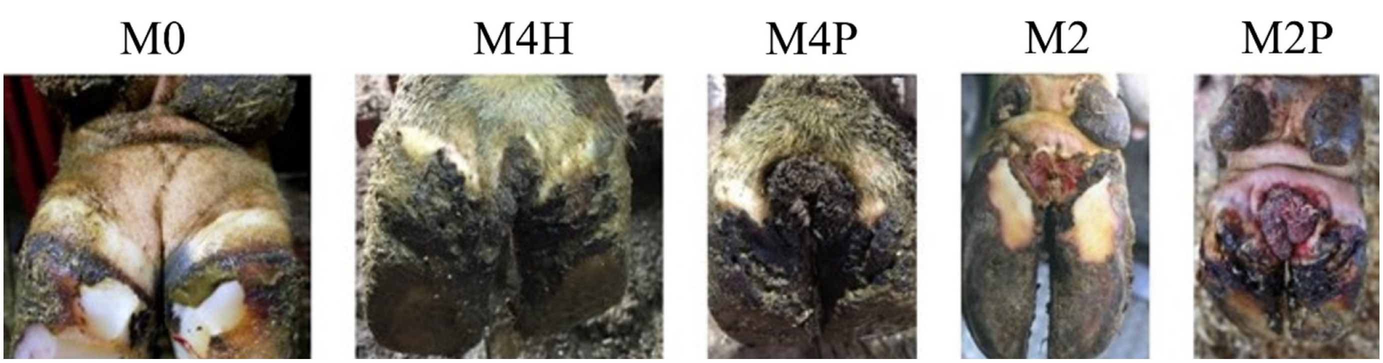

Figure 1. M-stages for the clinical stages of digital dermatitis used in this study. M0 = cattle with normal digital skin; M4H = chronic lesions characterized by a thickened epithelium (hyperkeratosis); M4P = chronic lesions characterized by proliferative growth of the epithelium; M2 = active ulcerative or granulomatous lesions ≥20 mm in diameter; M2P = active ulcerative or granulomatous lesions, ≥20 mm in diameter, with proliferative growth. The letter H represents hyperkeratotic, and the letter P represents the proliferative aspect of the lesion surfaces.

Table 4. Frequencies and relative percentages of digital dermatitis lesions[1] of cattle supplemented with or without organic trace mineral (OTM[2]) during the adaptation phase (APh, n = 2,081) and postadaptation phase (PAPh, n = 2,214) of the study

Item	M0	M2	M4	M2M4[3]
APh				
Control, no. of observations (%)	972 (46.7)	3 (0.1)	34 (1.6)	37 (1.8)
OTM, no. of observations (%)	1,025 (49.3)	3 (0.1)	44 (2.1)	47 (2.3)
PAPh				
Control, no. of observations (%)	803 (36.3)	68 (3.1)	229 (10.3)	297 (13.4)
OTM, no. of observations (%)	864 (39.0)	77 (3.5)	173 (7.8)	250 (11.3)

[1]M0 = cattle with normal digital skin; M2 = active ulcerative or granulomatous lesions ≥20 mm in diameter, with or without proliferative growth; M4 = chronic lesions characterized by a thickened epithelium (hyperkeratosis), with or without proliferative growth of the epithelium; M2M4 = class that belongs to cattle having any type of lesion compared with M0, which designates no visible lesion.

[2]Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide.

[3]There was no significant difference in the frequencies for M2M4 lesions between the CON and OTM groups during the APh ($P = 0.42$), whereas the difference between frequencies of M2M4 lesions between the CON and OTM groups was significant during the PAPh ($P < 0.05$).

CON group during the PAPh, with a relative risk of 0.83 (0.72–0.96 95% CI). The statistical significance of these findings was further explored in detail using the multivariable regression analysis.

Table 5 displays the frequencies of aggregated M-stage lesions (M4M2) during the APh and PAPh by intervention group at the pen level. As indicated previously, there was a relatively significant increase in the occurrence of M2M4 lesions from the APh to the PAPh, which was more pronounced in the CON pens compared with the OTM pens, with the exception of pen 7 OTM. The results signify that there is a need to control for the pen effect in the multivariable analysis.

Logistic Regression Models for DD Outcomes

The results illustrated in Table 6 from logistic regression Equation 2 using only the PAPh data indicate that the OTM group had a trend for fewer M2M4 lesions compared with the CON group (OR: 0.22, 95% CI: 0.04–1.18), $P = 0.077$ when correcting for covariates such as Pen, CattleType, InitialWTc, and DOF. This result was confirmed using the combined APh and PAPh data in logistic regression Equation 3.

The interactions of OTM group × DOF and OTM group × InitialWTc were significantly associated with increased M2M4 lesions, indicated by the OR of 1.01 (1.00–1.02 95%

Table 5. Pen-level frequencies of digital dermatitis lesions of cattle supplemented with (OTM[1]) or without (CON) organic trace mineral during the adaptation phase (APh, n = 2,081) and postadaptation phase (PAPh, n = 2,214) of the study

Item[2]	Pen 1 CON	Pen 2 CON	Pen 3 CON	Pen 4 CON	Pen 5 OTM	Pen 6 OTM	Pen 7 OTM	Pen 8 OTM
APh								
M0 observations, no.	238	236	260	238	249	251	271	254
M2M4 observations, no.	5	23	2	7	10	8	5	24
PAPh								
M0 observations, no.	230	202	216	155	250	225	183	206
M2M4 observations, no.	48	74	58	117	26	59	97	68

[1]Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide.

[2]M0 = cattle with normal digital skin; M2M4 = class that belongs to cattle having any type of lesion compared with M0, which designates no visible lesion.

CI) for Group × EvalDOF and the OR of 1.006 (1.002–1.011 95% CI) for Group × InitialWTc. The changes in slopes for the interaction terms Group × EvalDOF and Group × InitialWTc were numerically minor but statistically significant at the 95% confidence level. The interaction terms remained in the model to correct the Group effect for these interactions with InitialWTc and DOF (a proxy for passage of time). CoatColor could have been forced into the model to correct for potential differences in breeds; however, the term was removed because the model fit did not improve significantly by the addition of this covariate or its interaction terms. This model analyzed the effects of the OTM compared with the CON supplementation at the end of the feedlot period (PAPh), but the main effects of the OTM versus CON supplementation may occur at the earlier phase of the feedlot period. Therefore, an analysis including both phases of the study was performed, as shown in Equation [3], and the results are depicted in Table 7.

Logistic regression Equation [3] using the combined APh and PAPh data found that during the PAPh, the effect of increase probability for M2M4 lesions with increasing initial BW was more pronounced in the OTM group compared with the CON group. Therefore, ensuring that the recommended rate of the OTM supplement is provided to cattle that are heavier or have above average BW during PAPh is important. This analysis also indicates that during PAPh, there was a significantly lower increase in M2M4 lesions (OR: 0.18, 95% CI 0.08–0.40) in the OTM group compared with the CON group, $P < 0.05$. Additionally, increased DOF and increased InitialWTc in the OTM group were associated with significantly greater increases in M2M4 lesions compared with the CON group (OR: 1.013, 1.007–1.019 95% CI for DOF and OR: 1.005, 1.001–1.009 95% CI for InitialWTc). The numeric effect estimates are minor, and the 95% CI barely exclude OR = 1. However, the effects remain in the model to correct for these effects that reflect differences in initial weight and represent a proxy for time. Finally, during PAPh as DOF increases, the rate at which M2M4 lesions increased was significantly reduced in all cattle (OR: 0.99, 95% CI 0.98–1.00 for PhasePAPh × DOF). Although the effect is significantly different from one, OR = 1 is barely excluded from the 95% CI. This means that slight modifications in observations could alter these estimates into becoming nonsignificant.

Given the findings, caution is advised regarding the preventive effect of OTM against DD in cattle with an initial weight above average of the group, particularly at low DOF. The preventive effect of OTM with regard to a decrease in M2M4 lesions is more pronounced for cattle with lower or below average initial weights, in this study. This may be due to feeding rates of OTM that are easily below the feeding rates necessary for cattle with above average

Table 6. Logistic regression comparing the M2M4 lesion outcome (cattle having any type of lesion) with no lesion (M0) for the postadaptation phase (n = 2,214)

Variable[1]	Estimate	SE	*z*-value	Pr(>|*z*|)	OR[2]	2.50%[2]	97.50%[2]
Intercept	−0.805	0.577	−1.395	0.163	0.447	0.144	1.385
GroupOTM	−1.513	0.855	−1.769	0.077	0.220	0.041	1.177
CattleType2	2.082	0.157	13.229	0.000	8.018	5.896	10.910
CattleType3	5.038	1.027	4.904	0.000	154.101	20.596	1,153.920
EvalDOF	−0.004	0.003	−1.659	0.097	0.996	0.990	1.002
InitialWTc	−0.001	0.001	−0.942	0.346	0.999	0.997	1.001
Pen 2 CON	0.275	0.223	1.238	0.216	1.318	0.850	2.038
Pen 3 CON	0.24	0.227	1.056	0.291	1.272	0.815	1.984
Pen 4 CON	1.049	0.217	4.843	0.000	2.855	1.866	4.368
Pen 5 OTM	−0.864	0.273	−3.164	0.002	0.422	0.247	0.720
Pen 6 OTM	−0.19	0.226	−0.84	0.401	0.827	0.531	1.288
Pen 7 OTM	0.409	0.211	1.939	0.052	1.505	0.995	2.276
Pen 8 OTM	NA	NA	NA	NA	NA	NA	NA
Group × EvalDOF	0.008	0.004	2.009	0.046	1.008	1.000	1.016
Group × InitialWtC	0.006	0.002	2.970	0.003	1.006	1.002	1.011

[1]GroupOTM = organic trace mineral [OTM, Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide], reference = control (CON); CattleType2 = animals with 1× M2 lesion during the trial duration (reference = CattleType1—no M2 lesions during the duration of the trial); CattleType3 = animals with multiple M2 lesions during the trial duration (reference = CattleType1); M2 = active ulcerative or granulomatous lesions ≥20 mm in diameter, with or without proliferative growth; EvalDOF = days on feed at evaluation date; InitialWTc = initial BW at enrollment centered around the mean; Pen = identification number of the 8 enrolled pens of cattle (reference = Pen 1 CON).

[2]Parameter estimates were transformed in odds ratios (OR) and 95% CI by exponentiation.

Table 7. Logistic regression analysis comparing the M2M4 lesion outcome (cattle having any type of lesion) to no lesion (M0) for the adaptation and postadaptation phases (n = 4,295)

Variable[1]	Estimate	SE	*z*-value	Pr(>|*z*|)	OR[2]	2.50%[2]	97.50%[2]
Intercept	−4.622	0.450	−10.264	0.000	0.010	0.004	0.023
PhasePAPh	4.401	0.581	7.574	0.000	81.532	26.432	258.536
GroupOTM	−10.430	224.200	−0.047	0.963	0.000	NA	5.33E+10
CattleType2	1.840	0.132	13.939	0.000	6.297	4.865	8.165
CattleType3	2.852	0.310	9.192	0.000	17.322	9.488	32.096
EvalDOF	0.004	0.004	1.079	0.281	1.004	0.997	1.011
InitialWTc	−0.001	0.001	−0.388	0.698	0.999	0.997	1.002
Pen 2 CON	0.538	0.201	2.682	0.007	1.713	1.160	2.550
Pen 3 CON	0.121	0.215	0.560	0.575	1.129	0.740	1.720
Pen 4 CON	0.872	0.201	4.338	0.000	2.392	1.619	3.560
Pen 5 OTM	8.851	224.200	0.039	0.969	6,981.367	0.000	NA
Pen 6 OTM	9.268	224.200	0.041	0.967	10,593.544	0.000	NA
Pen 7 OTM	9.668	224.200	0.043	0.966	15,803.710	0.000	NA
Pen 8 OTM	9.688	224.200	0.043	0.966	16,122.966	0.000	NA
PhasePAPh × GroupOTM	−1.732	0.418	−4.143	0.000	0.177	0.077	0.399
GroupOTM × EvalDOF	0.013	0.003	4.059	0.000	1.013	1.007	1.019
GroupOTM × InitialWTc	0.005	0.002	2.628	0.009	1.005	1.001	1.009
PhasePAPh × EvalDOF	−0.011	0.004	−2.874	0.004	0.989	0.982	0.997

[1]PhasePAPh = postadaptation phase (reference = adaptation phase); GroupOTM = organic trace mineral [OTM, Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide], reference = control (CON); CattleType2 = animals with 1× M2 lesion during the trial duration (reference = CattleType1—no M2 lesions during the duration of the trial); CattleType3 = animals with multiple M2 lesions during the trial duration (reference = CattleType1); M2 = active ulcerative or granulomatous lesions ≥20 mm in diameter, with or without proliferative growth; EvalDOF = days on feed at evaluation date; InitialWTc = initial BW at enrollment centered around the mean; Pen = identification number of the 8 enrolled pens of cattle (reference = Pen 1 CON); PhasePAPh × GroupOTM = interaction term; GroupOTM × EvalDOF = interaction term; GroupOTM × InitialWTc = interaction term; PhasePAPh × EvalDOF = interaction term.

[2]Parameter estimates were transformed in odds ratios (OR) and 95% CI by exponentiation.

BW. Special care needs to be taken to supply sufficient OTM to cattle that are heavier or have above average BW from the start to benefit from the preventive effect of OTM supplementation against M2M4 lesions. Providing the optimal concentrations of trace minerals to livestock according to requirements that change during the rapid growth and development of the animal and the production cycle is necessary for ideal health and performance benefits (López-Alonso, 2012).

The analysis of the interaction term for phase and DOF (Phase × EvalDOF) indicated that during PAPh, increased DOF was associated with significantly greater probability for M2M4 lesions. However, the effect of EvalDOF having an increased probability of M2M4 lesions was more pronounced during the APh, whereas there was only a minor decreasing slope during the PAPh.

The beneficial effect of preventing M2M4 lesions using OTM supplementation appears to be more prominent early during the feeding period (APh) and less so during the PAPh. Awareness of DD prevention early during the feeding period should also result in improved hygiene, periodic usage of disinfecting footbaths, pen hygiene management, and topical treatment of active M2 lesions in a restraining chute. The results suggest that OTM supplementation with the aim to prevent DD starts best early during the feeding period. Supplementing increased levels of trace minerals for the prevention and control of DD does not have an immediate effect upon preventing DD. The results of this study indicate that to delay severity and frequency of DD lesions, supplementation with the OTM product needs to start early during the finishing period. Adjusting the concentration of OTM supplementation according to cattle BW to prevent undersupplementation in heavier cattle is essential in delaying DD outbreaks and reducing the severity of the lesions (Kulow et al., 2017).

The current trial confirms the findings from the previous trial by Kulow et al. (2017) regarding the preventive effect of OTM supplementation on M2 and M4 lesions. However, the current trial is an improvement of the Kulow et al. (2017) trial because the current trial has similar starting levels of M2 and M4 lesions compared with the previous trial, where the OTM group started at significantly higher levels of M2 and M4 lesions compared with the CON group.

The trace minerals zinc, iron, copper, manganese, and selenium are essential for normal immune function and disease resistance (Spears and Engle, 2016). Organic-source trace minerals have been shown to have increased bioavailability and retention compared with inorganic-source trace minerals (Nollet et al., 2007; Khatun et al., 2019). The skin is the first line of defense in the immune system. Zinc and manganese are key components for maintaining epithelial tissue integrity (Gombart et al., 2020). Research by Gomez et al. (2014) in gestating dairy heifers revealed that a diet with elevated OTM and iodine aided in the control of DD and reduced the size of active M2 lesions.

Pen-Level Analysis Equation 4

Analysis results at the pen level, with a random pen effect, revealed no statistically significant differences in M2 and M4 lesions between the CON and OTM group during the PAPh of the study. Therefore, the trending toward significance effect of the OTM supplement for reducing the number of M2M4 lesions developing in the OTM group compared with the CON group during the PAPh has been established at the individual animal level of analysis corrected for pen effect using a fixed effects model (see Equation 2).

Linear Regression Model for Production Parameter HCWc

A total of 995 cattle had recorded slaughter data, indicating that 125 cattle were missing recorded slaughter data. All the cattle with missing slaughter data originated from the OTM group. They were shipped for slaughter without the investigator's knowledge, and no HCW were recovered by error. The averages and frequencies of the variables for the analysis of the production parameter HCWc (hot carcass weight, centered around the mean) are displayed in Table 8. The linear regression results from Equation 6 are depicted in Table 9. The main effects for the HCWc model indicate that the HCWc values were significantly above the average HCW for cattle that received the OTM supplement. The OTM group compared with the CON group had an average increase of 9.7 kg (2.9–16.5 95% CI) HCW above the average HCWc per animal (Table 9). Providing adequate levels of bioavailable trace minerals can improve growth performance and enhance beef cattle profitability reflected by optimum gain and efficient feed conversion (López-Alonso, 2012; Kenny et al., 2018). Cattle with an M2M4 lesion had an average 4.8 kg (0.5–9.1 95% CI) above HCWc compared with cattle with no lesions, suggesting that the heavier cattle had more M2M4 lesions when in the OTM group compared with the CON group. This supports the concept that the trace mineral supplement must be fed according to the needs of the heavier cattle from the initial start of the finishing period. Feedlot animals are especially susceptible to DD due to the high risk during confinement (Sogstad et al., 2005). Typically, heavy cattle close to marketing are frequently affected by lameness caused by DD (Plummer and Krull, 2017). In addition, cattle in this study with above average InitialWTc were significantly associated with increased

Table 8. Average production parameters (hot carcass weight, initial weight, and days on feed), cattle type, and lesion frequencies and percentages of cattle supplemented with (OTM[1]) or without (CON) organic trace mineral (n = 995)

Production parameter[2]	CON group	OTM group
No. of heifers	555	440
HCWc, kg (SD)	−2.2 (30.0)	2.7 (28.1)
InitialWTc, kg (SD)	−0.2 (21.5)	−0.164 (23.9)
DOF, d (SD)	353.6 (32.6)	353.6 (32.5)
CattleType1, no. of heifers (%)	503 (90.6)	381 (86.6)
CattleType2, no. of heifers (%)	46 (8.3)	51 (11.6)
CattleType3, no. of heifers (%)	6 (1.1)	8 (1.8)
M0 lesions, no. of heifers (%)	337 (60.7)	334 (75.9)
M2M4 lesions, no. of heifers (%)	218 (39.3)	106 (24.1)

[1]Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide.

[2]HCWc = hot carcass weight at the time of slaughter centered around the mean; InitialWTc = initial BW at enrollment centered around the mean; DOF = days on feed; CattleType1 = animals that never develop M2 lesions during the trial duration; CattleType2 = animals with 1× M2 lesion during the trial duration; CattleType3 = animals with multiple M2 lesions during trial duration; M2 = active ulcerative or granulomatous lesions ≥20 mm in diameter, with or without proliferative growth; M2M4 = class that belongs to cattle having any type of lesion compared with M0, which designates no visible lesion.

Table 9. Linear regression analysis for the outcome production variable hot carcass weight centered[1] for cattle supplemented with (OTM[2]) or without (CON) organic trace mineral (n = 995)

Variable[3]	Estimate	SE	*t*-value	Pr(>|*t*|)
Intercept	−7.747	2.243	−3.454	0.001
M2M4	4.816	2.185	2.205	0.028
GroupOTM	9.702	3.454	2.808	0.005
CattleType2	1.339	3.284	0.408	0.683
CattleType3	−5.075	7.958	−0.638	0.524
InitialWTc	0.078	0.026	2.940	0.003
Pen 2 CON	3.192	3.493	0.914	0.361
Pen 3 CON	8.813	3.356	2.626	0.009
Pen 4 CON	6.512	3.522	1.849	0.065
Pen 5 OTM	1.981	4.050	0.489	0.625
Pen 6 OTM	−2.161	3.899	−0.554	0.580
Pen 7 OTM	−1.183	3.867	−0.306	0.760
Pen 8 OTM	NA	NA	NA	NA
GroupOTM × InitialWTc	0.052	0.052	1.377	0.169

[1]Hot carcass weight centered = hot carcass weight at the time of slaughter centered around the mean.

[2]Availa Plus (Zinpro Performance Minerals) is a trace mineral product containing a combination of complexed zinc, manganese, copper, and cobalt, plus potassium iodide.

[3]M2M4 = class that belongs to cattle having any type of lesion compared with M0, which designates no visible lesion (reference = M0); GroupOTM = Availa Plus (Zinpro Performance Minerals; reference = control); CattleType2 = animals with 1× M2 lesion during the trial duration (reference = CattleType1—no M2 lesions during the duration of the trial); CattleType3 = animals with multiple M2 lesions during the trial duration (reference = CattleType1); M2 = active ulcerative or granulomatous lesions ≥20 mm in diameter, with or without proliferative growth; InitialWTc = initial BW at enrollment centered around the mean; Pen = identification number of the 8 enrolled pens of cattle (reference = Pen 1 CON); GroupOTM × InitialWTc = interaction term.

HCWc compared with below average InitialWTc. Cattle exhibiting above the average initial weight were associated with an increase of 0.08 kg (0.03–0.13 95% CI) above the average HCWc.

APPLICATIONS

Digital dermatitis is an emerging threat in feedlot cattle, with animal welfare and economic consequences. Control and prevention strategies for DD in beef feedlots should focus on good hygiene, screening and prompt treatment of active DD lesions, and proper nutrition to ensure proper skin–environment barriers and optimal immune response to DD pathogens. The results of the current study suggest a role for OTM supplementation in reducing DD and increasing performance of beef cattle. These are key components to a successful production strategy in beef feedlot cattle during the finishing period.

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