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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

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Abstract

This 2-yr study evaluated the effects of winter vs. year-round supplementation of *Bos indicus*-influenced beef cows on cow reproductive performance and impact on their offspring. On day 0 of each year (approximately day 122 ± 23 of gestation), 82 to 84 mature Brangus cows/yr were stratified by body weight (BW; 475 ± 67 kg) and body condition score (BCS; 4.85 ± 0.73) and randomly assigned to 1 of 6 bahiagrass (*Paspalum notatum*) pastures (13 to 14 cows/pasture). Treatments were randomly assigned to pastures consisting of winter supplementation with molasses + urea (WMOL), or year-round supplementation with molasses + urea (YMOL) or wheat middling-based range cubes (YCUB). Total yearly supplement DM amount was 272 kg/cow and supplements were formulated to be isocaloric and isonitrogenous (75% TDN and 20% CP). On day 421 (weaning; approximately 260 ± 24 d of age), 33 to 35 steers/yr were vaccinated against parainfluenza-3 (PI_3) and bovine viral diarrhea virus type 1 (BVDV-1) and transported 1,193 km to a feedlot. Steers were penned according to maternal pasture and managed similarly until slaughter. Data were analyzed using the MIXED and GLIMMIX procedures of SAS. On day 217 (start of breeding season), BCS was greater ($P = 0.01$) for YMOL than WMOL cows, whereas BCS of YCUB did not differ ($P \geq 0.11$) to both WMOL and YMOL cows. The percentage of cows that calved, calving date, birth BW, and preweaning BW of the first offspring did not differ ($P \geq 0.22$) among maternal treatments. Plasma cortisol concentrations were greater ($P \leq 0.001$) for YCUB steers at feedlot arrival (day 422) than WMOL and YMOL steers. Moreover, YCUB steers had greater ($P = 0.02$) and tended ($P = 0.08$) to have greater plasma concentrations of haptoglobin compared to WMOL and YMOL steers, respectively. Antibody titers against PI_3 and BVDV-1 viruses did not differ ($P \geq 0.25$) among maternal treatments. Steer BW at feedlot exit was greater ($P \leq 0.05$) for YMOL and WMOL than YCUB steers. However, feedlot DMI did not differ ($P \geq 0.37$) by maternal treatment. Hot carcass weight, yield grade, LMA, and marbling did not differ ($P \geq 0.14$) among maternal treatments. Percentage of steers that graded low choice was enhanced ($P \leq 0.05$) for WMOL and YCUB than YMOL steers. Maternal year-round supplementation of range cubes or molasses + urea either did not impact or decrease growth, immune function, and carcass characteristics of the offspring when compared with maternal supplementation of molasses + urea during winter only.

Key words: feedlot performance, fetal-programming, molasses + urea, range cubes, supplementation frequency

Abbreviations: ADG, average daily gain; BCS, body condition score; BVDV, bovine viral diarrhea virus type; BW, body weight; CP, crude protein; DM, dry matter; G:F, gain:feed; HCW, hot carcass weight; IGF-1, insulin-like growth factor 1; IgG, immunoglobulin G; IVDOM, in vitro digestible organic matter; LMA, longissimus muscle area; NEFA, non-esterified fatty acid; NEg, net energy for gain; NEm, net energy for maintenance; PI-3, parainfluenza-3 virus

Introduction

Warm-season forages that dominate the Southeast United States do not always meet the monthly nutrient requirements of fall-calving grazing beef cows (NASEM, 2016). The limited nutritive value of warm-season grasses may lead to body condition score (BCS) loss during the first and third trimester of gestation (Palmer et al., 2020; Moriel et al., 2020a; Silva et al., 2021) and the need to provide relatively large amounts of supplemental protein and energy during winter. Nutrient restriction during the first (Long et al., 2009, 2012), second

(Underwood et al., 2010), or third (Moriel et al., 2016) trimester of gestation is detrimental to fetal development and long-term calf postnatal growth performance. In addition, increased refusals of salt-based trace mineral supplement were observed in the fall and winter months (Arthington and Swenson, 2004), which could impact overall trace mineral status of cows during gestation and modulate calf long-term performance (Marques et al., 2016b; Harvey et al., 2021). We are unaware of similar studies exploring year-round supplementation of protein and energy as a strategy to improve

cow BCS and as a vehicle for better salt-based trace mineral supplementation during gestation of *Bos indicus*-influenced beef cows. Marques et al. (2016a) revealed that increasing cow BCS during the second and third trimester of gestation improved calf preweaning growth compared to maintaining cows at an adequate BCS throughout the entire gestational period. It was hypothesized that year-round supplementation of protein and energy, regardless of supplement type, would increase BCS and liver trace mineral concentrations of cows during gestation, leading to enhanced calf postnatal performance compared to supplementation of protein and energy only during winter.

Supplement type offered during gestation can alter gene expression in fetal muscle and adipose tissue (Peñagaricano et al., 2014) and influence postnatal growth and carcass characteristics of the beef offspring (Radunz et al., 2012). In the Southeast United States, sugarcane molasses + urea and wheat middling-based range cubes are among the supplementation options for cow-calf operations. Molasses + urea and wheat middling-based range cubes differ in their carbohydrate profile, with sucrose being the primary carbohydrate of molasses (Pate, 1983) and starch plus digestible fiber as the primary carbohydrates of wheat middling-based range cubes (Poore et al., 2002). Mature cows supplemented with either a dry-based (citrus pulp) or liquid-based (molasses) supplement had a reduction in the amount of time required to complete supplement consumption and a decrease in daily forage intake on days when supplement was offered, which consequently led to alterations in circulating hormones and metabolites between the two dietary treatments (Cooke et al., 2007). Therefore, it was also hypothesized that supplement type (liquid molasses vs. dry range cubes) utilized in the year-round supplementation strategy will change cow circulating plasma concentrations of hormones and metabolites and subsequently alter calf postnatal productive performance. Therefore, the objectives of the present study were to evaluate the effects of supplement strategy (year-round vs. winter supplementation) and type (cubes vs. molasses) of mature *Bos indicus*-influenced cows on cow BCS and plasma concentrations of hormones and metabolites and subsequent impacts on offspring postnatal growth, immune function, and carcass characteristics.

Materials and Methods

A 2-yr study was performed at the University of Florida, Institute of Food and Agricultural Sciences, Range Cattle Research and Education Center (RCREC), Ona, Florida (27°23′N and 81°56′W) from June 2017 to August 2018 (year 1) and June 2018 to July 2019 (year 2). All procedures described herein were approved by the University of Florida Animal Care and Use Committee (#201709771).

Animals and diets
Precalving (days 0 to 161) and preweaning (days 162 to 421)

Prior to the initiation of the study, all mature cows utilized herein were previously sorted into four groups (20 to 21 cows/group), bred by natural service (1 Brangus bull/pasture; bulls rotated among pastures every 28 d during the breeding season), and confirmed pregnant by a trained veterinarian. On day 0 of each year (June; approximately day 122 ± 23 of gestation), pregnant, multiparous, Brahman × Angus crossbred cows (n = 82 to 84 cows/yr; age = 8 ± 3 yr) were stratified by initial body weight (BW; 475 ± 67 kg) and body condition score (BCS; 4.85 ± 0.73) and allocated randomly to 1 of 6 bahiagrass pastures (13 to 14 cows/pasture; 8.6 ha/pasture/yr). Pastures were divided in two paddocks and grazed with a rotational stocking rate with 7-d grazing and 7-d resting periods. Rotational stocking was utilized to enhance forage accumulation and grazing efficiency (Stewart et al., 2005). Treatments were randomly assigned to pasture (experimental unit; 2 pastures/treatment/yr) and consisted of the conventional maternal supplementation of sugarcane (*Saccharum officinarum*) molasses + urea during winter (days 150 to 299; WMOL), or maternal year-round supplementation of sugarcane molasses + urea (YMOL; days 0 to 365) or wheat middling-based range cubes (YCUB; days 0 to 365). All treatments provided a total annual supplement DM amount of 272 kg/cow, but the respective monthly supplement DM offered to cows differed among treatments (Table 1). The total quantity of supplement provided by the year-round supplements (YMOL and YCUB) was distributed throughout the year, but not uniformly (Table 1), allowing greater supplemental DM consumption during late-fall and winter (days 150 to 299) than the remainder of the year to avoid excessive cow BCS loss during early postpartum. Range cubes were formulated to provide equal daily amounts of total digestible nutrients (TDN) and crude protein (CP) on a DM basis compared with YMOL supplements (Table 2). Sugarcane molasses + urea supplements have self-limiting characteristics allowing for infrequent supplement delivery and reduced labor without detrimental impacts to cattle performance (Moriel et al., 2019). For this reason, the respective weekly DM amount

Table 1. Supplement DM offered of cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB; 13–14 cows/pasture; 2 pastures/treatment/yr)

Treatments[1,2]	June day 0	July day 30	Aug day 60	Sept day 90	Oct day 120	Nov day 150	Dec day 180	Jan day 210	Feb day 240	Mar day 270	Apr day 300	May day 360
					---------Supplement DM offered (kg/cow/d)---------							
WMOL	0	0	0	0	0	1.81	1.81	1.81	1.81	1.81	0	0
YMOL	0.23	0.23	0.68	0.68	0.68	1.14	1.36	1.36	1.14	1.14	0.23	0.23
YCUB	0.23	0.23	0.68	0.68	0.68	1.14	1.36	1.36	1.14	1.14	0.23	0.23

[1]YCUB supplements were formulated to deliver equal daily amounts of supplemental TDN and CP compared with YMOL supplements. Total yearly supplement DM amount was 272 kg/cow, regardless of treatment. Cows had ad libitum access to limpograss (*Hermathria altissima*) hay (IVDOM = 38.3% of DM; CP = 6.0% of DM) from days 217 to 301.
[2]Calving occurred on average on day 161 of the study while the breeding season occurred from days 217 to 301.

Table 2. Average nutritional composition[1] (DM basis) of range cubes and sugarcane (*Saccharum officinarum*) molasses + urea supplements

Item[2]	Range cubes [2]		Sugarcane molasses + urea [3]	
	year 1	year 2	year 1	year 2
DM, %	88.6	94.7	80.0	83.3
CP, %	18.8	18.8	20.9	21.0
Crude fat, %	–	–	1.5	1.4
ADF, %	12.4	13.2	–	–
aNDF, %	33.3	30.5	–	–
TDN, %[4]	77.0	77.0	75.0	75.0

[1]Samples of range cubes and sugarcane molasses + urea supplements were collected every 28 d throughout the study. Samples were composited within year and sent in duplicate to a commercial laboratory (Dairy One Forage Laboratory, Ithaca, NY) for wet chemistry analysis.
[2]Range cubes (Walpole Feed and Supply; Okeechobee, FL) consisted of 96.5% wheat middlings, 1.31% Ca carbonate, 0.93% binding agent (GeoBond; Bennett Mineral Company Inc., Walkerton, VA), 0.85% urea, and 0.75% Ca propionate (DM basis).
[3]As-fed basis: 92% liquid sugarcane molasses, 4% urea, and 4% water (Westway Feed Products LLC, Clewiston, FL).
[4]Calculated based on Weiss et al. (1992).

of YMOL and WMOL supplements were divided into two equal feeding events and offered in open plastic tanks every Tuesday and Friday at 0800 h. Tanks were placed 1 m above ground to avoid calf consumption of maternal supplementation from birth until weaning (day 421). Range cubes were also delivered twice weekly (Tuesdays and Fridays at 0800 h) to avoid confounding effects of different supplementation frequency compared to WMOL and YMOL supplementation. All cows were limit-fed the same commercial salt-based trace mineral/vitamin mixture throughout the study (16.8% Ca, 4% P, 21% NaCl, 1% Mg, 60 ppm Co, 1,750 ppm Cu, 350 ppm I, 60 ppm Se, 5,000 ppm Zn, 441 IU/g Vitamin A, 33 IU/g Vitamin D_3, and 0.44 IU/g of Vitamin E; University of Florida Cattle Research Winter Mineral; Vigortone, Brookville, OH). The weekly amount of trace mineral/vitamin mixture (357 g/cow/wk) was divided into two equal amounts and offered every Tuesday and Friday at 0800 h to achieve an average daily trace mineral/vitamin mixture intake of 51 g/cow. The trace mineral/vitamin mixture was mixed into YMOL and YCUB supplements throughout the study but offered to WMOL cows in separate plastic feed bunks. Any weekly refusals of trace mineral/vitamin mixture observed for WMOL cows were weighed, recorded, and discarded. This approach was utilized to mimic conventional supplementation strategies adopted by commercial cow-calf operations in Florida. In addition, mixing trace mineral/vitamin supplement with supplemental protein and energy for consistent mineral intake is one of the advantages of the year-round supplementation strategy.

Cows were monitored daily for signs of calving with the average calving date occurring on day 161 ± 23. Calves were weighed, tagged, and castrated if male, within the first 24 h of life but after consumption of maternal colostrum. Cows and calves were offered ad libitum access to limpograss (*Hemarthria altissima*) hay (in vitro digestible organic matter, IVDOM = 38.3% of DM; CP = 6.0% of DM) throughout the breeding season (days 217 to 301). During the breeding season, one mature Brangus bull (6 ± 3 yr of age) was placed in each group of cows. Bulls were rotated between treatment groups every 28 d. All bulls were observed daily for signs of injury and breeding activity. If necessary, bulls were replaced with another mature Brangus bull.

At the end of the breeding season (day 301), all calves were vaccinated against *clostridia* (2 mL s.c.; Ultrabac 8, Zoetis, Parsippany, NJ), infectious bovine rhinotracheitis, bovine viral diarrhea virus type 1 and 2 (BVDV-1 and 2), parainfluenza-3 (PI_3) virus, bovine respiratory syncytial virus, and *Mannheimia haemolytica* (2 mL s.c.; Bovi Shield Gold One Shot, Zoetis), and all cows and calves were treated with an oral anthelmintic (2.3 mL/45 kg of BW; Safe-Guard; Merck Animal Health, Madison, NJ). All calves were weaned on day 421 at 260 ± 24 d of age.

Postweaning (day 422 to slaughter)

At time of weaning (day 421), 33 (year 1) and 35 (year 2) steer calves (11 to 13 steer calves/maternal treatment; 3 to 8 steer calves/maternal treatment pasture) were randomly selected for a postweaning period in the feedlot. The selected steers were revaccinated with Ultrabac 8 (2 mL s.c.; Zoetis) and Bovi Shield Gold (2 mL s.c.; Zoetis) and immediately loaded onto a commercial trailer and transported for 1,193 km to a feedlot facility at North Carolina State University, Butner Beef Cattle Field Laboratory (36.18′N and 78.81′W). The combination of multiple stressors (weaning, transportation, and vaccination) was utilized to challenge the immune system of steers and to evaluate potential carryover effects of previous maternal supplemental treatment on offspring innate and humoral immune responses. At arrival (day 422), all steers were housed in a single 0.76-ha holding tall fescue (*Lolium arundinaceum*) pasture and had ad libitum access to water, free choice access to fescue hay (57% TDN and 10.4% CP) and were offered corn silage (0.4% to 5.0% of BW from days 422 to 435; 58% TDN and 9.2% CP) for 14 d. On day 435, all steers were treated for internal and external parasites with a topical (5 mL/50 kg; Ivermectin; Durvet, Blue Springs, MO) and oral (2.3 mL/45 kg; Safe-Guard; Merck Animal Health) anthelmintic and implanted with 200 mg of trenbolone acetate and 40 mg of estradiol (Revalor-XS; Merck Animal Health). Thereafter, steers were grouped according to previous maternal pasture assignment from day 0 to calf weaning on day 421, and then randomly allocated into 1 of 12 covered slatted concrete floor pens (130 m² and 2 to 3 steers/pen/yr) and were managed similarly until slaughter (days 661 and 623 of years 1 and 2, respectively). All steers were fed the same growing and finishing diet once daily at 0800 h. The growing and finishing diets consisted of 90% and 34% corn silage, 3.42% and 55.33% ground corn, 6.02% and 9.37% soybean meal, 0.36% and 1.06% limestone, 0.11% and 0.20% trace mineral supplement (91.5% NaCl, 1% Zn, 5000 ppm Cu, 2500 ppm Mn, 104 ppm I, 104 ppm Se, and 72 ppm Co), 0.0045% and 0.0312% monensin (Rumensin 90, Elanco Aimal Health, Greenfield, IN), and 0.0135% and 0.0264% vitamin ADE premix (9,922 IU/g of Vitamin A, 2,205 IU/g of Vitamin D_3, and 4.41 IU/g of Vitamin), respectively. Nutritional composition of growing and finishing diets is shown in Table 3. Steers were fed the growing diet for 104 and 86 d in years 1 and 2, respectively. Steers were transitioned from the growing diet to the finishing diet over an 8-d period by simultaneously decreasing the percentage of corn silage and increasing the percentage of concentrate by 6% daily. The finishing diet was fed for a total of 111 and 95 d in years 1 and 2, respectively.

At the end of the finishing period, all steers were loaded onto a commercial livestock trailer and transported for 790 km to a commercial packing facility (Cargill, Wyalusing, PA). During the feedlot period, steers were observed daily for signs of illness by trained personnel. In year 2, 2 steers (1 YMOL and 1 WMOL) were treated with antibiotics for lacerations and 1 steer (YMOL) for foot rot. An experimental timeline is presented in Figure 1.

Data collection

Herbage mass, herbage allowance, and forage nutritive value were determined from pastures on days 0, 74, 122, 161, 217, 301, and 360. The double sampling technique was utilized to determine herbage mass (Gonzalez et al., 1990). Thereafter, herbage allowance was calculated by dividing the herbage mass by the total cow (and calf) BW per pasture (Sollenberger et al., 2005). Forage nutritive value was assessed by collecting hand-plucked forage samples from each pasture. Immediately following collection, forage samples were dried in a forced-air oven at 60 °C for 72 h and then ground through a 1-mm stainless steel screen (Model

4, Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ). Trace mineral/vitamin mixture refusals were dried at 60 °C in a forced air oven for 48 h. The dry weight of trace mineral/vitamin mixture refused was subtracted from the total amount of trace mineral/vitamin mixture offered on a dry matter basis to determine supplemental trace mineral/vitamin mixture intake. Samples of sugarcane molasses + urea and range cube were collected every 28 d from days 0 to 360. Samples of the total mixed ration (TMR) fed during the growing and finishing phases were collected every 2 wk. All grain-based samples (range cubes and TMR) were dried in a forced-air oven at 60 °C for 72 h and ground through a 1-mm screen prior to nutrient analysis (Model 4, Thomas-Wiley Laboratory Mill, Thomas Scientific).

Cow full BW and BCS were collected on days 0, 56, 74, 122, 161, 217, 241, 269, 301, and 360 of each year. Calf full BW was collected within 24 h of birth and on days 217, 269, 301, 360, and 421 of each year. Full BW was collected from cows and calves to minimize the physiological stress that occurs with food and water withdraw when shrunk BW is utilized and avoid detrimental impacts to calf postnatal performance (Littlejohn et al., 2016). Individual calving date of first and second offspring was recorded to evaluate calving distribution. The second calf offspring is classified as the calf that was conceived during the breeding season which was initiated on day 217 and concluded on day 301 of the study. The percentage of pregnant cows was determined on day 360 via rectal palpation by a trained veterinarian.

Samples of liver tissue (100 mg of wet tissue) were collected from cows (4 to 5 cows/pasture randomly selected on day 0) on days 0, 122, 217, and 360, using biopsy procedures described by Arthington and Corah (1995). Briefly, liver tissue samples were collected from the intercostal spacing between the 11th and 12th rib using a Tru-Cut biopsy needle (CareFusion; 14 gauge × 15 cm; Becton Dickinson, Vernon Hills, IL). Liver samples were immediately placed on ice following collection and stored at –20 °C until samples could be shipped to a commercial laboratory for mineral analysis. Blood samples were collected from jugular vein (6 cows/pasture/yr randomly selected on day 0) into sodium-heparin containing tubes (10 mL; 158 USP; Vacutainer, Becton Dickson) to evaluate plasma concentrations of glucose, non-esterified fatty acids (NEFA), and insulin-like growth factor 1 (IGF-1) on days 0, 56, 122, 161, 217, 241, 269, and 301. Within the first 24 h of birth, blood samples from three male and three female calves/pasture were collected from jugular vein into tubes containing no additive (10 mL; Vacutainer, Becton Dickson) to determine the plasma concentrations of immunoglobulin G (IgG). Blood samples were collected from jugular vein of steers selected for

Table 3. Nutritional composition (DM basis) of the growing and finishing diets offered to steers during the feedlot phase (day 435 until slaughter)

Item[1]	Growing phase[2]		Finishing phase[2]	
	Year 1	Year 2	Year 1	Year 2
DM, %	39.7	40.8	69.2	71.4
CP, %	15.3	13.7	14.2	13.4
ADF, %	16.6	17.8	6.9	9.5
NDF, %	28.5	31.5	13.7	18.6
Ash, %	4.4	4.6	3.6	5.1
Ca, %	0.47	0.65	0.70	0.37
P, %	0.32	0.34	0.34	0.35
Mg, %	0.21	0.23	0.15	0.19
K, %	1.09	1.11	0.74	0.83
Na, %	0.11	0.11	0.13	0.13
Fe, ppm	111	219	84	95
Mn, ppm	41	68	44	65
Zn, ppm	55	62	57	70
Cu, ppm	22	21	16	18

[1]Growing and finishing diet samples were collected every 14 d. Samples were composited within each year and sent in duplicate to a commercial laboratory (Cumberland Valley Analytical Service, Waynesboro, PA) for wet chemistry analysis.
[2]The growing and finishing diets were fed for 104 d (year 1) and 86 d (year 2) and for 111 d (year 1) and 95 d (year 2), respectively.
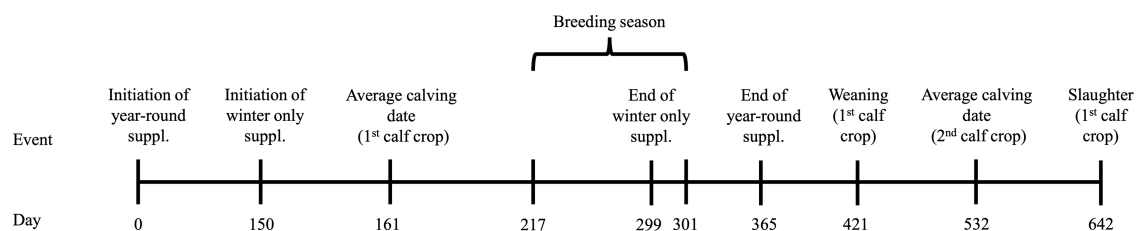
Figure 1. Experimental timeline of cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB).

the feedlot phase into: 1) sodium-heparin containing tubes (10 mL; 158 USP; Vacutainer, Becton Dickson) on days 421, 422, 423, 428, 435, and 463 to assess the plasma concentrations of haptoglobin and cortisol; and 2) tubes containing no additive (10 mL; Vacutainer, Becton Dickson) on days 301, 421, and 463 to determine the serum neutralization titers for PI_3 and BVDV-1. All blood samples were placed on ice immediately following collection and then centrifuged at 2,000 × g for 20 min at 4 °C. Serum and plasma samples were stored at –20 °C until further laboratory analysis.

Individual steer BW was collected immediately after unloading and arrival at the Butner Beef Cattle Field Laboratory (day 422), at feedlot entry (day 435), and then every 28 d until slaughter. Daily TMR intake was determined following feedlot entry by weighing the daily amount of TMR offered at 0800 h. Before the subsequent morning feeding, feed bunks were observed for any remaining orts. Orts were weighed and subtracted from the amount offered on the previous day. Samples of TMR were collected every 14 d to determine the DM percentage and to calculate the daily DMI of each feedlot pen. Hot carcass weights (HCW) were determined immediately following slaughter, whereas 12th-rib fat thickness, longissimus muscle area (LMA), and kidney, pelvic, and heart (KPH) fat were assessed following a 48-h chill period. Dressing percentage of individual steers was calculated by dividing HCW by the full BW obtained at feedlot exit.

Laboratory analysis

Forage samples were tested for N concentration using the micro-Kjeldahl technique (Gallaher et al., 1975) and multiplied by 6.25 to determine the CP concentration of each sample. The two-stage method as reported by Moore and Mott (1974) was used to assess IVDOM concentration. Samples of sugarcane molasses + urea, range cubes, and feedlot growing and finishing TMR were composited within each year prior to analysis. Molasses + urea and range cube samples were sent to Dairy One Forage Laboratory (Table 2; Ithaca, NY), whereas TMR samples were sent to Cumberland Valley Analytical Service (Table 3; Waynesboro, PA) for wet chemistry analysis.

Maternal liver and blood samples

Liver trace mineral concentrations were determined via inductively coupled plasma mass spectroscopy (Veterinary Diagnostic Laboratory, Michigan State University, Lansing, MI) and reported on a DM basis. Plasma concentrations of IGF-1 were evaluated using a human-specific commercial ELISA kit (SG100; R&D Systems, Inc, Minneapolis, MN) with 100% cross-reactivity to bovine plasma (Moriel et al., 2012). Commercial colorimetric kits were used to the determine the plasma concentrations of glucose (G7521; Pointe Scientific, Canton, MI) and NEFA (HR Series NEFA-2; Wako Pure Chemical Industries Ltd. USA, Richmond, VA). The intra- and inter-assay CVs for plasma concentrations of IGF-1, glucose, and NEFA were 2.88% and 3.25%, 2.00% and 1.75%, and 4.67% and 4.48%, respectively.

Offspring blood samples

A bovine-specific ELISA kit (E11-118; Bethyl Laboratories, Inc., Montgomery, TX) was utilized to assess the plasma concentrations of IgG. The intra- and inter-assay CV were 5.39% and 10.73%, respectively. Plasma concentrations of cortisol were determined using a bovine-specific chemiluminescent enzyme assay (Immulite 1000; Siemens Medical Solutions Diagnostics, Los Angeles, CA) with an intra- and inter-assay CV of 4.79% and 7.91%, respectively. A colorimetric assay (Cooke and Arthington, 2013) was used to determine the plasma concentrations of haptoglobin. The intra- and inter-assay CV for plasma haptoglobin were 2.29% and 2.74%, respectively.

Antibody titers against PI_3 and BVDV-1 viruses were assessed using procedures outlined by Rosenbaum et al. (1970) at the Oklahoma Animal Disease Diagnostic Laboratory (Stillwater, OK). Titer analysis identified the least and greatest dilutions for PI_3 and BVDV-1 as 1:4 and 1:256 and 1:4 and 1:1024, respectively. Individual serum samples were evaluated for the greatest dilution of antibody titers that achieved total protection of cells against PI_3 and BVDV-1 and are reported as the $\log_2$. Steers that had antibody titers for PI_3 and BVDV-1 ≥ 4 were considered seropositive and assigned a value of 1, whereas steers that had antibody titers < 4 for PI_3 and BVDV-1 were considered seronegative and assigned a value of 0. These scores were utilized to determine the percentage of steers that had positive seroconversion for antibody protection against PI_3 and BVDV-1 viruses as previously described by Richeson et al. (2008).

Statistical analysis

Except for binary data, all data were analyzed as a complete randomized design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC, version 9.4). Maternal prepartum pasture was considered the experimental unit for all dependent variables. Cow BW and BCS change, calf plasma IgG, offspring birth BW, calving date, steer average daily gain (ADG), steer DMI, gain:feed (G:F), and carcass measures were tested for the fixed effects of maternal treatment, year, and resulting interaction. Forage data, cow BCS, cow and calf BW, cow and calf blood data, trace mineral/vitamin mixture refusal, and liver trace mineral concentrations were analyzed as repeated measures and tested for the fixed effects of maternal treatment, year, day of study, and all resulting interactions. Binary data were analyzed using the GLIMMIX procedure of SAS (version 9.4). Positive seroconversion against PI_3 and BVDV-1 titers and calving distribution of second offspring were analyzed as repeated measures and tested for the fixed effects of maternal treatment, year, day of study, and all resulting interactions. Percentage of pregnant cows, cows that calved, and male calves at birth were tested for the fixed effects of maternal treatment, year, and the interaction. Pasture (maternal treatment × year) and cow (pasture) were included as random effects for all variables, except for forage and trace mineral/vitamin mixture refusal data which contained pasture (maternal treatment × year) as the random effect. Satterthwaite approximation was used to correct for the denominator degrees of freedom for all variables analyzed. Autoregressive (1) was used as the covariance structure for all forage data, whereas compound symmetry was used as the covariance structure for the remaining repeated measures analyses as they generated the lowest Akaike information criterion. Cow (pasture) or calf (pasture) was included as subjects. Calf sex and age and cow blood variables obtained on day 0 of each year were included as covariates but were removed from the model if $P > 0.10$. Results are reported as the least-square means with significance declared at $P \leq 0.05$ and tendencies observed at $0.05 < P \geq 0.10$. The PDIFF function in SAS was used to separate means when $P \leq 0.10$ was detected.

Results

Precalving (days 0 to 161) and preweaning (days 162 to 421)

Maternal treatment × day × year and maternal treatment × year effects were not detected ($P \geq 0.12$) for any of the variables measured herein. All forage data were covariate-adjusted ($P \leq 0.10$) for the respective forage variable on day 0. Maternal treatment × day and maternal treatment effects were not detected ($P \geq 0.40$) for any forage data. Effects of day were detected ($P < 0.001$) for herbage mass and herbage allowance. Herbage mass was least on days 0 and 360 but greatest on day 161 (Table 4). Herbage allowance was the greatest ($P < 0.001$) from days 74 to 122 and least on days 301 and 360 (Table 4). Effects of day were detected ($P < 0.05$) for forage CP and IVDOM. Forage CP was greatest ($P < 0.0001$) on day 0 and least on days 161 and 217 (Table 4). Forage IVDOM was greatest ($P < 0.05$) on day 0, least on days 161 and 217, but increased until day 360 (Table 4).

Cow BCS were covariate-adjusted ($P < 0.0001$) for cow BCS on day 0. A maternal treatment × day effect was detected ($P < 0.0001$; Figure 2A) for cow BCS. Cow BCS did not differ ($P \geq 39$) among treatments from days 0 to 74. On days 122 and 161, BCS was greater ($P \leq 0.03$) for YCUB and YMOL vs. WMOL cows; however, BCS of YCUB and YMOL cows did not differ ($P \geq 0.30$). On day 217, BCS was greater ($P = 0.01$) for YMOL vs. WMOL cows, whereas BCS of YCUB was intermediate ($P \geq 0.11$). On days 241 and 269, YMOL cows had greater ($P \leq 0.04$) BCS compared to WMOL and YCUB cows, whereas BCS of WMOL and YCUB cows did not differ ($P \geq 0.77$). On days 301 and 360, BCS of YMOL cows was greater ($P \leq 0.03$) compared to YCUB cows and tended ($P \leq 0.09$) to be greater compared to WMOL cows and did not differ ($P \geq 0.11$) between WMOL and YCUB cows.

Cow BW were covariate-adjusted ($P < 0.0001$) for cow BW on day 0. A maternal treatment × day effect was observed ($P < 0.0001$; Figure 2B) for cow BW. Cow BW did not differ ($P \geq 0.34$) among treatments on days 0, 56, 74, and 122. On day 161, cow BW was greater ($P \leq 0.03$) for YMOL vs. WMOL and YCUB cows but did not differ ($P = 0.78$) between WMOL and YCUB cows. On day 217, YMOL cows tended ($P = 0.09$) to have greater BW compared to YCUB cows; however, BW of WMOL cows did not differ ($P \geq 0.11$) compared with YMOL and YCUB cows. On days 241, 269,

and 301, YMOL cows had greater ($P \leq 0.04$) BW compared to YCUB cows, but WMOL cows did not differ ($P \geq 0.14$) from YMOL or YCUB. Body weight of YMOL cows tended ($P \leq 0.08$) to be greater than YCUB and WMOL cows on day 360; however, cow BW did not differ ($P = 1.00$) between YCUB and WMOL cows.

For the first calf offspring (calves in utero when the study began), the percentage of cows that calved, calving date, and calf birth BW was not influenced ($P \geq 0.22$: Table 5) by maternal treatment. Calf sex was used as a covariate ($P < 0.01$) for birth BW of first offspring. Calf plasma concentrations of IgG collected within the first 24 h of birth tended ($P = 0.10$; Table 5) to differ among treatments. Plasma concentrations of IgG were greater ($P = 0.03$) for WMOL vs. YMOL calves and were intermediate ($P \geq 0.26$) for YCUB calves. The percentage of pregnant cows on day 360 did not differ among treatments ($P = 0.93$; Table 5). For the second offspring (calves conceived during the breeding season and born between days 502 and 600), the percentage of cows that calved, calving date, percentage of male calves at birth, and calf birth BW did not differ ($P \geq 0.29$; Table 5) among treatments. Calving date was used as a covariate ($P < 0.01$) for birth BW of the second offspring. Effect of maternal treatment × day tended to be detected ($P = 0.10$; Figure 3) for calving distribution of the second offspring. A greater ($P \leq 0.03$) percentage of YMOL cows calved by days 537 and 544 compared to YCUB cows, whereas WMOL cows were intermediate ($P \geq 0.16$).

All plasma concentrations were covariate-adjusted ($P < 0.001$) for the respective plasma concentration on day 0. A tendency for a maternal treatment × day effect was detected ($P = 0.06$; Figure 4A) for cow plasma glucose concentrations. Plasma glucose concentrations were greater ($P \leq 0.01$) for YMOL and YCUB cows on day 56 compared to WMOL cows; however, plasma glucose concentrations for YMOL and YCUB cows did not differ ($P = 0.70$). A maternal treatment × day effect was detected ($P = 0.05$; Figure 4B) for plasma NEFA concentrations, which were greater on day 161 ($P \leq 0.0002$) for YCUB vs. WMOL and YMOL cows and did not differ ($P = 0.38$) between WMOL and YMOL cows. Effect of maternal treatment, but not maternal treatment × day ($P = 0.49$), was detected ($P = 0.01$) for plasma IGF-1 concentrations, which were greater ($P \leq 0.01$) for YMOL vs. YCUB and WMOL cows and did not differ ($P = 0.68$) between YCUB and WMOL cows (42.9, 38.1, and 38.8 ± 1.18 ng/mL for YMOL, YCUB, and WMOL, respectively). Additionally, a day

Table 4. Herbage mass, herbage allowance, crude protein (CP), and in vitro digestible organic matter (IVDOM) of bahiagrass (*Paspalum notatum*) pastures from days 0 to 360 (13–14 cows/pasture; 8.6 ha/pasture/yr; 2 pastures/treatment/yr)[1]

| Item[2,3]	Day of the study							SEM	P-value
	0	74	122	161	217	301	360		Day
Herbage mass, kg DM/ha	1963[a]	4708[c]	5326[e]	5050[d]	4018[b]	2219[a]	2255[a]	148	<0.0001
Herbage allowance, kg DM/ kg BW	2.56[b]	6.22[e]	5.98[e]	5.53[d]	4.33[c]	2.18[a]	1.97[a]	0.17	<0.0001
Crude protein, % of DM	17.7[e]	8.8[c]	7.3[b]	6.1[a]	6.5[a]	13.4[d]	13.4[d]	0.25	<0.0001
In vitro digestible organic matter, %	53.7[f]	42.6[d]	29.5[b]	24.8[a]	22.4[a]	37.9[c]	49.3[e]	1.20	<0.0001

[a,b]Within a row, means without a common superscript differ ($P \leq 0.05$).
[1]Herbage mass and allowance, CP, and IVDOM were covariate-adjusted for day 0 ($P \leq 0.10$).
[2]Herbage mass was determined using the double sampling procedure (Gonzalez et al., 1990). Herbage allowance was calculated by dividing the herbage mass by the total body weight in each pasture (Sollenberger et al., 2005). Forage IVDOM was determined using a modification of the two-stage method (Moore and Mott, 1974). Forage N concentration was determined using the micro-Kjeldahl technique (Gallaher et al., 1975) and then multiplied by 6.25 to determine the CP percentage of each sample.
[3]Calving occurred on average on day 161 of the study while the breeding season occurred from days 217 to 301.
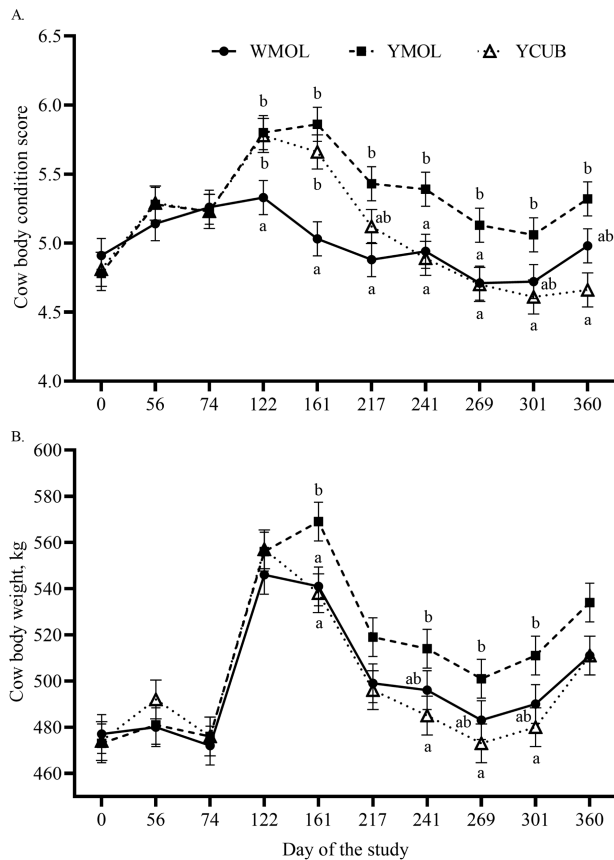
Figure 2. Body condition score (A; BCS) and body weight (B; BW) of cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB). Calving of first calf offspring occurred on average on day 161 of the study and the breeding season occurred from days 217 to 301. A treatment × day effect was observed ($P < 0.0001$) for cow BCS and BW. [a,b]Within day, means without common superscripts differ ($P \leq 0.05$).

effect was detected ($P < 0.0001$; Figure 5) for plasma IGF-1 concentrations. Plasma IGF-1 concentrations were greatest on day 122 and were least on day 269.

A maternal treatment × day effect was detected ($P < 0.0001$; Figure 6) for trace mineral/vitamin mixture refusals, which were greater ($P < 0.001$) for WMOL vs. YMOL and YCUB cows on days 84, 203, 210, 217, 224, 252, 259, 266, 273, and 279. All trace mineral liver concentrations were covariate-adjusted ($P < 0.0001$) for respective trace mineral status on day 0. Effects of maternal treatment × day or maternal treatment were not detected ($P \geq 0.22$; Table 6) for liver concentrations of Zn, Fe, and Mn. Effects of maternal treatment, but not maternal treatment × day effect ($P = 0.44$), tended to be detected ($P = 0.10$) for liver concentrations of Mo, which was greater ($P \leq 0.05$; Table 6) for YCUB vs. WMOL and YMOL cows and did not differ ($P = 0.85$) between WMOL and YMOL cows (3.79, 3.51, and 3.53 ± 0.119 μg/g for YCUB, WMOL, and YMOL, respectively). A maternal treatment × day effect was detected ($P \leq 0.01$; Table 6) for liver concentrations of Co, Cu, and Se. Liver Co concentrations did not differ ($P \geq 0.62$) among treatments on days 0 or 360 but were greatest ($P \leq 0.04$) for YCUB cows, intermediate for WMOL cows, and least for YMOL cows on day 122. On day 217, liver Co concentrations were greater ($P = 0.02$) for YCUB vs.

YMOL cows and tended ($P = 0.07$) to be greater for YCUB vs. WMOL cows. Liver Co concentrations did not differ ($P = 0.54$) between YMOL and WMOL cows on day 217. Liver Cu concentrations did not differ ($P \geq 0.86$) among treatments on day 0. Liver Cu concentrations on day 122 were greater ($P \leq 0.01$) for YCUB and WMOL vs. YMOL cows and did not differ ($P = 0.42$) between YCUB and WMOL cows. Liver Cu concentrations were greatest ($P \leq 0.05$) for YCUB, intermediate for WMOL, and least for YMOL cows on days 217 and 360. Liver Se concentrations did not differ ($P \geq 0.40$) among treatments on day 0 or 360. On days 122 and 217, liver Se concentrations were greater ($P \leq 0.03$) for YCUB cows than YMOL and WMOL cows and did not differ ($P \geq 0.54$) between YMOL and WMOL cows.

Calf preweaning BW gain included ($P = 0.03$) calf sex as a covariate, whereas calf preweaning ADG included ($P \leq 0.04$) both calf sex and calf age as covariates. First offspring preweaning BW was covariate-adjusted for calf sex ($P = 0.03$), whereas first offspring ADG from birth to weaning was covariate-adjusted for calf sex and age ($P \leq 0.04$). Effects of maternal treatment × day and maternal treatment were not detected ($P \geq 0.31$; Table 7) for first offspring preweaning BW and ADG from birth to weaning ($P = 0.83$; Table 7).

Postweaning (day 422 to slaughter)

A maternal treatment × day effect was detected ($P = 0.01$; Table 8) for plasma concentrations of cortisol, which were greater ($P \leq 0.01$) for YCUB than WMOL and YMOL steers on day 422 and did not differ ($P = 0.34$) between WMOL and YMOL steers. Effect of maternal treatment, but not maternal treatment × day ($P = 0.49$; Table 8), was detected ($P = 0.05$) for plasma concentrations of haptoglobin, which was greater ($P = 0.02$) and tended ($P = 0.08$) to be greater for YCUB than WMOL and YMOL steers, respectively. Effects of maternal treatment × day and maternal treatment were not detected ($P \geq 0.25$; Table 8) for serum titers against BVDV-1 and PI$_3$ viruses or seroconversion for BVDV-1 and PI$_3$ antibodies.

A maternal treatment × day effect was detected ($P = 0.02$; Table 9) for steer feedlot BW, which was greater ($P \leq 0.05$) at feedlot exit for YMOL and WMOL than YCUB steers and did not differ ($P = 0.97$) between YMOL and WMOL steers. Steer ADG from feedlot entry to feedlot exit was greater ($P = 0.02$; Table 9) for WMOL than YCUB steers, whereas YMOL did not differ from WMOL and YCUB ($P \geq 0.21$). Steer ADG from feedlot arrival to feedlot exit did not differ ($P = 0.11$) among treatments. Feedlot DM intake did not differ ($P \geq 0.37$; Table 9) among treatments. During the growing phase, G:F was greater ($P = 0.03$; Table 9) for YMOL than YCUB steers and were intermediate for WMOL and did not differ for YMOL and YCUB ($P \geq 0.16$). During the finishing phase or total feedlot period, G:F did not differ ($P \geq 0.42$) among treatments.

Hot carcass weight, dressing percent, LMA, KPH, yield grade, and marbling did not differ ($P \geq 0.14$; Table 10) among treatments. The 12th-rib fat thickness was greater ($P \leq 0.05$; Table 10) for WMOL than YCUB and YMOL steers and did not differ ($P = 0.70$) between YCUB and YMOL steers. The percentage of carcasses grading average choice did not differ ($P = 0.30$; Table 10) among treatments. The percentage of carcasses grading low choice was greater ($P \leq 0.05$) for WMOL and YCUB vs. YMOL steers and did not differ ($P = 0.31$) between WMOL and YCUB steers. The percentage of carcasses grading select was greater ($P \leq 0.02$) for YMOL vs. WMOL and YCUB steers and did not differ ($P = 0.87$) between WMOL and YCUB steers.

Table 5. Reproductive performance of cows and calf birth variables from calves born to cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB); 13–14 cows/pasture; 2 pastures/treatment/yr)

| Item[1] | Maternal treatment[2] | | | SEM | *P*-value |
	WMOL	YMOL	YCUB		Treatment
First offspring					
Calving date, day of study	164	161	158	4.3	0.65
Calving rate, %	95.7	95.7	94.2	2.35	0.91
Calf birth BW[3], kg	32	32	34	2.0	0.22
Calf plasma IgG[4], mg/mL	51.1[b]	37.7[a]	45.4[ab]	4.51	0.10
Second offspring					
Pregnant cows on day 360, %	77.9	75.7	74.4	7.28	0.93
Calving date, day of study	532	527	536	4.0	0.32
Calving rate, %	74.0	76.7	72.7	6.56	0.88
Male calves, %	52	39	55	9.4	0.29
Calf birth BW[5], kg	34	36	35	1.4	0.56

[a,b] Within a row, means without common superscript differ ($P \leq 0.05$).
[1] First offspring represents calves in utero when maternal treatments were provided. Second offspring represents calves conceived during the breeding season (days 217 to 301) and born between days 502 and 600.
[2] Range cubes and sugarcane molasses + urea supplements were isocaloric and isonitrogenous, and total yearly supplement offered to cows in each treatment was 272 kg of DM/cow.
[3] Covariate-adjusted for calf sex ($P < 0.01$).
[4] Calf plasma IgG concentrations were determined from blood collected within the first 24 of birth.
[5] Covariate-adjusted for calving date ($P < 0.01$).
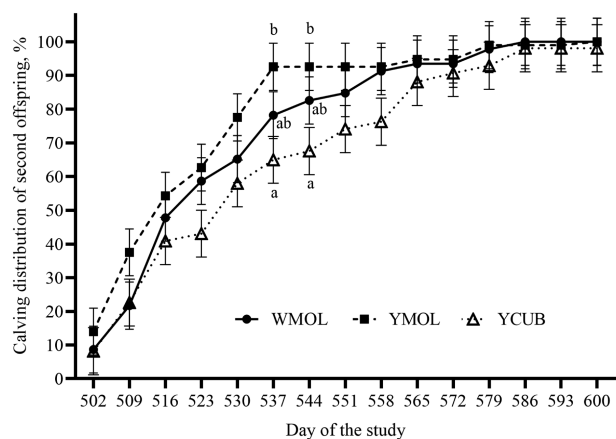
Figure 3. Calving distribution of second offspring born to cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB). Calves were conceived during the breeding season which occurred from days 217 to 301 of the study. Effects of treatment × week tended (*P* = 0.10) to be detected for calving distribution of second offspring. [a,b] Within day, means without common superscripts differ (*P* ≤ 0.05).

Discussion

### Precalving (days 0 to 161) and preweaning (days 162 to 421)

Maternal performance

Management of cow BCS during the gestational period is critical for cow reproductive success in the subsequent breeding season (Hess et al., 2005) and long-term effects on offspring performance (Marques et al., 2016a; Palmer et al., 2020; Moriel et al., 2020a). Cows assigned to WMOL supplementation lost BCS during final stages of the third trimester (days

122 to 161), whereas YMOL and YCUB supplementation were sufficient to maintain cow BCS during the same period. In the present study, herbage allowance was always above the minimum threshold (1.4 kg DM/ kg BW) to achieve ad libitum forage intake on warm-season grasses (Inyang et al., 2010). However, forage IVDOM was below cow energy requirements from days 74 to 360, whereas forage CP was below cow protein requirements from days 122 to 217 (NASEM, 2016). Therefore, the BCS loss of WMOL cows during final stages of third trimester of gestation can be attributed to the lack of precalving supplementation of protein and energy and reduced forage nutritive composition. In our previous studies, herbage allowance of bahiagrass pastures during the third trimester of gestation was slightly below (Palmer et al., 2020) or approximately 2.5-fold greater (Moriel et al., 2020a) than 1.4 kg DM/kg BW; however, in both studies, BCS of Brangus crossbred cows decreased during the third trimester of gestation when precalving supplementation of protein and energy was not provided. Combined, these results indicate that warm-season grasses did not provide sufficient TDN and CP to sustain cow BCS prior to calving, regardless of herbage allowance levels.

Year-round supplementation, regardless of supplement type, increased cow BCS from days 74 to 122, indicating that YMOL and YCUB cows were in a better nutritional status compared to WMOL cows. However, YCUB cows had greater BCS loss from day 122 until the end of the breeding season compared to WMOL and YMOL cows. This reduction in BCS of YCUB cows, despite receiving the same amount of supplemental TDN and CP as YMOL cows, can be potentially attributed to the frequency of supplementation utilized in the study (twice weekly on Tuesday and Friday) and the interaction between supplement type (dry vs. liquid) and feed intake behavior (Cooke et al., 2007). Cows offered range cubes consumed their total supplement allotment within the first hour after feeding, whereas cows offered liquid sugarcane
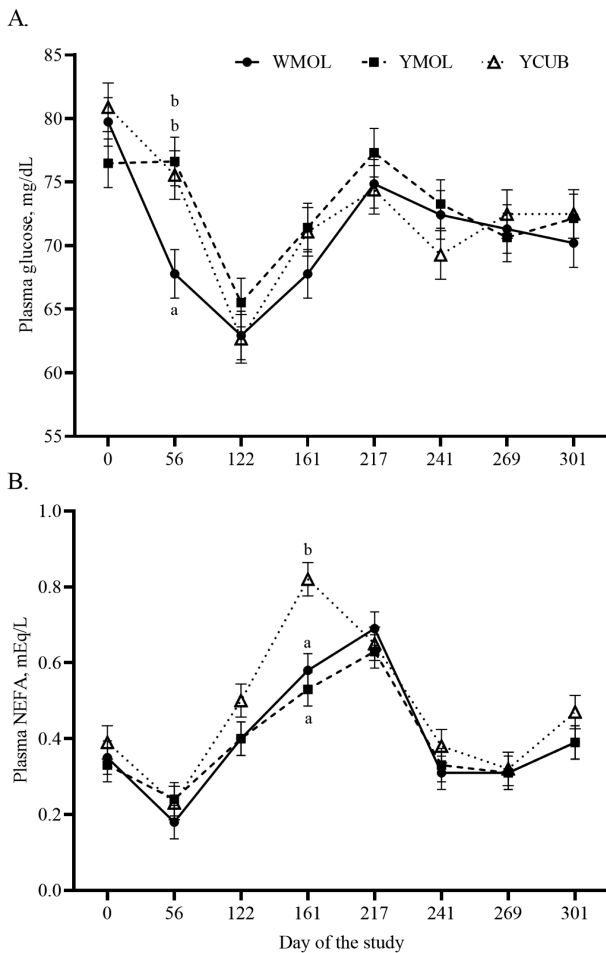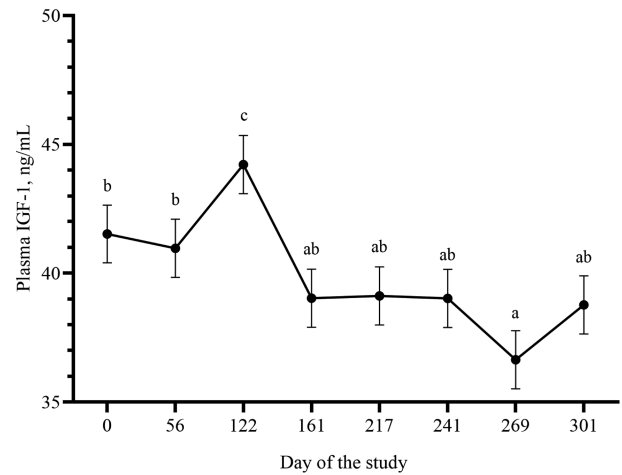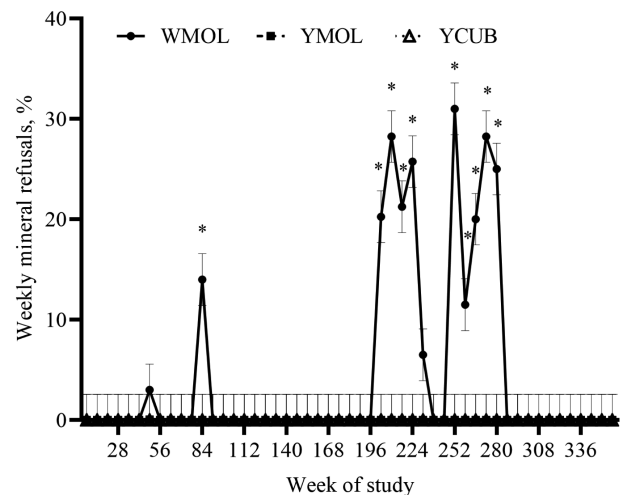
Figure 4. Plasma concentrations of glucose (A) and nonesterified fatty acids (B; NEFA) of cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB). Calving of first calf offspring occurred on average on day 161 of the study and the breeding season occurred from days 217 to 301. A maternal treatment × day effect was detected for plasma concentrations of glucose (*P* = 0.06) and NEFA (*P* = 0.05). [a,b]Within day, means without common superscripts differ (*P* ≤ 0.05).

Figure 5. Average daily plasma concentrations of insulin-like growth factor 1 (IGF-1) of cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB). Calving of first calf offspring occurred on average on day 161 of the study and the breeding season occurred from days 217 to 301. A day effect (*P* < 0.0001) was observed for plasma IGF-1 samples. [a,b]Days without common superscripts differ (*P* ≤ 0.05).

Figure 6. Trace mineral/vitamin mixture refusal (% of total weekly amount) by cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB). All cows were limit-fed the same commercial salt-based trace mineral/vitamin mixture throughout the study (target intake of 51 g/cow). The trace mineral/vitamin mixture was mixed into YMOL and YCUB supplements throughout the study but offered to WMOL cows in separate plastic feed bunks. Calving of first calf offspring occurred on average on day 161 of the study and the breeding season occurred from days 217 to 301. A maternal treatment × day effect was detected (*P* < 0.0001) for trace mineral/mixture supplement refusal. *Within day, WMOL mineral intake differs from YMOL and YCUB mineral intake (*P* ≤ 0.002).

molasses + urea required more than 24 h to consume the entire supplement DM amount offered. From days 150 to 300, supplemental TDN consumption of YCUB cows was ≥ 0.7% of their BW on days when supplementation was provided, which likely reduced voluntary forage intake (Moore et al., 1999). Infrequent supplementation of concentrate (for instance, 3×) has been shown to decrease the overall forage DM intake and growth performance of beef cattle compared to daily concentrate supplementation, which was attributed to the lower daily fluctuations in forage DM intake with frequent concentrate supplementation (Moriel et al., 2012; Artioli et al., 2015; Moriel et al., 2020b). Therefore, cows offered sugarcane molasses + urea had less daily fluctuations in supplement consumption within each week and likely had less fluctuations in forage DM intake compared to cows supplemented with range cubes, resulting in less detrimental effects to cow BCS change.

The percent of pregnant cows at pregnancy diagnosis, percent of cows that calved, and calving date of the second offspring did not differ among maternal treatments even though YMOL and YCUB cows had greater BCS at calving compared to WMOL cows. Despite the lesser BCS, WMOL cows calved in an acceptable BCS (BCS ≥ 5; Richards et al., 1986) and lost less BCS (−0.15) from calving until the start

Table 6. Liver trace mineral concentrations of cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB; 13–14 cows/pasture; 2 pastures/treatment/yr)

| Item[1,2] | Maternal treatment[3] | | | SEM | P-value | |
	WMOL	YMOL	YCUB		Treatment	Treatment × day
Co, µg/g of dry tissue						
day 0	0.32	0.33	0.33	0.015	0.06	0.01
day 122	0.31[b]	0.26[a]	0.35[c]			
day 217	0.28[ab]	0.26[a]	0.32[b]			
day 360	0.27	0.28	0.27			
Cu, µg/g of dry tissue						
day 0	148.3	146.4	146.0	9.49	0.004	<0.0001
day 122	147.7[b]	112.2[a]	158.8[b]			
day 217	155.9[b]	107.9[a]	193.7[c]			
day 360	123.4[b]	96.9[a]	191.3[c]			
Fe, µg/g of dry tissue						
day 0	307.8	286.9	313.7	17.47	0.73	0.72
day 122	325.6	341.1	321.1			
day 217	404.0	372.8	375.4			
day 360	329.4	325.5	323.1			
Mn, µg/g of dry tissue						
day 0	12.6	12.7	12.8	0.53	0.43	0.22
day 122	8.4	8.8	9.4			
day 217	10.1	9.5	10.0			
day 360	10.0	9.8	11.5			
Mo, µg/g of dry tissue						
day 0	3.75	3.82	3.84	0.156	0.10	0.44
day 122	3.33	3.41	3.84			
day 217	3.57	3.45	3.62			
day 360	3.39	3.46	3.88			
Se, µg/g of dry tissue						
day 0	1.13	1.14	1.13	0.046	0.03	<0.0001
day 122	0.90[a]	0.88[a]	1.05[b]			
day 217	1.09[a]	1.05[a]	1.48[b]			
day 360	0.84	0.88	0.90			
Zn, µg/g of dry tissue						
day 0	145.7	141.3	145.0	5.70	0.74	0.96
day 122	134.7	134.5	139.8			
day 217	140.4	136.7	137.1			
day 360	141.9	134.4	141.2			

[a,b]Within a row, means without common superscript differ ($P \leq 0.05$).

[1]Calving occurred on average on day 161 of the study while the breeding season occurred from days 217 to 301.

[2]All liver trace minerals covariate-adjusted for respective trace mineral concentration on day 0 ($P < 0.0001$)

[3] Range cubes and sugarcane molasses + urea supplements were isocaloric and isonitrogenous, and total yearly supplement offered to cows in each treatment was 272 kg of DM/cow. The trace mineral/vitamin mixture was mixed into YMOL and YCUB supplements throughout the study but offered to WMOL cows in separate plastic feed bunks.

of the breeding season compared to YMOL and YCUB cows, which likely explains the lack of treatment effects on cow pregnancy and calving percentages. Nonetheless, a greater percentage of YMOL cows calved their second offspring by days 537 and 544 compared to YCUB cows, which can be attributed to the greater BCS throughout the breeding season of YMOL vs. YCUB cows. In support, molasses + urea supplementation (1.07 kg/d) of mature *Bos indicus*-influenced cows from 47 ± 2.7 d prepartum to 23 ± 2.7 d postpartum improved

cow BCS at calving and at the start of the breeding season and led to cows calving 8 d earlier in the subsequent calving season compared to nonsupplemented cows (Palmer et al., 2020).

The nutritional status of cows during pre- and postpartum periods influences plasma concentrations of IGF-1 (Perry et al., 2002; Sullivan et al., 2009; Samadi et al., 2013). The somatotropic axis plays a critical role in reproduction (Chandrashekar et al., 2004), and increased IGF-1 concentrations in dairy cattle are associated with improved pregnancy

Table 7. Preweaning body weight gain of first offspring born to cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB; 13–14 cows/pasture; 2 pastures/treatment/yr)

| Item[1] | Maternal treatment[2] | | | SEM | P-value | |
	WMOL	YMOL	YCUB		Treatment	Treatment × day
First offspring BW[3], kg						
day 217	82	84	90	3.6	0.61	0.31
day 241	99	101	107			
day 269	120	121	124			
day 301	149	149	152			
day 360	209	210	211			
day 421	254	253	257			
First offspring ADG[4], kg/d						
Birth to weaning	0.86	0.84	0.84	0.02	0.83	-

[1]Maternal breeding season occurred from days 217 to 301 and weaning occurred on day 421.
[2]Range cubes and sugarcane molasses + urea supplements were isocaloric and isonitrogenous, and total yearly supplement offered to cows in each treatment was 272 kg of DM/cow.
[3]Covariate-adjusted for calf sex ($P = 0.03$).
[4]Covariate-adjusted for calf sex and age ($P \leq 0.04$).

Table 8. Postweaning plasma and serum data of steers born to cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB; 13–14 cows/pasture; 2 pastures/treatment/yr)

| Item[1] | Treatment[2] | | | SEM | P-value | |
	WMOL	YMOL	YCUB		Treatment	Treatment × day
Plasma cortisol, µg/dL						
day 421	2.09	2.19	2.38	0.23	0.17	0.01
day 422	2.54[a]	2.23[a]	3.58[b]			
day 423	2.50	2.37	2.91			
day 428	2.03	1.87	2.32			
day 435	2.01	1.74	2.32			
day 463	1.64	1.35	1.35			
Plasma haptoglobin, mg/mL	0.25[a]	0.26[ab]	0.32[b]	0.021	0.05	0.49
Serum BVDV-1[3]						
Titers, $\log_2$	3.53	3.71	4.41	0.391	0.25	0.45
Seroconversion, % total	75	89	85	5.8	0.31	0.58
Serum PI$_3$[3]						
Titers, $\log_2$	2.49	2.74	2.92	0.332	0.68	0.86
Seroconversion, % total	66	67	60	7.0	0.76	0.73

[a,b]Within a row, means without common superscript differ ($P \leq 0.05$).
[1]Calves received an oral anthelmintic (2.3 mL/45 kg of BW; Merck Animal Health, Madison, NJ) and vaccination against *clostridium* (2 mL s.c.; Ultrabac 8, Zoetis, Parisppany, NJ) and respiratory pathogens (2 mL s.c.; Bovi Shield Gold One Shot, Zoetis) on day 301. Calves were vaccinated with Ultrabac 8 (2 mL s.c.; Zoetis) and Bovi Shield Gold (2 mL s.c.; Zoetis) on day 421.
[2]Range cubes and sugarcane molasses + urea supplements were isocaloric and isonitrogenous, and total yearly supplement offered to cows in each treatment was 272 kg of DM/cow.
[3]Serum neutralization titers against PI$_3$ and BVDV-1were determined on days 301, 421, and 463. Serum titers are reported as the $\log_2$ of the greatest dilution of serum that provided complete protection of cells. Positive seroconversion was determined when serum neutralization values were ≥ 4. All steers had serum BVDV-1 and PI$_3$ neutralization values < 4 on day 301.

outcomes (Falkenberg et al., 2008; Gobikrushanth et al., 2018). In the present study, average plasma concentrations of IGF-1 were greater for YMOL cows compared to YCUB and WMOL cows. Ciccioli et al. (2003) reported that cows managed on a higher plane of nutrition (ad libitum access to feed) vs. a moderate plane of nutrition (limit-fed 2 kg/d) had greater BCS gain and increased plasma IGF-1 concentrations during a 71-d postpartum period. Furthermore, cows on the high nutrition diet had greater reproductive performance, as evidenced by a reduction in the postpartum interval and greater pregnancy percentages at first estrus (Ciccioli et al., 2003). Combined, these results support our rationale that YMOL cows were in a better nutritional status compared to YCUB which likely increased the percentage of cows pregnant earlier in the breeding season.

Table 9. Postweaning feedlot performance of steers born to cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB; 13–14 cows/pasture; 2 pastures/treatment/yr)

| Item[1] | Maternal treatment[2] | | | SEM | P-value | |
	WMOL	YMOL	YCUB		Treatment	Treatment × day
BW, kg						
Arrival	248	257	247	7.6	0.34	0.02
Feedlot entry	247	256	248			
End of growing phase	398	409	390			
Feedlot exit	564[b]	563[b]	542[a]			
ADG, kg/d						
Receiving phase	−0.08	−0.10	0.05	0.09	0.56	–
Growing phase	1.60[ab]	1.63[b]	1.51[a]	0.04	0.10	–
Finishing phase	1.49	1.38	1.36	0.05	0.21	–
Feedlot entry to exit	1.54[b]	1.49[ab]	1.43[a]	0.04	0.08	–
Arrival to feedlot exit	1.44	1.39	1.34	0.03	0.11	–
DMI, kg/d						
Growing phase	7.04	7.25	7.10	0.20	0.77	–
Finishing phase	9.04	8.78	8.45	0.30	0.37	–
Total	8.12	8.08	7.83	0.24	0.64	–
G:F						
Growing phase	0.21[ab]	0.22[b]	0.20[a]	0.005	0.08	–
Finishing phase	0.17	0.16	0.17	0.01	0.42	–
Total	0.18	0.18	0.18	0.005	0.97	–

[a,b]Within a row, means without common superscript differ ($P \leq 0.05$).
[1]Steers arrived at the feedlot on day 422, were kept on pasture 14 d following arrival, and entered the feedlot pens on day 435. The growing diet was fed for 104 and 86 d in years 1 and 2, respectively. The finishing diet was fed for 111 and 95 d in years 1 and 2, respectively.
[2] Range cubes and sugarcane molasses + urea supplements were isocaloric and isonitrogenous, and total yearly supplement offered to cows in each treatment was 272 kg of DM/cow.

Table 10. Carcass measurements of steers born to cows grazing bahiagrass (*Paspalum notatum*) pastures and offered supplementation of sugarcane (*Saccharum officinarum*) molasses + urea from days 150 to 299 (WMOL), or year-round supplementation (days 0 to 365) of sugarcane molasses + urea (YMOL) or range cubes (YCUB; 13–14 cows/pasture; 2 pastures/treatment/yr)

| Item | Maternal treatment[1] | | | SEM | P-value |
	WMOL	YMOL	YCUB		Treatment
Hot carcass weight, kg	337	334	323	6.2	0.28
Dressing percent[2], %	59.7	59.4	59.9	0.33	0.55
12th rib fat thickness, cm	1.77[b]	1.53[a]	1.48[a]	0.084	0.04
Longissimus muscle area, cm^2	78.9	79.2	77.4	1.45	0.64
KPH, %	2.95	2.81	2.92	0.13	0.72
Yield grade	3.8	3.5	3.5	0.13	0.14
Marbling[3]	522	519	527	14	0.92
Average choice, %	5	17	17	6.4	0.30
Low choice, %	72[b]	31[a]	58[b]	10	0.01
Select or less, %	23[a]	53[b]	25[a]	8	0.02

[a,b]Within a row, means without common superscript differ ($P \leq 0.05$).
[1] Range cubes and sugarcane molasses + urea supplements were isocaloric and isonitrogenous, and total yearly supplement offered to cows in each treatment was 272 kg of DM/cow.
[2]Calculated by dividing the unshrunk final BW by the hot carcass weight.
[3]500 = small.

Plasma concentrations of NEFA were greater for YCUB cows at calving (day 161), indicating greater mobilization of fat reserves compared to WMOL and YMOL cows (van der Drift et al., 2012; Schäff et al., 2013). Interestingly, both YCUB and WMOL cows lost BCS from days 122 to 161; however, only YCUB cows experienced elevated plasma NEFA concentrations at time of calving (day 161). During late gestation cows experience changes in energy metabolism in order to

meet the glucose and amino acid demands of the fetus (Bell, 1995; Wood et al., 2013). In dairy cattle, plasma NEFA concentrations begin to increase approximately 10 d prior to calving, reach peak concentrations at calving, and decrease thereafter (Grummer, 1995). Therefore, the observed differences in plasma NEFA concentrations between YCUB and WMOL cows at calving, despite the fact that both treatment groups lost BCS from days 122 to 161, are likely attributed to differences in the day of calving relative to blood sample collection. Cows on the WMOL treatment calved on average 3 d following blood sample collection, whereas YCUB cows calve on average 3 d prior to blood sample collection.

Plasma glucose concentrations were greater for YMOL and YCUB cows on day 56 compared to WMOL cows but did not differ among treatments after day 56. These results were unexpected considering that supplementation of wheat middlings to forage-based diets increases propionate production in the rumen (Poore et al., 2002), likely increasing gluconeogenic precursors. Furthermore, previous studies identified that mature *Bos indicus*-influenced cows had greater concentrations of plasma glucose following pre- and postpartum supplementation with molasses + urea vs. no pre- or postpartum supplementation (Palmer et al., 2020). The discrepancy between the two studies is likely attributed to the amount of supplementation offered. In Palmer et al. (2020), cows were fed an average of 1.07 kg/d of molasses, but in the present study cows were fed either 0.23 or 0.68 kg/d from days 0 to 149. Supplementation with molasses increases the production of butyrate in the rumen (Moloney et al., 1994). Butyrate is a non-gluconeogenic substrate that exerts inhibitory effects on propionate metabolism and reduces glucose production (Aiello and Armentano, 1987), which could explain why glucose was not impacted by year-round or winter only supplementation with molasses + urea. Additionally, in the present study, blood samples were not collected at the peak release of glucose following a feeding event (3 to 4 h after supplementation; Artioli et al., 2015; Silva et al., 2018), which partially explains the lack of treatment effects on plasma glucose concentrations.

Trace mineral/vitamin mixture intake of cattle grazing tropical/subtropical forages fluctuates throughout the year and declines during fall and winter (McDowell and Arthington, 2005). One strategy to mitigate the seasonal fluctuation in trace mineral/vitamin supplement intake is to provide cows with year-round supplementation of protein and energy mixed with trace mineral/vitamin supplement. In the present study, trace mineral/vitamin mixture intake was reduced by approximately 16% for cows offered free-choice mineral (WMOL) vs. control-fed mineral (YCUB and YMOL) from days 210 to 301, which is in agreement with Arthington and Swenson (2004). Nonetheless, liver concentrations of trace minerals of all treatments were always above the minimum thresholds associated with trace mineral deficiency (as defined by the reference ranges provided by Michigan State University, Diagnostic Center for Population and Animal Health). Also, WMOL cows had liver concentrations of trace minerals that were either above or did not differ compared to YMOL cows, indicating that WMOL were able to maintain optimal levels of trace mineral in the liver throughout the study despite the trace mineral/vitamin mixture refusals observed from days 210 to 301.

Sugarcane molasses-based supplements are known for containing relatively high concentrations of S which may

decrease Cu absorption (Arthington and Pate, 2002) by forming thiomolybdates in the rumen (Suttle, 1991). Cows on the YMOL supplementation had a reduction in liver Cu concentrations compared to WMOL and YCUB cows starting on day 122 which continued until day 360. Liver Cu concentrations were greater for YCUB vs. WMOL cows at the start of molasses + urea supplementation to WMOL cows on day 217. By day 360, YCUB cows still had greater liver Cu concentrations compared to WMOL cows, indicating that the antagonistic effect of S on Cu status may persist after molasses supplementation has ceased. Furthermore, the formation of thiomolybdates in the rumen can decrease dietary Mo absorption (Suttle and Field, 1983). Average liver Mo concentrations were reduced for WMOL and YMOL cows compared to YCUB cows. Increases in dietary S can have inhibitory effects on the absorption of Se as S and Se are similar in their chemical properties and both elements can compete for transporter sites within the small intestine (Drewnoski et al., 2014). Year-round supplementation with wheat middling-based range cubes increased liver Se concentrations on day 217 compared to WMOL and YMOL treatments, which is attributed to the greater S concentration of sugarcane molasses. However, YCUB cows had improved liver Se concentrations compared to WMOL cows prior to the start of molasses supplementation on day 122. Soils in southern Florida are generally deficient in Se; thus, it is plausible that wheat middling-based range cubes increased Se intake compared to WMOL cows before day 122. Overall, in terms of trace mineral status, year-round supplementation of sugarcane molasses + urea did not provide an advantage on liver concentrations of trace minerals compared to WMOL supplementation, and only year-round supplementation of range cubes improved overall liver concentrations of most trace minerals compared to all remaining treatments.

Offspring performance

Calf birth BW were not influenced by maternal treatments which has previously been reported (Stalker et al., 2006; Marques et al., 2016a; Palmer et al., 2020). During gestation, glucose is the primary substrate that drives fetal growth (Bell, 1995). Glucose is transported across the placental membranes via facilitative diffusion (Wooding et al., 2005; Crouse et al., 2016; Crouse et al., 2017); thus, the amount of glucose available to the developing fetus is dependent on circulating maternal glucose concentrations (Dunlap et al., 2015). Maternal plasma glucose concentrations were greater for YMOL and YCUB cows on day 56; however, cow glucose concentrations did not differ among maternal treatment groups for the remainder of the gestational period prior to parturition (days 122 and 161). Therefore, the lack of differences observed for birth BW of the first offspring is likely due to similar plasma glucose concentrations among maternal treatment groups close to parturition. Insulin-like growth factor 1 is also a critical factor impacting fetal growth by regulating glucose transport across the placenta (Jones et al., 2013) and enhancing glucose uptake by the fetus (Sferruzzi-Perri et al., 2006). Average plasma IGF-1 concentrations were greater for YMOL cows compared to WMOL and YCUB cows. However, the lack of differences found in birth BW of the first offspring could indicate that maternal IGF-1 concentrations are not an appropriate indicator of calf birth BW as previously suggested by Sullivan et al. (2009).

Immunity of the neonate calf is dependent on the passive transfer of IgG within the first 24 h of birth. Plasma concentrations of IgG were greater for WMOL vs. YMOL calves. Contrastingly, calves born to nutrient restricted (57% of NRC requirements) cows had similar serum IgG concentrations to calves born to cows that received adequate nutrition (100% of NRC requirements) during the last trimester of gestation (Hough et al., 1990). Moreover, maternal supplementation with protein and energy during the last trimester of gestation did not influence calf serum IgG concentrations (Stalker et al., 2006; Bohnert et al., 2013; Kennedy et al., 2019). The greater plasma concentrations of IgG in WMOL may be attributed to a greater capacity of immunoglobulin absorption across the intestinal membrane. In fact, fetuses from nutrient restricted cows have longer small intestines with larger villi compared to fetuses from cows that receive adequate nutrition during gestation (Duarte et al., 2013). Suggesting that offspring born to nutrient restricted dams are conditioned to more efficiently absorb nutrients compared to their cohorts.

The ADG from birth to weaning (day 421) of the first offspring did not differ among maternal treatment groups. Consequently, weaning weights of the first offspring were not impacted by maternal treatments. Increasing cow BCS during the second to third trimester of gestation improves calf weaning weights compared to maintaining cows at an adequate BCS throughout gestation (Marques et al., 2016a). Thus, these results were not anticipated as prepartum BCS was increased for YMOL cows during the second and third trimester of gestation. Moriel et al. (2020a) and Palmer et al. (2020) revealed that supplementation with a molasses + urea supplement during the third trimester of gestation and early lactation enhanced calf weaning weights above no pre- or postpartum supplementation. However, the amount of supplement offered in those studies was greater (1 kg/d vs. 0.23 kg/d from June to July and 0.68 kg/d from August to October) compared to the amount of prepartum supplement offered in the present study.

Postweaning (day 422 to slaughter)

Modifications to the maternal environment (i.e., prepartum transportation and nutrient restriction) can alter the hypothalamic-pituitary-adrenal (HPA) axis of beef offspring (Littlejohn et al., 2016; Moriel et al., 2016). During pregnancy, the developing fetus is protected from exposure to cortisol by the placental enzyme 11β-hydroxysteroid dehydrogenase 2 (11β-HSD2; Benediktsson et al., 1997). However, maternal stress has been shown to reduce the efficacy of the 11β-HSD2 enzyme (Langley-Evans et al., 1996; Welberg et al., 2005), consequently increasing fetal exposure to cortisol (Otten et al., 2004). Prenatal exposure to stress can have long-term impacts on the offspring's HPA axis as evident by alterations in methylation patterns of genes and pathways in beef cattle related to the postnatal stress response (Littlejohn et al., 2020). In the present study, YCUB steers had elevated plasma cortisol concentrations at feedlot arrival (day 422) compared to WMOL and YMOL steers. Cows on the YCUB supplementation lost BCS during the last stages of third trimester of gestation (days 122 to 161), which likely explains the alterations in circulating cortisol concentrations of their steer offspring. In contrast, nutrient restriction (70% of NRC energy requirements) during the last 40 d of gestation reduced plasma cortisol concentrations following an immunological challenge compared to calves born to cows that received adequate nutrition (100% of NRC energy requirement; Moriel et al., 2016). Discrepancies between Moriel et al. (2016) and the present study could be due to breed (*Bos taurus* vs. *Bos indicus*-influenced), as Brahman steers had greater plasma cortisol concentrations when dams were exposed to prepartum stress via transportation (Lay et al., 1997; Littlejohn et al., 2016). Furthermore, WMOL cows also had a decrease in BCS from days 122 to 161. Thus, mechanisms beyond nutrition-induced maternal stress could impact the postnatal cortisol concentrations of the offspring.

The production and release of haptoglobin, an acute-phase protein, from the liver increases during periods of stress and is triggered by circulating inflammatory cytokines (Gabay and Kushner, 1999). Furthermore, increases in circulating cortisol concentrations can promote an acute-phase protein response and increase circulating haptoglobin concentrations (Cooke and Bohnert, 2011). Steers born to YCUB cows had greater plasma concentrations of haptoglobin compared to WMOL steers during the feedlot phase. The influence of prepartum maternal nutrition on the acute-phase protein response of the offspring has been inconsistent. Moriel et al. (2016) reported a reduction in calf plasma haptoglobin concentrations when cows were energy-restricted (70% of energy requirements) during the last 40 d of gestation compared to calves born to cows offered 100% of the energy requirements. In comparison, plasma haptoglobin concentrations did not differ among beef calves born to cows that received a protein and energy supplement during the last 57 ± 5 d of gestation and calves born to cows that received no prepartum supplementation (Moriel et al., 2020a). It is possible that the degree of nutrient restriction experienced by the cow, type of supplement offered, and calf sex could partially explain the inconsistent results reported among studies (Moriel et al., 2021). Nonetheless, the present study indicates that supplementation with wheat middling-based range cubes during the last 161 ± 23 d of gestation led to greater postweaning physiological stress response of steers by increasing plasma concentrations of cortisol and haptoglobin during the feedlot period.

Antibody titers and seroconversion against PI_3 and BVDV-1 viruses were not impacted by previous maternal treatment. This result was unexpected as previous studies conducted at the same location consistently reported that maternal supplementation of protein and energy (1 to 2 kg/cow/d) during the third trimester of gestation enhanced the humoral immune response of the offspring compared to no precalving supplementation (Moriel et al., 2020a; Palmer et al., 2021). Additionally, calves born to cows managed to gain or maintain a BCS of 5 to 5.5 from days 84 to 175 of gestation had greater antibody titers to ovalbumin following an ovalbumin challenge compared to calves born to cows managed to lose 1 unit in BCS during the same period (Taylor et al., 2016). It is plausible that the amount of supplement offered to YMOL and YCUB cows prior to calving was not sufficient to elicit fetal programming effects on humoral immune response of the offspring. It is also plausible that the greater plasma concentrations of IgG within the first 24 h of life of WMOL vs. YMOL and YCUB calves led to carryover effects on postweaning innate immune response as supported by Wittum and Perino (1995).

In the present study, YMOL and YCUB supplementation initiated around day 122 ± 23 of gestation and continued throughout the third trimester of gestation. Muscle fiber and adipose tissue development predominantly occur during

second and third trimesters of gestation (Du et al., 2010); thus, dietary modifications during this window may impact muscle growth and carcass composition (Stalker et al., 2007; Larson et al., 2009; Underwood et al., 2010). Results from the present study indicated that year-round supplementation of wheat middling-based range cubes reduced steer BW at feedlot exit compared to year-round supplementation of sugarcane molasses + urea or no prepartum supplementation of sugarcane molasses + urea (WMOL). Furthermore, ADG from feedlot entry to feedlot exit decreased for YCUB vs. YMOL steers. The impact of prepartum nutrition on feedlot growth performance has been inconsistent (Moriel et al., 2021). Few studies have found that prepartum protein supplementation improved feedlot exit BW (Stalker et al., 2006; Stalker et al., 2007; Larson et al., 2009); however, other studies have reported no effects of prepartum maternal supplementation of protein or energy on calf feedlot performance (Bohnert et al., 2013; Wilson et al., 2015, 2016). The negative energy balance experienced by YCUB cows during the final stages of third trimester of gestation potentially induced adverse programming effects to fetal muscle development. However, steer BW at feedlot exit did not differ between YMOL and WMOL steers, and WMOL cows also lost BCS during late gestation, suggesting that other unknown mechanisms were likely involved in the feedlot BW reduction of YCUB steers.

The different carbohydrate profiles of supplements (primarily starch in YCUB and sucrose in YMOL and WMOL supplements) offered during gestation may have impacted the observed responses on feedlot performance. Peñagaricano et al. (2014) investigated the effect of isocaloric diets, that differed in carbohydrate profile, on the muscle and adipose tissue transcriptome of sheep fetuses during the last trimester of gestation. Authors reported a downregulation of genes related to muscle development in fetuses of ewes offered corn (starch-based) vs. hay and dried distillers grain diets, which corroborates with the reduction in feedlot exit BW of steers born to YCUB cows. However, alterations in the muscle transcriptome may not translate to differences in production characteristics of offspring. Radunz et al. (2012) observed that calf feedlot BW did not differ when cows were supplemented with either corn, hay, or dried distillers grains from day 160 of gestation until parturition. More research is warranted to determine how supplement type, amount, and timing influence the post-weaning performance of beef cattle offspring (Moriel et al., 2021).

Hot carcass weights did not differ among maternal treatments. Similarly, calves born to cows supplemented with either corn, hay, or dried distillers grains from day 160 until calving did not differ in HCW (Radunz et al., 2012). It is possible that the timing of prepartum supplementation could influence HCW. Providing cows with 0.45 kg/d of a protein supplement throughout the last trimester of gestation increased the HCW of calves compared to no prepartum supplementation (Stalker et al., 2007; Larson et al., 2009). Furthermore, the degree of nutrient restriction during gestation might also impact the programming effects on HCW. Calves born to cows that were allowed to graze improved pasture (11.1% CP) had greater HCW vs. calves born to cows that grazed native range (6.5% CP) from days 120 to 180 of gestation (Underwood et al., 2010). However, the 12th-rib fat thickness was greater for WMOL compared to YMOL and YCUB steers. This result was unexpected as previous research has observed that greater energy and protein intake

during the second to third trimester of gestation increased 12th-rib fat thickness (Underwood et al., 2010; Mohrhauser et al., 2015; Wilson et al., 2016). However, Long et al. (2012) reported that a 30% nutrient restriction from days 45 to 185 of gestation increased the diameter of adipocytes in subcutaneous adipose tissue of beef offspring. Additionally, authors reported elevated mRNA expression of fatty acid transporter 1 in the subcutaneous adipose tissue of nutrient restricted calves (Long et al., 2012). Fatty acid transporter 1 increases long-chain fatty acid uptake by tissues and its expression is mediated by insulin (Wu et al., 2006). Maternal gestational nutrition can impact glucose and insulin metabolism in offspring (Long et al., 2010; Wilson et al., 2016). Insulin promotes lipogenesis in bovine adipose cells (Etherton and Evock, 1986); thus, modulations in insulin production can have an impact on adipose tissue mass. In fact, prepartum nutrient restriction from day 110 of gestation until parturition can lead to greater insulin resistance and increased adiposity in sheep offspring (Gardner et al., 2005). Glucose and insulin metabolism of the offspring were not measured herein, but it is plausible that changes in circulating metabolites in steer calves may have influenced the observed carcass characteristics and increased subcutaneous fat deposition in WMOL steers.

Year-round supplementation of sugarcane molasses + urea negatively impacted carcass quality by increasing the percentage of carcasses that graded select or less and consequently decreased the percentage of carcasses grading low choice compared to WMOL and YCUB steers. Mohrhauser et al. (2015) revealed that cow energy status (100 vs. 80% of energy requirements) from days 102 to 193 ± 10.9 of gestation had different effects on fat deposition. In the present study, YCUB steers had improved carcass quality, but reduced 12th-rib fat thickness compared to YMOL. Collectively, the results indicate that maternal nutrient status throughout gestation could change how nutrients are partitioned, thus impacting adipose tissue depots. Additionally, Radunz et al. (2012) found that the type of gestational supplement offered can impact marbling. Authors reported that calves born to cows offered hay from day 160 until the end of gestation had greater marbling scores compared to calves born to cows offered corn. In the present study, YMOL supplementation was detrimental to carcass quality compared to YCUB and WMOL supplementation. Overall, the results currently available in the literature evaluating the impacts of maternal prepartum nutrition on offspring carcass quality have been contradictory (Moriel et al., 2021), and additional work is needed to unravel the mechanisms by which maternal gestational nutrition promotes carcass characteristics of offspring.

Conclusions

Maternal year-round supplementation of wheat middling-based range cubes or sugarcane molasses + urea improved BCS of *Bos indicus*-influenced beef cows at the time calving compared to no precalving supplementation of protein and energy. However, cows offered year-round supplementation with range cubes lost more BCS following calving and throughout the breeding season. Maternal year-round supplementation of range cubes and molasses + urea did not improve preweaning growth performance of the first offspring compared to winter supplementation of molasses + urea. In fact, maternal year-round supplementation of range cubes enhanced

the post-weaning physiological stress response of steers and decreased final feedlot BW of steers compared to winter and year-round supplementation of molasses + urea. Maternal year-round supplementation of molasses + urea decreased carcass quality of steers compared to maternal winter supplementation of molasses + urea and year-round supplementation of range cubes. Overall, when total annual supplement DM amount remained similar across treatments, maternal year-round supplementation of range cubes or molasses + urea offered minor advantages to cow BCS and calving distribution, respectively, but this strategy either did not impact or decrease liver trace mineral concentrations of cows and growth, immune function, and carcass characteristics of the offspring compared to a conventional, maternal supplementation of sugarcane molasses + urea during winter only.

Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

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