*Translational Animal Science*, 2022, **6**, 1–10
https://doi.org/10.1093/tas/txac105
Advance access publication 3 August 2022
**Fetal Programming**

# Monensin supplementation during late gestation of beef cows alters maternal plasma concentrations of insulin-like growth factors 1 and 2 and enhances offspring preweaning growth

**Marcelo Vedovatto, Vinicius Izquierdo, Elizabeth Palmer, Rhaiza A. Oliveira, Hiran M. Silva, João M. B. Vendramini, and Philipe Moriel[1]**

IFAS—Range Cattle Research and Education Center, University of Florida, Ona, FL 33865, USA
[1]Corresponding author: pmoriel@ufl.edu

## ABSTRACT

This study evaluated the effects of maternal prepartum supplementation of dried distillers grains (**DDG**), with or without monensin addition, on maternal performance and physiology and offspring preweaning growth. On day 0 (approximately 197 ± 4 d prepartum), 150 multiparous, Brangus crossbred beef cows were ranked by their initial body weight (**BW**; 524 ± 51 kg) and body condition score (**BCS**; 5.0 ± 0.63), and then randomly assigned into one of 15 bahiagrass (*Paspalum notatum*) pastures (10 cows and 8.1 ha/pasture). Maternal treatments were randomly assigned to pastures (5 pastures/treatment) and consisted of no prepartum supplementation of DDG (**NOSUP**) or supplementation of DDG at 1 kg/cow/d (dry matter basis; **DM**) added with 0 mg (**SUP**) or 200 mg/d of monensin (**SUPMO**) from days 0 to 77. Effects of maternal treatment and maternal treatment × day of the study were not detected ($P \geq 0.63$) for any forage data. Cow BCS on day 35 and near calving (day 77) did not differ ($P \geq 0.19$) between SUP and SUPMO cows but both groups had greater ($P \leq 0.001$) BCS compared with NOSUP cows. Cow BCS at the start of the breeding season (day 142) and on day 168 were the greatest ($P < 0.0001$) for SUPMO cows, least for NOSUP cows, and intermediate ($P \leq 0.02$) for SUP cows. Maternal plasma concentrations of glucose did not differ ($P \geq 0.25$) among treatments. Plasma concentrations of insulin-like growth factor 1 (**IGF-1**) on day 77 were the least for NOSUP cows ($P \leq 0.05$) and did not differ ($P = 0.66$) between SUP and SUPMO cows, whereas plasma concentrations of IGF-2 on days 35 and 77 were greatest ($P \leq 0.05$) for SUPMO cows and did not differ ($P \geq 0.60$) between NOSUP and SUP cows. Birth BW of first offspring did not differ ($P = 0.77$) between SUP and SUPMO calves but NOSUP calves were lighter at birth ($P \leq 0.05$) compared with SUP and SUPMO calves. Percentage of cows pregnant with a second offspring did not differ ($P = 0.72$) between SUP and SUPMO cows and were the least for NOSUP cows ($P \leq 0.05$). First offspring BW at weaning (day 325) was greatest ($P \leq 0.05$) for SUPMO calves, least for NOSUP calves, and intermediate for SUP calves. Therefore, adding monensin into prepartum DDG supplements for *Bos indicus*-influenced beef cows did not increase cow prepartum BCS but led to greatest offspring preweaning growth, likely by modulating maternal plasma concentrations of IGF-1 and IGF-2 during gestation.

## Lay summary

Supplementing protein and energy during third trimester of gestation provides an opportunity to impact fetal development and increase offspring growth performance from birth to weaning. Including feed additives, such as ionophores, into protein and energy supplements during late gestation of beef cows has been poorly explored, particularly for *Bos indicus*-influenced beef cattle. In the current study, cows were assigned to receive no precalving supplementation, precalving supplementation of protein and energy, or precalving supplementation of protein and energy added with ionophore (monensin) for 77 d during late gestation. After calving, all cows and their calves were managed similarly. Overall, cows that received precalving supplementation (with or without monensin) had greater body condition score at calving and pregnancy percentage and weaned heavier calves compared with cows that did not receive precalving supplementation. Adding monensin to maternal supplements did not improve maternal performance compared with maternal supplementation without monensin but increased preweaning growth of their offspring.

**Key words:** beef cows, indicus, monensin, offspring, supplementation

## INTRODUCTION

Increasing body condition score (BCS) of beef cows during the third trimester of gestation, via supplementation of energy and protein, provides an opportunity to modulate maternal circulating concentrations of hormones and metabolites essential for fetal growth, such as glucose and insulin-like growth factors 1 (**IGF-1**) and 2 (**IGF-2**; Bell et al., 2005; Sferruzzi-Perri et al., 2006), and enhance subsequent postnatal offspring growth (Marques et al., 2016a). The exact outcomes of maternal prepartum supplementation of protein and energy on beef offspring preweaning growth are variable (Moriel et al., 2021) and dependent on multiple factors, including supplementation timing (Palmer et al., 2022a), frequency (Izquierdo et al., 2022), carbohydrate type (Palmer et al., 2022b), and source of trace minerals source (Marques

Received May 24, 2022 Accepted July 29, 2022.

et al., 2016b). Studies evaluating the impacts of adding feed additives, such as ionophores, into prepartum supplementation of beef cows are limited (Turner et al., 1980; Walker et al., 1980; Linneen et al., 2015), particularly for *Bos indicus*-influenced beef cows reared in tropical and subtropical environments (Cooke et al., 2020).

Ionophores, such as monensin, are widely used in cattle diets to alter the ruminal microbiome, optimizing fermentation routes, and reducing the rates of digestive disorders (Marques and Cooke, 2021). Monensin supplementation may also support rumen propionate production (Sousa et al., 2022) and subsequently the circulating concentrations of glucose and IGF-1 (Vendramini et al., 2018; Moriel et al., 2019). Our hypothesis was that adding monensin into prepartum supplementation of protein and energy during late gestation of *Bos indicus*-influenced beef cows would increase cow BCS at calving, modulate maternal circulating concentrations of hormones and metabolites essential for fetal growth, and increase calf preweaning growth to levels above those observed for prepartum supplementation of energy and protein without monensin. The objectives of this study were to evaluate the effects of maternal prepartum supplementation of dried distillers grains (**DDG**), with or without monensin addition, on maternal BCS change and circulating concentrations of glucose and IGF-1 and 2, and preweaning growth performance of their offspring.

## MATERIALS AND METHODS

The current study was conducted at the University of Florida/Institute of Food and Agricultural Sciences, Range Cattle Research & Education Center, Ona, FL (27° 26′ N and 82° 55′ W) from August 2019 to July 2020. All animals were cared for according to experimental protocols approved by the Institutional Animal Care and Use Committee from University of Florida (#201910816).

### Animals and Diets

On day 0 of the study (on average 197 d prepartum), 150 multiparous, fall-calving, Brangus crossbred beef cows (mean ± standard deviation here and throughout: 8.0 ± 3.4 yr of age; <25% *Bos indicus*) were ranked by their initial body weight (**BW**; 524 ± 51 kg) and BCS (5.0 ± 0.63), and then randomly assigned into 1 of 15 bahiagrass (*Paspalum notatum*) pastures (10 cows and 8.1 ha/pasture). Maternal treatments were randomly assigned to pastures (5 pastures/treatment) and consisted of no prepartum supplementation of DDG (**NOSUP**) or DDG supplementation at 1 kg/cow/d (dry matter basis; **DM**) added with 0 mg (**SUP**) or 200 mg/d of monensin (**SUPMO**) from days 0 to 77. The supplemental amount of DDG was selected based on previous studies demonstrating improved offspring preweaning growth following similar maternal supplementation amount and timing and geographical location as utilized herein (Palmer et al., 2020, 2022a). The monensin dosage utilized herein was recommended by the company and previously reported to increase offspring postnatal growth following monensin supplementation during late gestation of *Bos taurus* beef cows (Linneen et al., 2015). Average nutritional composition of DDG was (DM basis): 89.1% DM, 33.1% crude protein (**CP**), 82.5% total digestible nutrients (**TDN**), 35.2% neutral detergent fiber, 15.2% acid detergent fiber, 0.04% Ca, 1.12% P, 0.33% Mg, 1.28% K, 0.26%Na, 0.69% S, 88 mg/kg Fe, 77 mg/kg Zn, 7 mg/kg Cu, 17 mg/kg Mn, and 1.7 mg/kg Mo. Rumensin 90 (Elanco Animal Health, Greenfield, IN) was hand-mixed into DDG immediately before supplementation at equivalent amounts to achieve the recommended daily intake of 200 mg of monensin/cow. All supplements (SUP and SUPMO) were delivered to cows at 0800 h into plastic feed bunks (1 m/cow).

On day 77, treatments were terminated, and cows were randomly distributed into one of eight groups (18 to 19 cows/group) with all treatments equally represented in each group. Then, each group was randomly assigned to two bahiagrass pastures (8.1 ha/pasture) and rotated between pastures every 14 d until calf weaning on day 325. Cows calved on average on day 86 ± 3.8 of the study. From days 110 to 231, all cow-calf pairs were provided free choice access to stargrass (*Cynodon nlemfuensis*) hay and limit-fed a commercial sugarcane molasses (*Saccharum officinarum*) and urea supplement at 12.4 kg of DM/cow/wk (82.4% DM; 22% CP and 75% TDN; Westway Feed Products LLC, Clewiston, FL) formulated to provide sufficient protein and energy to minimize cow BCS loss (NASEM, 2016; Palmer et al., 2022a). The total weekly supplement amount of sugarcane molasses and urea was divided by 2 and offered in open plastic tanks every Monday and Thursday at 0800 h. All plastic tanks were placed 1 m above the ground to avoid calf consumption of maternal supplements. Throughout the entire study, a commercial complete trace mineral and vitamin mixture was provided in loose meal form once weekly and at equivalent amounts to achieve a target intake of 56 g/animal/d (University of Florida Cattle Research Winter Mineral; Vigortone, Brookville, Ohio, USA; 16.8%, 1.0%, 20.7%, and 4.0% of Ca, Mg, NaCl, and P, respectively, and 60, 1,750, 350, 60, and 5,000 mg/kg of Co, Cu, I, Se, and Zn, respectively). One Brangus bull (6 ± 3 yr of age) was placed with each cow-calf group on day 142 and then bulls were rotated among groups every 28 d from days 142 to 231. Bulls were checked daily for visual signs of injury or difficulty on mounting and replaced by another similar Brangus bull as needed. Calf health was monitored daily by trained personal from birth until calf weaning on day 325. From day 325 until calving date of the second offspring, cows were maintained in bahiagrass pastures and did not receive protein or energy supplementation until calving. Calf birth BW and gender of the second offspring was recorded for each cow immediately after birth.

### Sample and Data Collection

Herbage mass and hand-plucked samples of bahiagrass pastures were collected on days 0, 35, and 77 to determine the concentrations of CP and in vitro digestible organic matter (**IVDOM**) using the double sampling technique described by Gonzalez et al. (1990). Herbage allowance was calculated as the herbage mass (kg of DM/ha) of each pasture divided by the respective total BW on each pasture (Sollenberger et al., 2005). Samples of DDG supplement were collected weekly from days 0 to 77 (2 samples/wk). All forage samples were dried at 56 °C for 72 h using a forced-air oven and ground to pass a 4-mm stainless steel screen (Model 4, Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ). Samples of DDG supplement were combined and sent in duplicates to Dairy One Forage Laboratory (Ithaca, NY) for wet chemistry analyses of CP (AOAC, 2006), TDN (Weiss et al., 1992), net energy for maintenance (NEm), and gain (NEg; NASEM, 2016). Nutritional composition of forage samples

was assessed in duplicates at the University of Florida Forage Evaluation Support Laboratory using the micro-Kjeldahl technique for N (Gallaher et al., 1975) and the two-stage technique for IVDOM (Moore and Mott, 1974).

Individual unshrunk BW and BCS (assessed by two technicians according to Wagner et al. 1988; 1 to 9 scale) of cows were assessed once on days 0 (start of treatment supplementation), 35, 77 (near calving), 142 (start of the breeding season), 168, and 325 (calf weaning). Shrunk BW of pregnant cows was not utilized to not interfere with feeding behavior and prevent any physiological stress induced feed and water withdraw which could potentially interfere with postnatal offspring performance (Marques et al., 2012; Littlejohn et al., 2016). Blood samples (10 mL) were collected on days 0, 35, 77, and 142 from 5 cows/pasture (same cows randomly selected on day 0), via jugular venipuncture into sodium-heparin (158 USP) containing tubes (Vacutainer, Becton Dickinson, Franklin Lakes, NJ). Cow blood samples were collected between 3 and 4 h after supplementation to correspond with the peak of ruminal fermentation and release of end products (Moriel et al., 2008). Steer calves were castrated immediately after birth. Blood samples were collected from three steers and three heifers per precalving maternal pasture, within 12 h after birth but after colostrum consumption, into commercial tubes containing no additive (Vacutainer, Becton Dickson). All blood samples were placed on ice immediately following collection and then centrifuged at 1,200 × g for 25 min at 4 °C. Plasma samples were stored frozen at −20 °C until laboratory analysis. Plasma samples of cows were obtained to determine the concentrations of glucose, IGF-1 and IGF-2, and nonesterified fatty acids (**NEFA**). Plasma concentrations of IGF-2 of cows were only assessed during the prepartum period (days 0, 35, and 77) as IGF-2 increases with gestation length (Kubota et al., 1992). Serum samples of calves were obtained to assess the serum concentrations of immunoglobulin G (**IgG**).

Percentage of cows pregnant on day 278 (47 d after bull removal) was determined via rectal palpation by a trained veterinarian and confirmed at calving. Unshrunk calf BW was recorded within 12 h after birth and on days 142 and 325. Additional preweaning data of cows and calves from days 141 to 342 and postweaning data of calves were not collected due to the university mandate to cease research data collection after the onset of the coronavirus disease (COVID-19) pandemic in February 2020. Only normal operating procedures (e.g., pregnancy percentage on day 278 and calf weaning on day 325) were authorized by the University of Florida—IFAS Research office and performed following the guidelines established by the Centers for Disease Control and Prevention (Atlanta, GA).

### Laboratory Analyses

Plasma concentrations of glucose were determined using commercial colorimetric assays (#G7521; Pointe Scientific Inc., Canton, MI). Plasma concentrations of IGF-1 were measured using a commercial ELISA kit validated for bovine samples (SG100; R&D Systems Inc., Minneapolis, MN; Moriel et al., 2012). Commercial bovine-specific ELISA kits were utilized to determine the plasma concentrations of IGF-2 (LS-F51244; LifeSpan BioSciences, Inc., Seattle, WA) and serum concentrations of IgG (E11-118; Bethyl Laboratories, Inc., Montgomery, TX). Plasma concentrations of NEFA were determined using a commercial kit (HR Series NEFA-2; Wako Pure Chemical Industries Ltd, Richmond, VA; Pescara et al., 2010). Intra-assay and interassay CV for assays of glucose, IGF-1, IGF-2, IgG, and NEFA were 1.44 and 2.23, 3.68 and 4.11, 4.98 and 5.77, 3.21% and 4.45%, and 2.23% and 1.49%, respectively.

### Statistical Analyses

All data were analyzed as a complete randomized study using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC, version 9.4), except for any binary data. Pasture was considered the experimental unit. Pasture (maternal treatment) and cow (pasture) or calf (pasture) were included as random effects in all statistical analyses, except for forage data which included only pasture (maternal treatment) as the random effect. Cow BW and BCS change, and calf birth BW and ADG were tested for fixed effects of maternal treatment. Cow BW, cow BCS, calf BW, plasma data, and forage data were analyzed as repeated measures and tested for fixed effects of maternal treatment, day of the study, and the resulting interaction using cow(pasture) or calf(pasture) as subjects. The compound symmetry covariance structure was selected for all repeated measures analyses because it generated the lowest Akaike information criterion. All binary data was tested for fixed effects of maternal treatment using the GLIMMIX procedure of SAS. Cow BCS and BW on day 0 did not differ among treatments ($P \geq 0.55$) but were included as covariates ($P < 0.0001$) in the statistical analyses of cow BCS and BW, respectively. Effects of calf sex, sire, calving date, and birth BW were included as covariates in the model for all calf performance variables, but removed from the model when $P \geq 0.10$. Birth BW of the first offspring was covariate-adjusted for calf sex ($P = 0.03$) and calving date ($P = 0.0008$). Birth BW of the second offspring was covariate-adjusted for calf sex ($P = 0.02$). First offspring BW and ADG were covariate-adjusted to calf sex and age ($P \leq 0.05$). All results are reported as least-square means. Means were separated by PDIFF when a significant F-test was detected. Significance was fixed at $P \leq 0.05$, and tendencies when $P > 0.05$ and $\leq 0.10$.

## RESULTS

Effects of day of the study, but not maternal treatment and maternal treatment × day of the study ($P \geq 0.63$), were detected ($P < 0.0001$) for herbage mass, herbage allowance, and forage CP and IVDOM (Table 1). Herbage mass, herbage allowance, and forage CP gradually decreased ($P \leq 0.0003$) from days 0 to 35 and then days 35 to 77. Forage IVDOM was lowest on day 35 and intermediate on day 77 ($P \leq 0.0075$).

Cow BCS and BW on day 0 did not differ among treatments ($P \geq 0.55$) but was included as covariate ($P < 0.0001$) in the statistical analyses of cows BCS and BW, respectively. Effects of maternal treatment × day of the study were detected ($P < 0.0001$) for cow BCS (Table 2). Cow BCS on days 35 and 77 did not differ ($P \geq 0.19$) between SUP and SUPMO cows but both groups had greater ($P \leq 0.001$) BCS compared with NOSUP cows. Cow BCS on days 142 and 168 were greatest ($P < 0.0001$) for SUPMO cows, least for NOSUP cows, and intermediate ($P \leq 0.02$) for SUP cows. Cow BCS change from days 0 to 35 did not differ ($P = 0.44$) between SUP and SUPMO cows and both groups gained BCS whereas NOSUP cows lost BCS ($P < 0.0001$). From days 35 to 77, NOSUP cows lost BCS ($P < 0.0001$), whereas SUPMO cows had greater ($P = 0.01$)

**Table 1.** Herbage mass, herbage allowance, in vitro digestible organic matter (IVDOM), and crude protein (CP) of bahiagrass pastures from days 0 to 77 (10 cows and 8.1 ha/pasture)[1]

| | Day of the study[2] | | | | *P*-value[3] |
|---|---|---|---|---|---|
| Item | 0 | 35 | 77 | SEM | Day |
| Herbage mass, kg of DM/ha | 6086[c] | 5138[b] | 3746[a] | 179 | <0.0001 |
| Herbage allowance, kg of DM/kg of BW | 1.18[c] | 0.94[b] | 0.70[a] | 0.033 | <0.0001 |
| IVDOM, % | 45.4[c] | 37.1[a] | 40.1[b] | 0.62 | <0.0001 |
| CP, % of DM | 11.7[c] | 9.9[b] | 7.5[a] | 0.27 | <0.0001 |

[1]Herbage mass and hand-plucked samples of bahiagrass pastures were collected on days 0, 35, and 77. Herbage mass and allowance were determined as described by Gonzalez et al. (1990) and Sollenberger et al. (2005), respectively.
[2]Treatments were randomly assigned to pastures (5 pastures/treatment) and consisted of no prepartum supplementation of DDG (NOSUP) or DDG supplementation at 1 kg of DM/cow/d added with 0 mg (SUP) or 200 mg/d of monensin (SUPMO) from days 0 to 77.
[3]Maternal treatment and maternal treatment × day of the study were not detected ($P \geq 0.63$) for herbage mass, herbage allowance, and forage CP and IVDOM.
[a–c]Within a row, means without a common superscript differ ($P \leq 0.05$).

**Table 2.** Body condition score (BCS), body weight (BW), and BCS and BW change of beef cows grazing bahiagrass pastures (10 cows and 8.1 ha/pasture) and assigned to receive no prepartum supplementation of DDG (NOSUP) or DDG supplementation at 1 kg of DM/cow/day added with 0 mg (SUP) or 200 mg/d of monensin (SUPMO) from days 0 to 77 (5 pastures/treatment)

| | Maternal treatment[1] | | | | *P*-value | |
|---|---|---|---|---|---|---|
| Item[2] | NOSUP | SUP | SUPMO | SEM | Treatment × day | Treatment |
| BCS | | | | | | |
| Day 35 | 4.97[a] | 5.44[b] | 5.36[b] | 0.090 | <0.0001 | <0.0001 |
| Day 77 | 4.68[a] | 5.57[b] | 5.74[b] | 0.091 | | |
| Day 142 | 4.58[a] | 5.08[b] | 5.37[c] | 0.091 | | |
| Day 168 | 4.48[a] | 4.80[b] | 5.14[c] | 0.091 | | |
| Day 325 | 5.26[a] | 5.40[ab] | 5.54[b] | 0.091 | | |
| BCS change | | | | | | |
| Day 0 to 35 | −0.15[a] | 0.25[b] | 0.19[b] | 0.071 | – | <0.0001 |
| Day 35 to 77 | −0.30[a] | 0.12[b] | 0.41[c] | 0.099 | – | <0.0001 |
| Day 77 to 142 | −0.13[b] | −0.53[a] | −0.37[a] | 0.106 | - | 0.0008 |
| Day 142 to 168 | −0.09[b] | −0.26[a] | −0.18[a] | 0.099 | – | 0.22 |
| Day 168 to 325 | 0.65[b] | 0.54[ab] | 0.29[a] | 0.129 | – | 0.02 |
| BW, kg | | | | | | |
| Day 35 | 554[a] | 548[a] | 556[a] | 5.6 | <0.0001 | 0.01 |
| Day 77 | 538[a] | 539[a] | 558[b] | 5.6 | | |
| Day 142 | 493[a] | 493[a] | 524[b] | 5.6 | | |
| Day 168 | 480[a] | 486[a] | 516[b] | 5.6 | | |
| Day 325 | 540[a] | 538[a] | 548[a] | 5.6 | | |
| BW change, kg | | | | | | |
| Day 0 to 35 | 35 | 28 | 34 | 3.6 | – | 0.13 |
| Day 35 to 77 | −21[a] | −16[a] | −1[b] | 6.0 | – | 0.006 |
| Day 77 to 142 | −45 | −46 | −33 | 6.9 | – | 0.17 |
| Day 142 to 168 | −13[a] | −7[b] | −9[b] | 2.9 | – | 0.08 |
| Day 168 to 325 | 50[b] | 45[b] | 28[a] | 5.4 | – | 0.0004 |

[1]Treatments were provided to cows from days 0 to 77, which concurred with 197 ± 4 d prepartum until 274 ± 4 d prepartum. On day 77, cows were distributed into one of eight groups (18 to 19 cows/group) with each treatment equally represented in each group. Then, each group was allocated to two bahiagrass pastures (8.1 ha/pasture) and rotated between pastures every 14 d until calf weaning on day 325. From days 110 to 231, all cow-calf pairs were provided free choice access to stargrass hay and limit-fed sugarcane molasses and urea-based supplement (12.4 kg of DM/cow/week).
[2]Cow BCS and BW on day 0 did not differ among treatments ($P \geq 0.55$) but were included as covariate ($P < 0.0001$) in the statistical analyses of cow BCS and BW.
[a–c]Within a row, means without a common superscript differ ($P \leq 0.05$).

BCS gain compared with SUP cows. From days 77 to 142, NOSUP cows had the least BCS loss ($P \leq 0.02$), which did not differ ($P = 0.19$) between SUP and SUPMO cows. From days 168 to 325, NOSUP cows gained ($P = 0.005$) more BCS compared with SUPMO cows, whereas SUP cows were intermediate ($P \geq 0.11$).

Cow BW from days 77 to 168 was the greatest ($P \leq 0.01$) for SUPMO cows and did not differ ($P \geq 0.34$) between

NOSUP and SUP cows, whereas cow BW on days 35 and 325 did not differ ($P \geq 0.21$) among treatments. Cow BW change from days 0 to 35 and days 77 to 142 did not differ ($P \geq 0.13$) among treatments. From days 35 to 77, cow BW change did not differ ($P = 0.35$) between NOSUP and SUP cows, which lost ($P \leq 0.03$) more BW compared with SUPMO cows. Cow BW change from day 142 to 168 was greater ($P = 0.03$) for NOSUP vs. SUP cows and was intermediate ($P \geq 0.18$) for SUPMO cows. Cow BW change from days 138 to 325 did not differ ($P = 0.32$) between NOSUP and SUP cows, but both groups gained ($P \leq 0.009$) more BW than SUPMO cows.

Calving percentage, calving date, and percentage of male calves of first offspring did not differ ($P \geq 0.23$) among treatments (Table 3). Calf birth BW of first offspring did not differ ($P = 0.77$) between SUP and SUPMO calves, but NOSUP calves were lighter ($P \leq 0.05$) at birth compared with SUP and SUPMO calves after covariate adjustment for effects of calf sex ($P = 0.03$) and calving date ($P = 0.0008$; Table 3). Percentage of cows pregnant with a second offspring on day 278 tended ($P = 0.07$) to differ among treatments, which did not differ ($P = 0.72$) between SUP and SUPMO cows and were the least for NOSUP cows ($P \leq 0.05$; Table 3). Percentage of cows calving a second offspring tended ($P = 0.09$) to differ among treatments, which was greater ($P = 0.03$) for SUP vs. NOSUP cows. Percentage of SUPMO cows calving a second offspring did not differ compared with SUP and NOSUP cows ($P \geq 0.17$; Table 3). Calving date, birth BW, and percentage of male calves in the second offspring did not differ ($P \geq 0.28$) among treatments (Table 3).

Effects of day of the study, but not maternal treatment and maternal treatment × day of the study ($P \geq 0.25$), were detected ($P < 0.0001$) for plasma concentration of glucose and NEFA (Table 4). Effects of maternal treatment × day of the study tended ($P = 0.07$) to be detected for plasma concentrations of IGF-1 and IGF-2 (Table 4). Plasma concentrations of IGF-1 on days 0, 35, and 142 did not differ ($P \geq 0.17$) among treatments, whereas plasma concentrations of IGF-1 on day 77 were the least for NOSUP cows ($P \leq 0.05$) and did not differ ($P = 0.66$) between SUP and SUPMO cows. Plasma concentrations of IGF-2 on days 35 and 77 were the greatest ($P \leq 0.05$) for SUPMO cows and did not differ ($P \geq 0.60$) between NOSUP and SUP cows. Effects of maternal treatment were detected ($P = 0.002$) for calf serum concentrations of IgG collected within 12 h after birth, which did not differ ($P = 0.50$) between NOSUP and SUP calves but were the greatest ($P \leq 0.002$) for SUPMO calves (Table 4).

Effects of maternal treatment × day of the study were detected ($P < 0.0001$) for the first-offspring BW, which did not differ among treatments on day 142. The first-offspring BW on day 325 was the greatest ($P \leq 0.05$) for SUPMO calves, least for NOSUP calves, and intermediate for SUP calves (Table 4). The first-offspring ADG from birth to day 142 tended ($P = 0.08$) to differ among treatments, which did not differ ($P = 0.92$) between NOSUP and SUP calves but were the greatest ($P \leq 0.05$) for SUPMO calves (Table 5). The first offspring ADG from days 142 to 325 did not differ ($P = 0.29$) between SUP and SUPMO calves but were the least ($P \leq 0.05$) for NOSUP calves (Table 5). First offspring ADG from birth to day 325 were greater ($P = 0.0005$) for SUPMO vs. NOSUP calves, and intermediate for SUP calves ($P \leq 0.05$; Table 5).

## DISCUSSION

Herbage mass, herbage allowance, and forage IVDOM and CP concentrations from days 0 to 77 did not differ among treatments, indicating that availability and nutritive value

**Table 3.** Reproductive performance of beef cows grazing bahiagrass pastures (10 cows and 8.1 ha/pasture) and assigned to receive no prepartum supplementation of DDG (NOSUP) or DDG supplementation at 1 kg of DM/cow/d added with 0 mg (SUP) or 200 mg/d of monensin (SUPMO) from days 0 to 77 (5 pastures/treatment)

| | Maternal treatment[1] | | | | *P*-value |
|---|---|---|---|---|---|
| Item | NOSUP | SUP | SUPMO | SEM | Treatment |
| First offspring | | | | | |
| Calving percentage, % of total cows | 93.6 | 90.0 | 94.7 | 4.15 | 0.66 |
| Calving date, day of the study | 86 | 86 | 87 | 3.8 | 0.95 |
| Calf birth BW[2], kg | 34.1[a] | 37.0[b] | 36.6[b] | 1.05 | 0.03 |
| Male calves, % of total calves | 43.2 | 42.9 | 59.0 | 7.99 | 0.23 |
| Second offspring | | | | | |
| Pregnant on day 278, % of total cows | 82.1[a] | 94.9[b] | 92.3[b] | 5.15 | 0.07 |
| Calving percentage, % of total cows | 76.9[a] | 92.1[b] | 86.8[ab] | 5.98 | 0.09 |
| Calving date, day of the study | 453 | 451 | 456 | 3.1 | 0.53 |
| Calf birth BW[2], kg | 38.3 | 36.8 | 37.9 | 1.79 | 0.28 |
| Male calves, % of total calves | 54.8 | 57.6 | 40.6 | 8.86 | 0.33 |

[1]Treatments were provided to cows from day 0 to 77, which concurred with 197 ± 4 d prepartum until 274 ± 4 d prepartum. On day 77, cows were distributed into one of eight groups (18 to 19 cows/group) with each treatment equally represented in each group. Then, each group was allocated to two bahiagrass pastures (8.1 ha/pasture) and rotated between pastures every 14 d until calf weaning on day 325. Bulls were placed with cows (1 bull/group) on day 142 and rotated among groups every 14 d until day 231.
[2]Birth BW of the first offspring was covariate-adjusted for calf sex ($P = 0.03$) and calving date ($P = 0.0008$). Birth BW of the second offspring was covariate-adjusted for calf sex ($P = 0.02$) but not calving date ($P = 0.85$).
[a,b]Within a row, means without a common superscript differ ($P \leq 0.05$).

**Table 4.** Plasma concentrations of glucose, non-esterified fatty acids (NEFA), insulin-like growth factor-1 (IGF-1) and -2 (IGF-2) of beef cows and serum concentrations of immunoglobulin G (IgG) of their first offspring. Cows grazed bahiagrass pastures (10 cows and 8.1 ha/pasture) and were assigned to receive no prepartum supplementation of DDG (NOSUP) or DDG supplementation at 1 kg of DM/cow/day added with 0 mg (SUP) or 200 mg/day of monensin (SUPMO) from day 0 to 77 (5 pastures/treatment)

| | Maternal treatment[1] | | | | *P*-value | | |
|---|---|---|---|---|---|---|---|
| Item[2] | NOSUP | SUP | SUPMO | SEM | Treatment × day | Treatment | Day |
| Cows | | | | | | | |
| Plasma glucose, mg/dL | 70 | 72 | 72 | 1.14 | 0.36 | 0.46 | <0.0001 |
| Plasma NEFA, mEq/L | 0.63 | 0.57 | 0.58 | 0.039 | 0.25 | 0.38 | <0.0001 |
| Plasma IGF-1[3], ng/mL | | | | | | | |
| Day 0 | 32.3[a] | 31.9[a] | 30.8[a] | 1.81 | 0.07 | 0.38 | <0.0001 |
| Day 35 | 35.8[a] | 38.3[a] | 36.4[a] | 1.81 | | | |
| Day 77 | 24.8[a] | 29.9[b] | 28.7[b] | 1.81 | | | |
| Day 142 | 23.9[a] | 22.6[a] | 26.9[a] | 1.81 | | | |
| Plasma IGF-2[3], ng/mL | | | | | | | |
| Day 0 | 2165[a] | 1997[a] | 2084[a] | 331.8 | 0.07 | 0.01 | 0.03 |
| Day 35 | 1223[a] | 1190[a] | 1896[b] | 331.8 | | | |
| Day 77 | 1077[a] | 1289[a] | 2576[b] | 331.8 | | | |
| First offspring | | | | | | | |
| Serum IgG (12 h within birth), mg/mL | 47.3[a] | 41.6[a] | 75.3[b] | 7.10 | - | 0.002 | - |

[1]Treatments were provided to cows from day 0 to 77, which concurred with 197 ± 4 d prepartum until 274 ± 4 d prepartum. On day 77, cows were distributed into one of eight groups (18 to 19 cows/group) and managed similarly until calf weaning on day 325. Brangus bulls were placed with cows (1 bull/group) on day 142 and rotated among groups every 14 d until day 231.
[2]Blood samples (10 mL) were collected on days 0, 35, 77, and 142 from 5 cows/pasture (same cows randomly selected on day 0).
[3]Plasma concentrations of IGF-1 and IGF-2 on day 0 did not differ ($P \geq 0.47$) among treatments but were covariate-adjusted ($P < 0.0001$) for the respective plasma data obtained on day 0. Blood samples of cows were collected from 5 cows/pasture on days 0, 35, 77, and 142. Blood samples of the first offspring were collected from three steers and three heifers/pasture within 24 h after birth but after colostrum consumption.
[a,b]Within a row, means without a common superscript differ ($P \leq 0.05$).

**Table 5.** Preweaning growth performance of first offspring born to beef cows grazing bahiagrass pastures (10 cows and 8.1 ha/pasture) and assigned to receive no prepartum supplementation of DDG (NOSUP) or DDG supplementation at 1 kg of DM/cow/d added with 0 mg (SUP) or 200 mg/d of monensin (SUPMO) from day 0 to 77 (5 pastures/treatment)

| | Maternal treatment[1] | | | | *P*-value | | |
|---|---|---|---|---|---|---|---|
| Item | NOSUP | SUP | SUPMO | SEM | Treatment × day | Treatment | Day |
| First offspring BW[2], kg | | | | | | | |
| Day 142 | 77[a] | 80[a] | 83[a] | 4.3 | <0.0001 | 0.08 | <0.0001 |
| Day 325 | 243[a] | 256[b] | 267[c] | 4.3 | | | |
| First offspring ADG[2], kg/day | | | | | | | |
| Birth until day 142 | 0.79[a] | 0.80[a] | 0.93[b] | 0.050 | – | 0.08 | – |
| Day 142 to 325 | 0.87[a] | 0.92[b] | 0.95[b] | 0.025 | – | 0.009 | – |
| Birth until day 325 | 0.84[a] | 0.89[b] | 0.94[c] | 0.041 | – | 0.002 | – |

[1]Treatments were provided to cows from day 0 to 77, which concurred with 197 ± 4 d prepartum until 274 ± 4 d prepartum. On day 77, cows were distributed into one of eight groups (18 to 19 cows/group). Then, each group was allocated to two bahiagrass pastures (8.1 ha/pasture) and rotated between pastures every 14 d until calf weaning on day 325. Brangus bulls were placed with cows (1 bull/group) on day 142 and rotated among groups every 14 d until day 231.
[2]First offspring BW and ADG covariate-adjusted to calf sex and age ($P \leq 0.05$).
[a–c]Within a row, means without a common superscript differ ($P \leq 0.05$).

(and potentially forage DM intake) were not significantly impacted by the selected amount of supplemental protein and energy (Moriel et al., 2020; Palmer et al., 2022a,b; Izquierdo et al., 2022) and monensin consumed (Moriel et al, 2019; Oliveira et al., 2020, 2021; Vendramini et al., 2018). As expected, NOSUP cows lost BCS during late gestation due to the limited herbage allowance and forage nutritive value not sufficiently meeting the increasing pregnancy-associated energy and protein requirements. Herbage allowance from day 0 to 77 was always below the minimum threshold for ad libitum intake of warm-season forages (1.40 kg DM/kg of BW; Inyang et al., 2010), whereas forage IVDOM concentrations from days 0 to 77 and forage CP concentrations on day 77 were below the amount of TDN and CP required by beef cows during late gestation (53% TDN and 8.1% CP of DM; NASEM, 2016). Nevertheless, the amount of maternal supplemental protein and energy provided to SUP and SUPMO cows in the current study led to prepartum BCS gain and increased BCS at calving compared with NOSUP cows, agreeing with previous studies (Moriel et al., 2020; Palmer

et al., 2020, 2022a,b; Izquierdo et al., 2022). All cows were managed similarly from day 77 until calf weaning on day 325 and received same amount of molasses and urea supplementation from days 110 to 231. However, postpartum BCS loss was greater for SUP and SUPMO cows, which was reported previously (Moriel et al., 2020; Palmer et al., 2020, 2022a; Izquierdo et al., 2022) and can be attributed to the greater energy and protein requirements caused by their greater postpartum BCS compared with NOSUP cows.

Monensin inclusion into maternal prepartum supplementation did not impact cow BCS change from days 0 to 35 but induced BCS gain from days 35 to 77 (and numerically increased cow BCS near calving) compared with SUP cows. These responses partially agree with our hypothesis and are not surprising as the impacts of monensin supplementation on cattle growth performance have been variable. Monensin supplementation at ≥200 mg/d did not impact prepartum BCS of beef cows (Moseley et al., 1977; Turner et al., 1980; Linneen et al., 2015) and dairy cows (Arieli et al., 2008; Chung et al., 2008; Vasquez et al., 2021) or improved prepartum BCS of beef cows (Barnett et al., 1982) and dairy cows (Melendez et al., 2006). Likewise, previous studies conducted at the same geographical location and similar bahiagrass pastures observed that monensin supplementation increased ADG of early-weaned and creep-fed beef calves ( Vendramini et al., 2018; Oliveira et al., 2020, 2021) or did not affect overall ADG of developing replacement beef heifers (Vendramini et al., 2015; Moriel et al., 2019). The exact reasons for the inconsistent monensin-induced effects on cattle growth performance reported in the literature and observed herein are unknown but likely explained by the different animal categories, forage type and nutritive value, supplement amount and composition, and monensin dosage evaluated. The greater BCS gain from days 35 to 77, combined with a numerically lessened BCS loss from days 77 to 168 of SUPMO cows compared with SUP cows, allowed SUPMO cows to achieve the greatest BCS early in the breeding season even though monensin supplementation ceased on day 77. These results suggest that positive effects of prepartum supplementation of monensin to beef cows persisted at least during early postpartum period. Supporting this rationale, beef steers previously fed monensin continued to have a reduced ruminal acetate to propionate ratio for at least 7 d after monensin withdrawal (Bell et al., 2017).

It is important to highlight that the current study was not designed to evaluate the reproductive performance of cows, which would require greater number of animals and replicates. Nonetheless, maternal treatment effects tended to be detected for the percentage of cows pregnant and calving their second offspring, which were both greater for SUP and SUPMO cows compared with NOSUP cows, likely attributed to the differences in BCS at calving and start of the breeding season among treatments. In previous studies, prepartum supplementation of protein and energy supplementation increased prepartum BCS of beef cows grazing warm-season grasses but did not impact their subsequent pregnancy percentage (Moriel et al., 2020; Palmer et al. 2020, 2022a,b; Izquierdo et al., 2022). The major difference between the current study and our previous studies is the resulting BCS of nonsupplemented cows at the time of calving. In previous studies, despite the lesser BCS at calving, cows that did not receive prepartum supplementation of protein and energy calved slightly above the minimum acceptable calving BCS (≥5.0) to maintain adequate reproductive performance in the subsequent breeding season (Hess et al., 2005). In the current study, however, NOSUP cows calved at a BCS < 5 and continued

to lose BCS during the start of the breeding season. Prepartum supplementation of monensin did not impact pregnancy percentage of SUPMO cows, supporting previous studies with beef (Linneen et al., 2015; Turner et al., 1980; Walker et al., 1980) and dairy cows (Melendez et al., 2006). Despite their greater BCS throughout the breeding season, it is likely that the slight increment on postpartum BCS of SUPMO cows compared with SUP cows was not large enough in magnitude to significantly alter their pregnancy percentage and calving distribution.

Plasma concentrations of glucose, IGF-1, and IGF-2 are positively correlated with energy and protein consumption (Sullivan et al., 2009; Cappellozza et al., 2014), whereas monensin supplementation may support rumen propionate production and subsequently the synthesis and release of glucose, insulin, and IGF-1 (Vendramini et al., 2018; Moriel et al., 2019; Sousa et al., 2022). Nevertheless, the impacts of prepartum supplementation of protein and energy on circulating concentrations of glucose, IGF-1, and IGF-2 have been variable. Prepartum supplementation of sugarcane molasses and urea at 0.20% to 0.26% of BW (DM basis) increased prepartum plasma concentrations of IGF-1 and IGF-2 (but not glucose) in beef heifers (Moriel et al., 2020) or increased prepartum plasma concentrations of glucose (but not IGF-1 and IGF-2) in multiparous beef cows (Palmer et al., 2020). Despite the similar animal category and bahiagrass pastures, prepartum supplementation of DDG at 0.20% to 0.40% of BW (DM basis) increased prepartum plasma concentrations of IGF-1 (but not glucose and IGF-2) in multiparous beef cows (Palmer et al., 2022a) or increased prepartum plasma concentrations of glucose and IGF-1 (but not IGF-2) in multiparous beef cows (Izquierdo et al., 2022). Likewise, supplemental monensin led to mixed results on plasma concentrations of glucose and IGF-1 in growing and mature beef cattle (Linneen et al., 2015; Moriel et al. 2019; Vendramini et al. 2015, 2018Oliveira et al. 2020, 2021), primarily due to differences in animal category and precursor amount for rumen propionate production (Sousa et al., 2022). More specifically, maternal supplementation of 200 mg of monensin per day during the second trimester of gestation did not alter prepartum blood concentrations of glucose (IGF-1 and -2 not reported) compared with no monensin supplementation (Linneen et al., 2015). In the current study, prepartum plasma concentrations of IGF-1 (but not glucose and IGF-2) increased for SUP vs. NOSUP cows, whereas prepartum plasma concentrations of IGF-2 (but not IGF-1) increased for SUPMO vs. SUP cows. Glucose is essential for fetal growth (Bell et al., 2005) and glucose availability to the fetus is regulated by maternal glucose concentrations (Baumann et al., 2002), whereas plasma concentrations of IGF-1 and IGF-2 are synthesized by the placenta, maternal, and fetal tissues (Gicquel and Le Bouc, 2006) and regulate nutrient partitioning between maternal tissues and fetus (Sferruzzi-Perri et al., 2006). Therefore, the inconsistent results described above demonstrate that maternal circulating concentrations of hormones and metabolites, following maternal supplementation of protein, energy, and monensin, are the end result of a dynamic process involving timing of blood collection relative to peak release of hormones and metabolites, supplemental

protein and energy consumption amount, monensin dosage, animal category, and nutrient uptake and hormonal synthesis by maternal and fetal tissues.

Immunoglobulin transfer from maternal serum to colostrum in cattle initiates 28 d before calving and peaks near calving (Olson et al., 1981). Serum concentrations of IgG in calves are positively correlated with colostrum IgG intake (Hopkins and Quigley, 1997). In the current study, serum concentrations of IgG at birth did not differ between NOSUP and SUP cows, corresponding with previous studies (Bohnert et al., 2013; Kennedy et al., 2019; Moriel et al., 2020; Palmer et al., 2022a; Izquierdo et al., 2022). However, prepartum supplementation of monensin increased serum concentrations of IgG of the first offspring compared with NOSUP and the SUP offspring. Vasquez et al. (2021) observed that multiparous dairy cows supplemented with monensin tended to have lower colostrum IgG concentration compared with cows offered no monensin supplementation, whereas colostrum IgG concentration from primiparous dairy cows was not impacted by prepartum supplementation of monensin. Literature data on effects of monensin on IgG concentrations in the colostrum and offspring blood are scarce and a clear mechanism underlying the results observed herein and by Vasquez et al. (2021) remains unknown. Nonetheless, in the current study, serum concentrations of IgG in the first offspring were above levels required for adequate passive immune transfer (>16 mg/mL; Witum and Perino, 1995), regardless of the previous maternal treatment.

Maternal supplementation of protein and energy and monensin during gestation influence offspring BW at birth and during preweaning phase, by altering nutrient availability and glucose transfer to the fetus via IGF system regulation (Kubota et al., 1992; Perry et al., 2002; Sferruzzi-Perri et al., 2006; Sullivan et al., 2009). Maternal supplementation of protein and energy during gestation had either no effects or increased offspring birth BW by on average 3.2 kg (Moriel et al., 2021). Subsequent studies, conducted at the same research site as herein, demonstrated that maternal supplementation of DDG at 1 to 2 kg/d (DM basis) during late gestation of beef cows did not impact (Palmer et al., 2022a) or increased calf birth BW by 2.9 kg (Izquierdo et al., 2022), but increased calf BW at weaning by 6 to 16 kg (Izquierdo et al., 2022; Palmer et al., 2022a). Maternal supplementation of monensin during prepartum and early lactation periods did not impact cow milk production but improved calf performance during the experimental supplementation period, even though calf had no opportunity to consume maternal supplements (Linneen et al., 2015). In contrast, Turner et al. (1980) and Walker et al. (1980) reported no differences in calf BW at birth and preweaning phase following maternal prepartum supplementation of monensin, although forage was limit-fed at 90% of the total forage amount provided to cows offered no monensin supplementation. In the current study, birth BW of the first offspring was 2.5 to 2.9 kg greater for SUP and SUPMO vs. NOSUP calves and did not differ between SUP and SUPMO calves, whereas first offspring BW at weaning was 13 and 24 kg greater for SUP and SUPMO calves, respectively, compared with NOSUP calves and was greatest for SUPMO calves. Treatment-induced differences in milk production of cows are possible, but less likely, as previous studies reported improved calf preweaning growth despite no differences in cow milk production following maternal prepartum supplementation of protein and energy (Marques et al. 2016a,b) or monensin (Linneen et al., 2015). Further studies unraveling the mechanisms by which calf preweaning growth is impacted by prepartum maternal supplementation of protein and energy and monensin are required. However, it remains plausible that: 1) the preweaning growth performance of SUP vs. NOSUP calves was associated with the greater prepartum BCS gain ( Marques et al. 2016a,b) and plasma IGF-1 concentrations in SUP cows; and 2) the greatest preweaning growth performance detected for SUPMO calves was a combined effect of greater prepartum BCS gain and plasma concentrations of both IGF-1 and IGF-2 in SUPMO cows.

## CONCLUSION

In conclusion, prepartum supplementation of DDG to *Bos indicus*-influenced beef cows increased cow BCS at calving, cow pregnancy percentage, and offspring preweaning growth performance compared with no prepartum supplementation of DDG. Adding monensin into prepartum DDG supplementation: 1) did not increase cow BCS near calving and subsequent reproduction to levels beyond those observed for prepartum DDG supplementation without monensin, but 2) led to greatest offspring preweaning growth performance, likely by modulating maternal plasma concentrations of IGF-1 and IGF-2 during third trimester of gestation.

## ACKNOWLEDGMENTS

We thank all the staff at the Range Cattle Research and Education Center (Ona, FL) for their assistance on cattle handling and sample collection and Westway Feed Products LLC (Clewiston, FL) for donating the sugarcane molasses + urea.

### Conflict of interest statement

None declared.

## LITERATURE CITED

Arieli, A., U. Dicken, I. Dagoni, Y. Spirer, and S. Zamwel. 2008. Production and health of cows given monensin prepartum and a high-energy diet postpartum. *J. Dairy Sci.* 91:1845–1851. doi:10.3168/jds.2007-0795

AOAC. 2006. *Official methods of analysis*, 18th ed. Arlington (VA): AOAC International.

Barnett, D. T., N. W. Bradley, and R. M. Stone. 1982. Effects of Rumensin and level of feed intake on gestating beef cows. In: *Proceedings Sheep Profit Day*, Univ. of Kentucky, Lexington, KY, vol. 265, p. 5–6.

Baumann, M. U., S. Deborde, and N. P. Illsley. 2002. Placental glucose transfer and fetal growth. *Endocrine* 19:13–22. doi:10.1385/ENDO:19:1:13

Bell, A. W., P. L. Greenwood, and R. A. Ehrhardt. 2005. Regulation of metabolism and growth during prenatal growth. In: D. G. Burrin and H. J. Mersmann, editors, *Biology of metabolism in growing animals*. Edinburgh (UK): Elsevier Limited, p. 7–31.

Bell, N. L., T. R. Callaway, R. C. Anderson, M. O. Franco, J. E. Sawyer, and T. A. Wickersham. 2017. Effect of monensin withdrawal on intake, digestion, and ruminal fermentation parameters by *Bos taurus indicus* and *Bos taurus* steers consuming bermudagrass hay. *J. Anim. Sci.* 95:2747–2757. doi:10.2527/jas.2016.1013.

Bohnert, D. W., L. A. Stalker, R. R. Mills, A. Nyman, S. J. Falck, and R. F. Cooke. 2013. Late gestation supplementation of beef cows differing in body condition score: effects on cow and calf performance. *J. Anim. Sci.* 91:5485–5491. doi:10.2527/jas.2013-6301

Cappellozza, B. I., R. F. Cooke, M. M. Reis, P. Moriel, D. H. Keisler, and D. W. Bohnert. 2014. Supplementation based on protein or energy ingredients to beef cattle consuming low-quality cool-season forages: II. Performance, reproductive, and metabolic responses of replacement heifers. *J. Anim. Sci.* 92:2725–2734. doi:10.2527/jas.2013-7442

Chung, Y. H., M. M. Pickett, T. W. Cassidy, and G. A. Varga. 2008. Effects of prepartum dietary carbohydrate source and monensin on periparturient metabolism and lactation in multiparous cows. *J. Dairy Sci.* 91:2744–2758. doi:10.3168/jds.2007-0781

Cooke, R. F., C. L. Daigle, P. Moriel, S. Smith, L. O. Tedeschi, and J. M. B. Vendramini. 2020. Board Invited Review – Cattle adapted to tropical and subtropical environments (I): social, nutritional, and carcass quality considerations. *J. Anim. Sci.* 98:1–20. doi:10.1093/jas/skaa014

Gallaher, R. N., C. O. Weldon, and J. G. Futral. 1975. An aluminum block digester for plant and soil analysis. *Soil Sci. Soc. Am. J.* 39:803–806. doi:10.2136/sssaj1975.03615995003900040052x

Gicquel, C., and Y. Le Bouc. 2006. Hormonal regulation of fetal growth. *Horm. Res.* 65:28–33. doi:10.1159/000091503

Gonzalez, M. A., M. A. Hussey, and B. E. Conrod. 1990. Plant height, disk and capacitance meters used to estimate bermudagrass herbage mass. *Agron. J.* 82:861–864. doi:10.2134/agronj1990.00021962008200050002x

Hess, B. W., S. L. Lake, E. J. Scholljegerdes, T. R. Weston, V. Nayigihugu, J. D. C. Molle, and G. E. Moss. 2005. Nutritional controls of beef cow reproduction. *J. Anim. Sci.* 83(E. Suppl.):E90–E106. doi:10.2527/2005.8313_supplE90x

Hopkins, B. A., and J. D. Quigley. 1997. Effects of method of colostrum feeding and colostral supplementation on serum IgG concentrations in neonatal calves. *J. Dairy Sci.* 80:979–983. doi:10.3168/jds.S0022-0302(97)76023-5

Inyang, U., J. M. B. Vendramini, L. E. Sollenberger, B. Sellers, A. Adesogan, L. Paiva, and A. Lunpha. 2010. Forage species and stocking rate effects on animal performance and herbage responses of "Mulato" and bahiagrass pastures. *Crop Sci.* 50:1079–1085. doi:10.2135/cropsci2009.05.0267

Izquierdo, V., M. Vedovatto, E. A. Palmer, R. A. Oliveira, H. M. Silva, J. M. B. Vendramini, and P. Moriel. 2022. Frequency of maternal supplementation of energy and protein during late gestation modulates preweaning growth of their beef offspring. *J. Anim. Sci.* In review.

Kennedy, V. C., J. J. Gaspers, B. R. Mordhorst, G. L. Stokka, K. C. Swanson, M. L. Bauer, and K. A. Vonnahme. 2019. Late gestation supplementation of corn dried distiller's grains plus solubles to beef cows fed a low-quality forage: III. Effects on mammary gland blood flow, colostrum and milk production, and calf body weights. *J. Anim. Sci.* 97:3337–3347. doi:10.1093/jas/skz201

Kubota, T., S. Kamada, M. Taguchi, and T. Aso. 1992. Determination of insulin-like growth factor-2 in feto-maternal circulation during human pregnancy. *Eur. J. Endocrinol.* 127:359–365. doi:10.1530/acta.0.1270359

Linneen, S. K., A. L. McGee, J. R. Cole, J. S. Jennings, D. R. Stein, G. W. Horn, and D. L. Lalman. 2015. Supplementation of monensin and optimase to beef cows consuming low-quality forage during late gestation and early lactation. *J. Anim. Sci.* 93:3076–3083. doi:10.2527/jas.2014-8406

Littlejohn, B. P., D. M. Price, J. P. Banta, A. W. Lewis, D. A. Neuendorff, J. A. Carroll, R. C. Vann, T. H. Welsh, and R. D. Randel. 2016. Prenatal transportation stress alters temperament and serum cortisol concentrations in suckling Brahman calves. *J. Anim. Sci.* 94:602–609. doi:10.2527/jas.2015-9635

Marques, R., R. F. Cooke, M. C. Rodrigues, T. G. Filho, B. I. Cappellozza, P. Moriel, and D. W. Bohnert. 2016b. Effects of organic or inorganic Co, Cu, Mn, and Zn supplementation to late-gestating beef cows on productive and physiological responses of the offspring. *J. Anim. Sci.* 94:1215–1226. doi:10.2527/jas.2015-0036

Marques, R. S., and R. F. Cooke. 2021. Effects of ionophores on ruminal function of beef cattle. *Animals* 11(10):2871. doi:10.3390/ani11102871.

Marques, R. S., R. F. Cooke, C. L. Francisco, and D. W. Bohnert. 2012. Effects of twenty-four hour transport or twenty-four hour feed and water deprivation on physiologic and performance responses of feeder cattle. *J. Anim. Sci.* 90:5040–5046. doi:10.2527/jas.2012-5425

Marques, R. S., R. F. Cooke, M. C. Rodrigues, P. Moriel, and D. W. Bohnert. 2016a. Impacts of cow body condition score during gestation on weaning performance of the offspring. *Livest. Sci* 191:174–178. doi:10.1016/j.livsci.2016.08.007

Melendez, P., J. P. Goff, C. A. Risco, L. F. Archbald, R. Littell, and G. A. Donovan. 2006. Pre-partum monensin supplementation improves body reserves at calving and milk yield in Holstein cows dried-off with low body condition score. *Research Vet. Sci.* 82:349–357. doi:10.1016/j.rvsc.2006.09.009

Moore, J. E., and G. O. Mott. 1974. Recovery of residual organic matter from "in vitro" digestion of forages. *J. Dairy Sci.* 57:1258–1259. doi:10.3168/jds.S0022-0302(74)85048-4

Moriel, P., R. F. Cooke, D. W. Bohnert, J. M. B. Vendramini, and J. D. Arthington. 2012. Effects of energy supplementation frequency and forage quality on performance, reproductive, and physiological responses of replacement beef heifers. *J. Anim. Sci.* 90:2371–2380. doi:10.2527/jas.2011-4958

Moriel, P., E. A. Palmer, K. M. Harvey, and R. F. Cooke. 2021. Improving beef progeny performance through developmental programming. *Front. Anim. Sci.* 2:728635. doi:10.3389/fanim.2021.728635

Moriel, P., T. S. Scatena, O. G. Sá Filho, R. F. Cooke, and J. L. M. Vasconcelos. 2008. Concentrations of progesterone and insulin in serum of non-lactating dairy cows in response to carbohydrate source and processing. *J. Dairy Sci.* 91:4616–4621. doi:10.3168/jds.2008-1286

Moriel, P., M. Vedovatto, E. A. Palmer, R. A. Oliveira, H. M. Silva, J. Ranches, and J. M. B. Vendramini. 2020. Maternal supplementation of energy and protein, but not methionine hydroxy analogue, enhanced postnatal growth and response to vaccination in *Bos indicus*-influenced beef calves. *J. Anim. Sci.* 98:1–12. doi:10.1093/jas/skaa123

Moriel, P., J. M. B. Vendramini, C. Carnelos, M. B. Piccolo, and H. M. Silva. 2019. Effects of monensin on growth performance of beef heifers consuming warm-season perennial grass and supplemented with sugarcane molasses. Trop. Anim. *Health* 51:339–344. doi:10.1007/s11250-018-1693-5

Moseley, W. M., M. M. McCartor, and R. D. Randel. 1977. Effects of monensin on growth and reproductive performance of beef heifers. *J. Anim. Sci.* 45:961–968. doi:10.2527/jas1977.455961x

NASEM (National Academics of Sciences, Engineering, and Medicine). 2016. Nutrient requirements of beef cattle. 8th ed. *Animal Nutrition Series*. Washington (DC): The National Academies Press

Oliveira, R. A., P. Moriel, J. M. B. Vendramini, H. M. Silva, M. Vedovatto, J. N. M. Neiva, F. R. C. Miotto, M. Miranda, and D. P. Silva. 2020. Supplemental monensin impacts growth, physiology, and coccidiosis infestation of early-weaned beef calves consuming warm-season perennial or cool-season annual grasses. *Applied Anim. Sci* 36:108–117. doi:10.15232/aas.2019-01930

Oliveira, R. A., J. M. B. Vendramini, M. Vedovatto, E. Palmer, H. M. da Silva, J. N. M. Neiva, F. R. C. Miotto, and P. Moriel. 2021. Growth, physiology, and coccidiosis infestation of suckling beef calves grazing warm-season grasses and offered creep-feeding supplementation with or without monensin. *Trop. Anim. Health Prod.* 53:363. doi:10.1007/s11250-021-02789-x.=

Olson, D. P., R. C. Bull, L. F. Woodward, and K. W. Kelley. 1981. Effects of maternal nutritional restriction and cold stress on young calves: absorption of colostral immunoglobulins. *Am. J. Vet. Res.* 42:876–880.

Palmer, E. A., M. Vedovatto, R. A. Oliveira, J. Ranches, J. M. B. Vendramini, M. H. Poore, T. Martins, M. Binelli, J. D. Arthington, and P. Moriel.

2022a. Timing of maternal supplementation of dried distillers grains during late gestation influences postnatal growth, immunocompetence, and carcass characteristics of *Bos indicus*-influenced beef calves. *J. Anim. Sci.* 100(2):skac022. doi:10.1093/jas/skac022

Palmer, E. A., M. Vedovatto, R. A. Oliveira, J. Ranches, J. M. B. Vendramini, M. H. Poore, T. Martins, M. Binelli, J. D. Arthington, and P. Moriel. 2022b. Effects of maternal winter vs. year-round supplementation of protein and energy on postnatal growth, immune function, and carcass characteristics of *Bos indicus*-influenced beef offspring. *J. Anim. Sci.* 100(3):skac003. doi:10.1093/jas/skac003

Palmer, E. A., M. Vedovatto, R. A. Oliveira, H. M. Silva, J. Ranches, J. M. B. Vendramini, and P. Moriel. 2020. Maternal supplement type and methionine hydroxy analogue fortification on performance of Bos indicus-influenced beef cows and their offspring. *Livestock Sci* 240:104176. doi:10.1016/j.livsci.2020.104176.

Perry, V. E. A., S. T. Norman, R. C. W. Daniel, P. C. Owens, P. Grant, and V. J. Doogan. 2002. Insulin-like growth factor levels during pregnancy in the cow are affected by protein supplementation in the maternal diet. *Anim. Reprod. Sci.* 72:1–10. doi:10.1016/s0378-4320(02)00069-6

Pescara, J. B., J. A. A. Pires, and R. R. Grummer. 2010. Antilipolytic and lipolytic effects of administering free or ruminally protected nicotinic acid to feed-restricted Holstein cows. *J. Dairy Sci.* 93:5385–5396. doi:10.3168/jds.2010-3402

Sferruzzi-Perri, A. N., J. A. Owens, K. Pringle, J. S. Robinson, and C. T. Roberts. 2006. Maternal insulin-like growth factors-I and -II act via different pathways to promote fetal growth. *Endocrinology* 147:3344–3355. doi:10.1210/en.2005-1328

Sollenberger, L. E., J. E. Moore, V. G. Allen, and C. G. S. Pedreira. 2005. Reporting forage allowance in grazing experiments. *Crop Sci.* 45:896–900. doi:10.2135/cropsci2004.0216

Sousa, J. T. L., J. M. B. Vendramini, P. Moriel, J. M. D. Sanchez, H. M. da Silva, N. Alencar, L. F. de Sousa, H. M. R. de Oliveira, and E. Palmer. 2022. Monensin and concentrate supplementation level effects on forage ruminal parameters and forage in-situ disappearance of beef cattle receiving bermudagrass. *Applied Anim. Sci* 38:141–149. doi:10.15232/aas.2021-02249

Sullivan, T. M., G. C. Micke, N. Perkins, G. B. Martin, C. R. Wal- lace, K. L. Gatford, J. A. Owens, and V. E. A. Perry. 2009. Dietary protein during gestation affects maternal insulin-like growth factor, insulin-like growth factor binding protein, leptin concentrations, and fetal growth in heifers. *J. Anim. Sci.* 87:3304–3316. doi:10.2527/jas.2008-1753

Turner, H. A., D. C. Young, R. J. Raleigh, and D. ZoBell. 1980. Effect of various levels of monensin on efficiency and production of beef cows. *J. Anim. Sci.* 50:385–390. doi:10.2527/jas1980.503385x

Vasquez, J. A., M. M. McCarthy, B. F. Richards, K. L. Perfield, D. B. Carlson, and A. L. Lock. 2021. Effects of prepartum diets varying in dietary energy density and monensin on early-lactation performance in dairy cows. *J. Dairy Sci.* 104:2881–2895. doi:10.3168/jds.2020-19414

Vendramini, J. M. B., P. Moriel, R. F. Cooke, J. D. Arthington, H. M. da Silva, M. B. Piccolo, J. M. D. Sanchez, V. Gomes, and P. A. Mamede. 2018. Effects of monensin into increasing amount of concentrate on growth and physiological parameters of early-weaned beef calves consuming warm-season grasses. *J. Anim. Sci.* 96:5112–5123. doi:10.1093/jas/sky374

Vendramini, J. M. B., J. M. D. Sanchez, R. F. Cooke, A. D. Aguiar, P. Moriel, W. L. da Silva, O. F. R. Cunha, P. D. S. Ferreira, and A. C. Pereira. 2015. Stocking rate and monensin level effects on growth performance of beef cattle consuming warm-season grasses. *J. Anim. Sci.* 93:3682–3689. doi:10.2527/jas.2015-8913

Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wettemann, and L. E. Walters. 1988. Carcass composition in mature Hereford cows: estimation and effect on daily metabolizable energy requirement during winter. *J. Anim. Sci.* 66:603–612. doi:10.2527/jas1988.663603x

Walker, P. M., B. A. Weichenthal, and G. F. Cmarik. 1980. Efficacy of monensin for beef cows. *J. Anim. Sci.* 51:532–538. doi:10.2527/jas1980.513532x

Weiss, W. P., H. R. Conrad, and N. R. St. Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. *Anim. Feed Sci. Technol.* 39:95–110. doi:10.1016/0377-8401(92)90034-4

Wittum, T. E., and L. J. Perino. 1995. Passive immune status at postpartum hour 24 and long-term health and performance of calves. *Am. J. Vet. Res.* 56:1149–1154.