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NUTRITIONAL STRATEGIES FOR DEVELOPING REPLACEMENT *BOS TAURUS* AND *BOS INDICUS*-INFLUENCED BEEF HEIFERS

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Introduction

Development of replacement heifers is a major economic investment, with costs associated with managing heifers prior to weaning their first calf recovered through subsequent calf crops. In beef cow-calf operations, profitability can be directly tied to the productive lifespan of cows within the herd. Management decisions made over the first year of life can influence heifer performance and reproduction, as well as play a key role in establishing heifer fertility and longevity. Therefore, it is critical to understand not only how management practices affect reproductive performance and lifetime productivity but evaluate if fertility can be enhanced based on the development strategies utilized.

The association between nutritional management, puberty attainment, and pregnancy rates in heifers is well established (reviewed in Patterson et al., 1992, Funston et al., 2012). Traditionally, development of replacement heifers has considered puberty attainment as the foremost factor (Patterson et al., 1992). Nutritional management and growth rate during the post-weaning development period have been determined to be important factors influencing age at puberty and reproductive performance in beef heifers (Joubert, 1954; Short and Bellows, 1971; Wiltbank et al., 1985; Patterson et al., 1992). Therefore, the focus of heifer development research has been on the impact of management strategies on reproductive performance, with a major focus of past and current research on nutritional management. While management strategies have changed over time due to shifts in cattle genetics, selection, and management, successful development strategies must be implemented that allow heifers to reach their reproductive potential.

Bos taurus and *Bos indicus* cattle exhibit biological differences related to metabolism and reproductive function, therefore, respond differently to nutritional and reproductive management strategies (Sartori et al., 2016; Cooke et al., 2020). Nutritional management and development of both *Bos taurus* and *Bos indicus* replacement heifers represents a crucial aspect of cow-calf operations where management practices and decisions can have a significant influence on reproductive performance. This paper will discuss current nutritional management strategies for developing heifers, the relationship between nutrition and reproduction, and differences in development of *Bos taurus* and *Bos indicus* beef heifers.

Bos taurus beef heifers

The primary goal of development of replacement heifers is to optimize reproductive performance, economic efficiency, and lifetime productivity of heifers. Heifers are expected to grow to 65-75% of mature size, attain puberty, and produce their first calf within the first 2 years of life (Summers et al., 2019). Nutrition has been a major focus within heifer development research because it is the management tool that producers have the most control over. Extensive research has been conducted evaluating the impact of nutritional management during development on puberty attainment, reproductive tract development, fertility, and reproductive efficiency in beef heifers. This research has not only established a strong relationship between nutrition and reproduction but has sought to identify management strategies that can be utilized in both intensive and low-input or extensive systems.

A significant proportion of the research evaluating the influence of nutritional management on reproductive development and performance of replacement heifers has been conducted in *Bos taurus* heifers. As discussed later in this paper, reproductive physiology differs between *Bos taurus* and *Bos indicus* cattle, with differences in puberty attainment and response to nutritional management playing key roles in the development of management strategies utilized to develop beef heifers. In the sections below, we will provide a review of research focused on nutritional management strategies designed to optimize reproductive performance and efficiency of *Bos taurus* beef heifers

1. Pre-weaning management

As indicated previously, there is substantial research demonstrating that age at puberty is directly influenced by nutritional management during the first year of life. Previous research has suggested pre-weaning body weight gain influences age at puberty more than post-weaning growth (Cardoso et al., 2014; Roberts et al., 2017). Heifers pubertal at the beginning of the breeding season have been reported to have an increase in average daily gain from birth to weaning and were heavier at weaning (Roberts et al., 2017). Furthermore, the same study reported that a greater proportion of heifers pubertal by the start of the first breeding season were born in the first 21 days of the calving season (Roberts et al., 2017).

Research evaluating early calfhood nutritional strategies and early weaning have provided additional insights into the impact of nutrition and management of calves before 7 months of age. In addition, recent research has evaluated programming the onset of puberty through the use of stair-step type diets where nutrition is increased and decreased during different developmental windows. The onset of puberty occurred at a younger age in early weaned heifers fed to target a high rate of gain between 4 and 6 months of age compared to heifers fed to attain a low rate of gain during the same developmental window (Cardoso et al., 2014). In the same study, early weaned heifers fed to attain a low rate of gain between 4 and 6 months of age, who were then stepped up to target a high rate of gain from 6 to 9 months of age, had the majority of heifers attain puberty between 11 and 14 months of age (Cardoso et al., 2014). These results would suggest that the timing of puberty can be programmed to occur before the start of the breeding season, while limiting the incidence of precocious puberty associated with high rates of gain during the juvenile period.

While pre-weaning nutrition and early weaning can decrease age at puberty, challenges exist in implementing these strategies. In most cow/calf operations, especially extensive or range-based operations, management of pre-weaning nutrition is limited. Creep feeding or creep grazing can increase nutrient intake of calves and increase pre-weaning performance. In many scenarios, creep feeding has a low-economic return and is not an economically viable option for many operations. Furthermore, producers generally utilize early weaning strategies in response to drought or limited feed conditions or as a means to improve reproductive performance within the cowherd. Regardless of the potential improvement in age at puberty, increased feed inputs and labor, as well as challenges with managing lighter-weight calves have limited the utilization of early weaning as a management strategy for developing replacement heifers.

2. *Target body weight approach*

Considerable research contributed to the guideline that heifers should be developed to 60 to 65% of mature body weight at the start of the breeding season (reviewed in Patterson et al., 1992; Funston et al., 2012). This research demonstrated that limiting post-weaning growth negatively impacted age at puberty attainment and pregnancy rates (Joubert, 1954; Short and Bellows, 1971; Wiltbank et al., 1985). Studies evaluating different target body weights and post-weaning rates of gains have explored countless nutritional strategies and feeds to evaluate the relationship between reproduction and nutrition. The target body weight approach, specifically the recommendation that heifers be developed on a higher rate of gain to at least 60 to 65% mature body weight by the start of the breeding season, became the industry standard. During the time when this research was conducted (1960-1980's) there was a readily available supply of inexpensive feed sources, allowing for increased use of cereal grains and harvested forages within heifer development systems making it more affordable to raise heifers to 60 to 65% mature body weight.

Research over the last several decades has demonstrated that there has been a shift in the association between heifer body weight, puberty, and pregnancy rates (reviewed in Funston et al., 2012; Endecott et al., 2013). The shift in the relationship among puberty attainment, fertility, and body weight is likely a result of increased selection pressure for age at puberty and fertility, as well as changes in genetics over time. Several management factors contributing to this have been suggested, including the change in the industry standard of calving heifers at 3 years of age to calving heifers at 2 years of age, the association between bull scrotal circumference and daughter age at puberty, and potential changes in the relationship between the timing of puberty attainment prior to the breeding season and subsequent pregnancy rates (Funston et al., 2012; Endecott et al., 2013). Together these factors suggest an overall increase in selection pressure for age at puberty and fertility, in general, has occurred within the industry.

Recent heifer development research has emphasized comparing traditional, more intensive systems to low-input extensive development systems. Increased development costs, driven by increased feed costs have been a significant driver behind the investigation of more extensive heifer development systems. Low-input heifer development systems have typically relied on grazing heifers on dormant forages or native range, developing heifers to a lighter percent mature body weight, and(or) rely on periods of compensatory gain. The objective of more extensive low-input systems has been to develop management strategies that are more economically efficient for producers while maintaining reproductive performance in heifers (Freetly et al., 2001; Funston and Deutscher, 2004; Roberts et al., 2009; Funston and Larson, 2011; Summers et al., 2014). These studies reported no differences in pregnancy rates, calf birth date, and second season pregnancy rates, although an increased age at puberty in some studies was reported (Table 1). Traditional target body weight development research suggested that heifers below the 60 to 65% mature body weight threshold at the start of the breeding season would have reduced reproductive performance because of an increased percentage of non-cycling heifers. Protocols that develop heifers to a lighter target body weight at breeding (50 to 57% of mature body weight) have reduced development costs while not impairing reproductive performance. Martin et al. (2008) reported that heifers can be developed to as low as 50% of mature body weight and maintain similar pregnancy rates as heifers developed to 57% mature body weight over a 60-day breeding season. Funston and Deutscher (2004) reported heifers developed to 53% mature body weight prior to the breeding season had reduced body weight and percentage of heifers cycling prior to the breeding season compared to cohorts at 58% mature body weight. Pregnancy rates, however, were similar among heifers developed to 53 or 58% mature body weight.

Studies comparing post-weaning nutritional management of heifers are inconsistent regarding the impacts of extensive development systems on age at puberty or the percentage of heifers cycling at the start of the breeding season (reviewed in Summers et al., 2019; Table 1). Overall heifer pregnancy rates, however, have been demonstrated to be similar regardless of if heifers were managed in extensive, low-input heifer development systems or in traditional heifer development systems (Lynch et al., 1997; Freetly et al., 2001; Funston and Deutscher, 2004; Mulliniks et al., 2013; Summers et al., 2014). Heifers may, therefore, be developed to lighter than traditional target body weights or managed in lower input development systems without detrimental effects on reproductive performance.

Table 1. Influence of postweaning nutrition on heifer reproductive performance (adapted from Summers et al. 2019).

Treatment	**Age at puberty**[a]	**Heifer pregnancy rate**[a]	**Mean Calving date**[a]	**Second-year pregnancy rate**[a]	**Reference**
Even gain vs. Late gain	INCR[b]	NS	—	—	Lynch et al., 1997
Low-High vs. High	—	NS	NS	NS	Freetly et al., 2001
Low gain vs. High gain	DECR[c,d]	NS	NS	NS	Funston and Deutscher, 2004
Restricted vs. Control	INCR[e]	NS	—	—	Roberts et al., 2009b
Drylot vs. Extensive	DECR[c,d]	NS	NS	NS	Funston and Larson, 2011
Corn Residue vs. Drylot	NS	NS	NS	—	Summers et al., 2014
Low-High vs. Constant	NS	NS	NS	—	Rosasco et al., 2017

[a]Effect of reduced or late nutrient intake or growth compared with control; INCR = increased compared with control; DECR = decreased compared with control; NS = not significant.
[b]In year 2 only ($P < 0.01$).
[c]Reported as cyclic prior to breeding season.
[d]Means within study differ ($P < 0.05$).
[e]Means within study differ ($P < 0.10$).

Management of heifers to maximize economic efficiency and ensure development costs can be recuperated in a timely manner is an important consideration when making decisions regarding how to develop and manage replacement heifers. Furthermore, available resources vary among operations, therefore, development systems are unique to each operation. Effective utilization of resources that allows for optimal reproductive performance of heifers not only in their first breeding season but over their lifetime is an essential component of heifer development systems. Research has established that heifers that calve in the first 21 days of their first calving season have increased longevity in the herd and wean more pounds of calf over their lifetime compared with heifers calving in the second or third 21-day calving period (Cushman et al., 2013). Therefore, development of management strategies that focus on heifers conceiving early in their first breeding season can help increase survivability and lifetime productivity of heifers.

3. Growth pattern (Stair-step strategy)

Altering the rate and timing of heifer body weight gain during the post-weaning development has been utilized as a nutritional management strategy to optimize post-weaning growth, reproductive performance, and economic efficiency. Modifying the pattern of growth during heifer development can result in periods of compensatory growth, which can potentially reduce feed inputs and increase economic efficiency and feasibility (Clanton et al., 1983; Lynch et al., 1997; Freetly et al., 2001). Clanton et al. (1983) reported no difference in reproductive performance in heifers developed on a constant rate of gain, late gain (majority of gain occurring in the last half of the development period), or early gain (majority of gain achieved in the first half of the development period). Research by Clanton et al. (1983) was one of the first to demonstrate that timing of body weight gain could be varied without significant differences in reproductive performance. Additionally, this research also introduced utilizing compensatory gain, reporting late gain heifers gained more than predicted each year of the 3 yr study. Additional research has confirmed that pregnancy rates are similar between heifers developed utilizing a stair-step nutritional program (period of low gain, followed by a period of high gain) and heifers developed on a constant rate of gain (Lynch et al., 1997; Freetly et al., 2001).

Utilizing a stair-step nutritional management strategy during the post-weaning development period has also been reported to influence the size of the ovarian reserve in beef heifers. Primordial follicles formed during gestation represent the ovarian reserve and the growing pool of follicles the animal will utilize over her reproductive lifespan. Previous research has suggested the size of the ovarian reserve corresponds with fertility in cattle (Cushman et al., 2009; Mossa et al., 2012). Previously, it was believed heifers are born with a finite number of follicles within their ovaries, the ovarian reserve, and depletion of the ovarian reserve occurred at a constant rate that cannot be altered (Rajakoski, 1960; Erickson, 1966; Scaramuzzi et al., 2011). Research evaluating the influence of nutrient intake on the ovarian reserve, however, has demonstrated that nutrition can influence primordial follicle numbers in the ovary of both rodents and cattle.

Recent research in cattle has evaluated the impact of altering growth patterns through nutritional management on the ovarian reserve. Freetly et al. (2014) reported heifers on a stair-step nutritional scheme, where caloric intake was reduced between 8 and 11 months of age and then increased between 11 and 14 months of age, had an increased number of primordial follicles at 14 months of age compared to control heifers developed on a constant rate of caloric intake from 8 to 14 months of age (Freetly et al., 2014). Amundson et al. (2015) developed heifers in a drylot utilizing the same single-phase stair-step development system and ovariectomized heifers at 3 different time points to determine when differences in the ovarian reserve occurred. Primordial follicle numbers were similar among treatments at 8 and 11 months of age, however, stair-step heifers had an increased number of primordial follicles at 13 months of age compared to control heifers (Amundson et al., 2015). Mechanisms controlling the number of primordial follicles, however, are poorly understood. Slowing depletion of the primordial follicle pool through either slowing the rate of activation of primordial follicles or stimulating formation of new primordial follicles could increase the size of the ovarian reserve at the start of the breeding season and potentially allow for an increase in the reproductive lifespan of cows. It is important to note, once primordial follicles are activated and transition into the growing pool of follicles the process cannot be reversed (Scaramuzzi et al., 2011).

While many spring-born heifers are developed from weaning to breeding in a dry-lot and fed a diet consisting of a combination of forage and concentrate feeds, based on research previously discussed, implementation of heifer development systems utilizing grazing have become more common. Previous studies evaluating the utilization of a stair-step nutritional program developed heifers in the drylot and failed to determine if the increase in the primordial follicle pool is possible in heifers developed grazing native range and supplemented to follow a stair-step nutritional scheme. Recently, researchers at New Mexico State University examined this, investigating if utilizing a stair-step nutritional strategy would slow activation of primordial follicles, increasing the size of the ovarian reserve in beef heifers regardless of whether they were developed in a drylot or grazing native range (Rosasco et al., 2020). Angus cross-bred heifers (n = 40) were utilized to determine the effect of a stair-step development system on fertility and ovarian dynamics. Heifers (11 months) were assigned to 1 of 4 treatments: 1) constant gain drylot (CG-d), 2) stair-step drylot (SS-d), 3) constant gain native range (CG-r), and 4) stair-step native range (SS-r). Heifers were fed individually with a constant gain target of 1.1 lb/d average daily gain, while stair-step heifers were targeted to gain 0.55 lb/d the first 45 day (period 1) and 1.65 lb/d over the last 45 day (period 2). Heifers developed grazing native range were individually supplemented three times per week. All heifers were ovariectomized at the end of the 90-day development period. Ovarian measurements were collected to assess difference in ovarian dynamics. Histology was performed on ovarian tissue to determine the number of microscopic follicles (primordial, primary, and secondary follicles) and evaluate the influence of dietary treatments.

Heifer body weight was similar at initiation of treatments. Heifers grazing native range had an increased body weight at day 45 and day 90 ($P < 0.01$) compared to drylot heifers. Overall average daily gain and average daily gain over the first 45 days was greater in native range heifers ($P < 0.01$) compared to drylot heifers. During the last 45 days, CG-r and SS-r heifers had an increased average daily gain compared to CG-d and SS-d heifers, with SS-d also having an increased average daily gain ($P = 0.03$) compared to CG-d heifers. The lack of differences in performance among native range treatments may be attributed to the fact that supplementation often alters grazed forage intake and can decrease grazing selectivity (Krysl and Hess, 1993; Moore et al., 1999). The divergence in growth performance among drylot and native range developed heifers was a result of heifers being managed in the drylot, permitting nutrient intake to be strictly monitored and controlled. Additionally, performance of heifers grazing native range exceeded anticipated gains based on supplement and forage nutrient values. This is likely due to the natural ability of grazing ruminants to selectively graze, thereby increasing diet quality.

Dominant follicle diameter and concentrations of estradiol in the follicular fluid of the dominant follicle were increased ($P < 0.01$; Table 2) in native range heifers compared to drylot heifers. Follicular fluid progesterone concentrations and the estradiol:progesterone ratio, however, were similar among all treatments. The microenvironment within the dominant follicle, comprised of growth factors and steroid hormones, influences quality of the oocyte, directly impacting reproductive success. Follicular fluid estradiol concentrations can be an indicator of the ability of the oocyte to be fertilized, with an estradiol:progesterone ratio > 1 indicative of an estrogen active follicle (Sunderland et al., 1994). While increased concentrations of estradiol in native range heifers were likely driven by an increase in dominant follicle diameter, dominant follicle diameter has been reported to influence pregnancy success. Perry et al. (2007) observed heifers ovulating follicles ≥ 12.8 mm in diameter had increased pregnancy rates compared with heifers ovulating follicles < 10.7 mm in diameter. While all treatments had a dominant follicle diameter > 10.7 mm, increased dominant follicle diameter in heifers developed grazing native range suggests native range heifers would potentially have an increase in reproductive performance due to enhanced ovarian function. The potential improvement in ovarian function in heifers developed grazing native range compared to drylot developed heifers implies that reproductive success may have been enhanced due to differences in dietary treatment. This may be attributed to the increased average daily gain in native range heifers compared to drylot heifers during the last 45 days of the development period (1.09 lb/d vs 2.18 lb/d, respectively), providing a flushing effect in native range heifers.

Table 2 Ovarian characteristics of heifers raised in the drylot or on native range receiving either a constant gain or a stair-step diet (Rosasco et al., 2020).

	Drylot		**Native range**			***P*-value**		
Item	**CG[1]**	**SS[2]**	**CG[1]**	**SS[2]**	**SEM**	**Trt**	**Group**	**Trt x Group**
Dominant follicle, mm	10.7[a]	11.1[a]	13.1[b]	14.4[b]	0.7	0.20	<0.01	0.46
Estradiol, ng/mL	153.0[a]	158.5[a]	439.1[ab]	531.2[b]	110.5	0.65	<0.01	0.69
Progesterone, ng/mL	219.3	115.6	219.3	462.4	123.1	0.57	0.16	0.16
Estradiol:Progesterone	5.5	2.0	4.5	2.3	1.7	0.10	0.86	0.69
Primordial follicles/section	35.9[a]	84.2[b]	69.9[ab]	84.4[b]	15.0	0.04	0.24	0.25

[a,b] Means within a row without a common superscript differ $P < 0.05$.
[1]CG = constant gain heifers targeted to gain 1.1 lb/d for 90d.
[2]SS = stair-step heifers targeted to gain 0.55 lb/d the first 45-days and 1.65 lb/d the last 45-days.

Primordial follicles/histological section were increased ($P = 0.04$; Figure 1) in SS-r and SS-d heifers compared to CG-d heifers, with CG-r similar to all other treatments. Utilization of a stair-step development program positively impacted primordial follicle numbers, increasing the size of the ovarian reserve, and potentially resulting in greater reproductive longevity. These results suggest mechanisms controlling primordial follicle activation may be slowed due to utilization of a stair-step compensatory growth program, however, these mechanisms are not well understood. Similarities in primordial follicle numbers between CG-r and SS-r heifers suggest the constant gain diet in the drylot had a larger impact on mechanisms controlling primordial follicle activation than in heifers on a constant gain diet grazing native range. Further research is already underway and focused on identifying mechanisms contributing to the influence of nutritional programming on the ovarian reserve. In a recent study by Freetly et al. (2021) authors reported heifers developed on a stair-step growth pattern had an increase in reproductive longevity and stayability. These results further suggest the increase in the size of the ovarian reserve in stair-step developed heifers, regardless of if they are managed in a drylot or grazing range, may potentially program fertility, resulting in an increase in reproductive longevity.

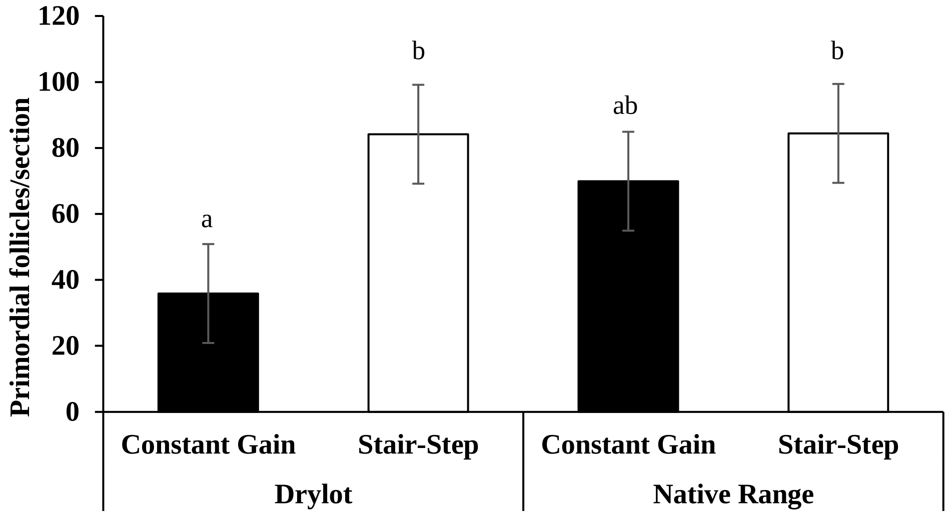


Figure 1 - Number of primordial follicles per section of constant gain and stair-step heifers developed either in the drylot or grazing native range. Primordial follicles per histological section was increased (P = 0.04) in stair-step heifers developed grazing native and stair-step drylot heifers compared to constant gain drylot heifers, with constant gain native range heifers being similar to all other treatments.

4. Influence of heifer development on longevity

The interaction between nutrition and reproduction in heifer development has been well established, however, research regarding the mechanisms controlling the interaction and the impacts of heifer development systems on cow longevity is limited. The effect of post-weaning development strategies on cow longevity and lifetime productivity is complex as it can be influenced by the environment, nutritional status, and management practices utilized throughout the animal's life. Heifers developed on restricted gain to 53% of mature body weight had similar pregnancy rates through the fourth calving season compared to heifers developed to 58% of mature body weight (Funston and Deutscher, 2004). Research comparing the effect of winter supplemental feed level on herd retention and survivability revealed cows receiving the low level of nutritional supplementation appeared to have an improved average lifespan (14.65 year) compared to medium (13.07 year) and high (10.88 year) supplemented cows (Pinney et al., 1972). Additionally, Pinney et al. (1972) suggested that differences in survivability or longevity are established early in life. In a 10-year study, Hughes et al. (1978) suggested an advantage in retention rate for beef cows on a lower plane of nutrition compared to cows maintained on a greater plane of nutrition. Cows developed and maintained on a low or moderate plane of nutrition had a 77% retention rate compared to cows that were developed and maintained on a high or very high plane of nutrition that had a 63% retention rate. Heifer development systems that manage heifers in extensive systems may better prepare heifers for future production environments and positively impact survivability. Mulliniks et al. (2013) reported a greater retention rate through 5 years of age in range-developed heifers receiving a high-RUP supplement (68%) compared with range-developed counterparts fed a low-RUP supplement (41%) and heifers fed in the drylot (41%). These data indicate that where a heifer is managed during pre-breeding development (drylot vs. extensive), as well as specific nutrient content may influence survivability. It should be noted that differences among retention rates reported in current research can be influenced by specific culling criteria.

Heifer development systems focused on acclimation of heifers to extensive production environments may allow heifers to be better adapted and prepared for future challenges facing the grazing animal. Exposure and adaptation of animals to their grazing environment early in life may allow for animals to gain invaluable grazing experience and develop improved grazing behavior over the course of their life. Thus, heifers managed grazing in a range setting may be better adapted to their future production environment, which may improve animal performance and result in an increase in longevity compared to animals developed in intensive management systems (i.e., drylot or high rate of gain). Overall, studies evaluating the influence of heifer development systems on cow longevity are limited. Current research, however, suggests developing heifers to lighter target body weights and(or) grazing native range may allow for animals to be better adapted to their future nutritional environment and periods of negative energy balance experienced in many range settings (Endecott et al., 2013; Mulliniks et al., 2013; Summers et al., 2014). Understanding the demands of future production environments and the influence of management strategies used during development of heifers on performance and longevity must be considered when designing heifer development strategies. Longevity impacts producer sustainability and profitability; therefore, current and future economic implications of heifer development studies must be considered.

***Bos indicus* and *Bos indicus*-influenced beef heifers**

Approximately 45% of U.S. beef cows are in southern and southeastern states where *Bos indicus*-influenced cattle and extreme heat conditions predominate (NASS, 2017). Despite their wide importance, *Bos indicus*-influenced cattle are typically managed using practices developed for *Bos taurus* breeds reared in temperate zones. *Bos taurus* and *Bos indicus* are different subspecies that diverge in social and biological functions (Cooke et al., 2020). Under the same environmental and nutritional conditions, *Bos taurus* and *Bos indicus* cattle exhibit different feed digestion (Habib et al., 2008; Bell et al., 2017) and physiology (Sartori et al., 2016).

A major limiting factor for reproductive success of *Bos indicus*-influenced beef heifers is the late attainment of puberty due to genetics, environment (i.e., heat stress), and nutrition. Heat stress is detrimental to cattle metabolism, growth, reproduction, health, and welfare (Mader, 2003; Key et al., 2014) and will become a greater challenge in the future if global climate change occurs (IPCC, 2007). Environmental conditions are considered thermoneutral when thermal-humidity index (**THI**) ≤ 70, mild heat stress when $70 \leq$ THI < 74, heat stress when $74 \leq$ THI < 77, and severe heat stress when THI ≥ 77 (Davis et al., 2003). Figure 2 shows the average, minimum and maximum daily THI values obtained at the University of Florida - Range Cattle Research & Education Center (Ona, FL). From June to October 2019, average THI values were within or above the threshold considered as heat stress. Also, maximum THI values often reached severe heat stress levels. These challenging conditions during summer partially explain the poorer average daily gain (Table 3) of heifers, despite the greater nutritional composition of forage during Summer vs. Fall.

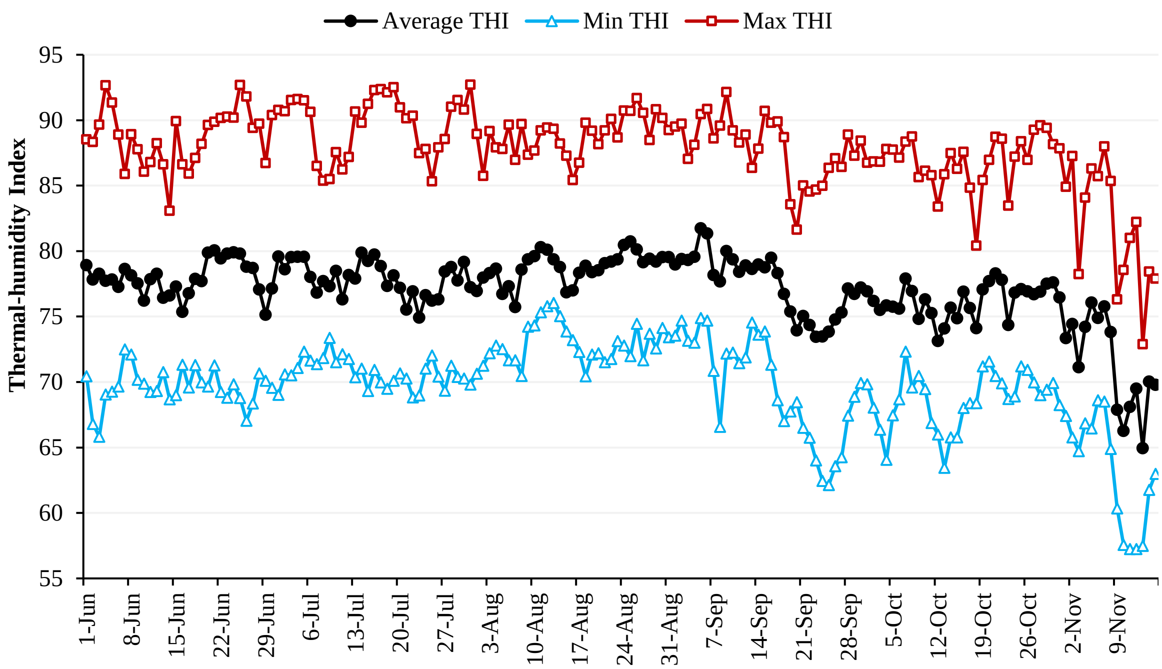


Figure 2 – Daily average, minimum and maximum thermal-humidity index (THI) values observed from June to November 2019 at the Range Cattle Research and Education Center. THI = (1.8 × Temperature + 32) – [(0.55-0.0055 × Relative Humidity) × (1.8 × Temperature – 26)].

Table 3. Growth performance of beef heifers assigned to a low, medium, or high post-weaning growth rates during a 168-day development period (3 years; Adapted from Moriel et al., 2017).

	Supplementation amount				
Average daily gain, lb/day	**Low**	**Medium**	**High**	**SEM**	***P***
Sep to Oct	0.24[a]	0.31[a]	0.70[b]	0.110	0.02
Oct to Nov	0.42[a]	0.99[b]	1.19[b]	0.101	<0.0001
Nov to Dec	0.66[a]	1.30[b]	1.45[b]	0.093	<0.0001
Dec to Jan	0.59[a]	0.93[b]	1.28[c]	0.068	0.001
Jan to Feb	0.48[a]	0.73[b]	0.77[b]	0.081	0.10
Feb to Mar	0.77[a]	1.12[b]	1.37[c]	0.068	0.002
Overall	**0.55[a]**	**0.90[b]**	**1.12[c]**	**0.044**	**<0.0001**
Target	1.00	1.61	2.20		

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

The cow-calf industry in tropical and subtropical environments relies on warm-season forages as the main source of feed for beef cattle. Warm-season forages often do not meet the requirements of growing heifers, even if herbage mass is not a limiting factor. Moore et al. (1991) compiled the nutritional analysis of 637 samples of forages commonly grown in Florida (bahiagrass, bermudagrass, digitgrass, stargrass, and limpograss) and reported that most of these grasses contained between 5 to 7% CP and 48 to 51% TDN (dry matter basis]. Developing heifers require at least 55% TDN and 8.5% CP of diet dry matter to achieve adequate growth rates (≥ 1.10 lb/day; NRC, 1996). Nevertheless, successful reproductive performance can still be obtained if heifers become pubertal before the initiation of breeding season (Moriel et al., 2017). For instance, average final pregnancy rates were 82% for heifers that achieved puberty **BEFORE** the start of the breeding season compared to 36% for heifers that achieved puberty **DURING** the breeding season. In the sections below, we will provide a summary of studies designed to optimize growth and reproduction of *Bos indicus*-influenced beef heifers in tropical/subtropical environments.

1. Age and target mature body weight

Lifetime production was either greater, or not significantly different, when heifers first calved at 2 vs. 3 years of age, and overall, heifers calving at 2 years of age produced 0.7 more calves in their lifetime than if calving first at 3 years of age (Morris, 1980). Nonetheless, the age at first calving depends upon the economics of management input against returns required for heifers to reach suitable target body weight by the start of breeding season, which is dependent on the quality and quantity of available feed and the genetics of the herd (Day and Nogueira, 2013; Silva et al., 2022). For instance, more than 95% of heifers in the northern and central USA, comprised mainly of *Bos taurus* breeds, calve first at 2 years of age, whereas less than 50% of heifers in Florida and about 35% in Texas calved later than 2 years of age (Short et al., 1994).

Body weight is the major factor affecting age at puberty**,** and subsequent weight gains are needed to ensure that heifers continue experiencing regular estrous cycles (Patterson et al., 1992). Feeding to a target body weight for a given genotype is a practical management tool to ensure high potential fertility. While breed differences exist, age and body weight at puberty across all breeds studied were approximately 357 days and 705 lb, respectively (Thallman et al., 1999). While some disagreement exists as to the ideal target weight for heifers at the start of their first breeding season, nutritional management during this phase is crucial to breeding success (Day and Nogueira, 2013).

In Australia, high pregnancy rates (>80%) was achieved in Brahman crossbred heifers (minimum of 75% Brahman) calving for the first time at 3 years of age when these heifers were naturally bred at a body weight of 660 lb or heavier (Silva et al., 2022). For heifers calving for the first time at 2 years of age, traditional guidelines demonstrated that *Bos taurus* heifers need to achieve between 60 to 65% of mature body weight at breeding (Patterson et al., 1992; Gasser et al., 2013). But as described in previous sections of this article, recent studies indicated that, I special situations, acceptable reproductive success could be achieved in *Bos taurus* heifers reaching 50 to 55% of mature body weight at the start of the breeding season.

In terms of *Bos indicus* crossbred heifers, Table 2 summarizes the nutritional management, post-weaning average daily gain, mature body weight at the start of the breeding season, and pregnancy rates of Brangus crossbred heifers that were or were not submitted to a hormonal protocol (either a puberty induction or an estrus synchronization protocol), and then were placed with bulls for a breeding season of 90 days. When heifers were not submitted to a hormonal protocol, unacceptable pregnancy rates were observed when heifers achieved <60% of mature body weight at the start of the breeding season. Contrary, pregnancy rates of 70% and >80% were attained when heifers achieved 60% and 70% of mature body weight at the start of the breeding season, respectively (Table 4).

Table 4. Summary of studies conducted at the Range Cattle Research and Education Center (Ona, Florida) that evaluated different nutritional strategies for *Bos indicus* crossbred heifers bred for the first time at 14 to 15 months of age.

Author	Post-weaning supplementation	Average daily gain, lb/day	Mature weight[1], %	Pregnancy, %	Hormonal protocol
Arthington et al. (2004)	6.0 lb Molasses	0.97	53.7	76.3	No
	5.2 lb Cubes	1.04	54.0	49.2	
Cooke et al. (2007)	4.6 lb Molasses	0.66	52.0	58.0	No
	5.0 lb Citrus pulp	0.88	53.0	60.0	
Cooke et al. (2008)	5.7 lb Soyhulls-based supp.	0.73	48.6	50.0	No
		0.90	49.4	60.0	
Cooke et al. (2009)	6.0 lb Soyhulls-based supp.	1.10 1.28	64.0	60.0	No
Moriel et al. (2012)	5.0 lb Soyhulls-based supp.	0.59	51.5	16.6	No
Moriel et al. (2014)	Normally weaned + 1.5% of body weight; Soyhulls-based supp.	1.41	58.7	70.0	No
	Early weaned + 1.5% of body weight; Soyhulls-based supp.	1.67	66.7	89.0	
Martins et al. (2016)	6.0 lb Molasses	0.37	50.0	49.5	No
Moriel et al. (2017)	4.0 lb Molasses slurry	0.55	53.7	64.2	No
	6.4 lb Molasses slurry	0.90	57.6	70.0	
	9.7 lb Molasses slurry	1.12	58.6	70.0	
Moriel et al. (2020)	1.25% of body weight; Soyhulls-based supp.	1.43	64.7	64.8	Yes
	1.75% of body weight; Soyhulls-based supp.	1.56	66.4	83.0	
Moriel et al. (2022)	Constant: 1.50% of body weight	1.23	56.0	84.4	Yes
	Stair-Step: 1.05% then 1.95% of body weight	1.39	57.0	94.8	

[1]*Assuming a mature body weight of 1200 lb.*

Day and Nogueira (2013) evaluated both nutritional and hormonal intervention in Nelore (100% *Bos indicus*) and Nelore & Angus crossbred heifers to achieve acceptable pregnancy rates in heifers bred with artificial insemination (AI) at 12 to 15 months of age. Heifers were fed to achieve an average body weight of approximately 660 lb at the start of a hormonal treatment to induce puberty. Two consecutive estrous synchronization protocols were then used in conjunction with timed AI (initial timed AI and resynchronization of non-pregnant heifers) leading to final pregnancy rates of nearly 60% in Nelore and 80% in Nelore & Angus heifers. These results are similar to those observed for Nelore heifers calving for the first time at 3 or 4 years of age under traditional management (only grass). Subsequent pregnancy rates for primiparous Nelore cows that calved at 2 years of age were above 80% in cows that were provided supplemental feed during the first 3 months post-partum and above 50% for cows provided only pasture during the postpartum period. These findings indicate that a majority of Nelore and Nelore & Angus heifers can successfully calve at 2 years of age and rebreed as primiparous cows if sufficient nutritional management and a hormonal approach in conjunction with timed AI are implemented. The economic and managerial feasibility of this approach requires further investigation (Day and Nogueira, 2013). Likewise, Table 4 indicates that when *Bos indicus* crossbred heifers were submitted to a hormonal protocol (Moriel et al., 2020, 2022), pregnancy rates of >80% were observed for heifers attaining 60-65% of mature body weight at the start of the breeding season.

2. Post-weaning energy intake

Increasing the post-weaning energy intake led to positive impacts on the reproductive physiology of heifers (Moriel et al., 2017). Our group has observed that Brangus crossbred heifers supplemented with concentrate dry matter at 1.75% of their body weight for the entire development period (September to March) had greater overall average daily gain, puberty attainment before the start of the breeding season, and pregnancy rates compared to heifers supplemented at 1.25% of their body weight (Moriel et al., 2020; Table 5). Lifetime productivity is significantly improved when heifers calve early in their first calving season (Cushman et al., 2013). Supplementation at 1.75% also increased the percentage of heifers calving during the first 4 weeks of the calving season. Total amount of supplement consumed during the study was 1,350 lb and 1,888 lb for heifers supplemented at 1.25% and 1.75% of body weight, respectively. Concentrate supplement cost was $0.15/lb. Total feed cost per heifer was $203 and $283 for heifers supplemented at 1.25% and 1.75%, respectively. Assuming all calves from these heifers are weaned with 550 lb @ $1.40/lb, the net return per heifer after discounting feed costs would be $87 greater for heifers supplemented at 1.75% vs. 1.25% of body weight**,** despite their greater supplementation cost.

Table 5. Reproductive performance of Brangus crossbred heifers supplemented at 1.25% or 1.75% of their body weight (dry matter basis) for 167 days (September to March; Adapted from Moriel et al., 2020).

Item	**1.25% of body weight**	**1.75% of body weight**	**SEM**	***P***
Overall average daily gain, lb/day	1.43	1.56	0.033	0.02
Pubertal heifers at start of the breeding season, % of total	81	92	4.0	0.05
Final pregnancy rate, % of total	65	83	5.3	0.02
Heifers calving within the first 4 weeks of the calving season, % of total	68	51	7.7	0.05

3. ***Frequency of concentrate supplementation***

Up to 63% of annual production costs in cow/calf operations are associated with feeding (Miller et al., 2001). Decreasing the frequency of concentrate supplementation from daily to 3 times weekly can help to reduce these costs by more than half. When supplementation frequency is reduced, the amount of supplement fed weekly remains the same (for example, 46.2 lb/week), but the amount of concentrate fed at each feeding event is increased compared to daily supplementation (6.6 lb/day for 7 days *vs.* 15.4 lb/day on Mondays, Wednesday, and Fridays).

Reducing the frequency of energy supplementation from daily to 3 times weekly had no impact (Drewnoski et al., 2011; Moriel et al., 2016) or decreased average daily gain of beef calves by 10 to 21% (Cooke et al., 2008; Artioli et al., 2015). Discrepancies among these results can be associated to differences in supplement composition, animal breed and sex, location of the study, forage species and quality, and the potential interactions among those factors (Artioli et al., 2015). However, differences in daily forage intake between cattle offered frequent or infrequent energy supplementation is the primary factor explaining the variable growth performance among these studies. When supplementation frequency is reduced, cattle consume a large portion of concentrate in a single day and receive no concentrate supplementation on the next day. This less frequent schedule of supplementation leads to fluctuations in forage and nutrient intake.

In terms of performance of beef heifers, reducing the frequency of energy supplementation may be detrimental to reproduction. Moriel et al. (2012) evaluated the impact of similar weekly energy supplementation that was offered either daily (**S7 heifers**) or 3 times weekly (**S3 heifers**; Monday, Wednesday, and Friday) on growth and reproduction of beef heifers fed stargrass. Supplements were offered at weekly rates of 35 lb of dry matter/heifer. On days that both S3 and S7 heifers were supplemented, S3 heifers had lower hay dry matter intake compared with S7 heifers (5.62 vs. 7.40 lb/day, respectively). On days that only S7 heifers were supplemented, S3 heifers also had lower hay dry matter intake (6.93 vs. 7.44 lb/day for S3 and S7 heifers, respectively). Consequently, overall mean hay dry matter intake was 15.4% lower for S3 vs. S7 heifers. Estimated NEg intake followed the same pattern observed on total dry matter intake, and overall estimated NEg intake was slightly greater for S7 vs. S3 heifers (2.75 vs. 2.59 Mcal/day, respectively). However, the magnitude of differences on estimated overall NEg intake between S7 and S3 heifers was not sufficient to impact average daily gain (0.62 vs. 0.59 lb/day for S3 and S7, respectively). Despite the similar average daily gain, attainment of puberty and pregnancy were delayed by decreasing the frequency of energy supplementation (Figure 3). At the end of the breeding season, approximately 38% of S7 heifers were pubertal, whereas only 17% of S3 heifers were pubertal. Final pregnancy rates did not differ between treatments but S7 heifers became pregnant earlier in the breeding season (Figure 3).

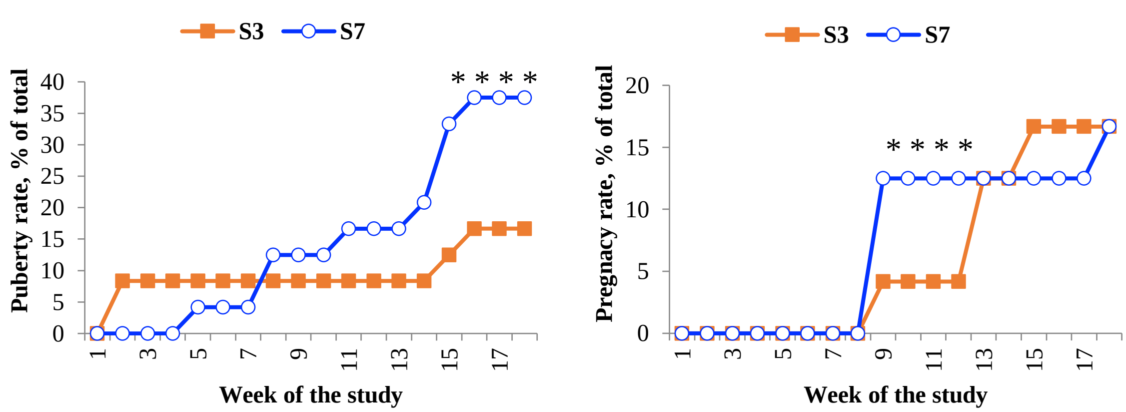
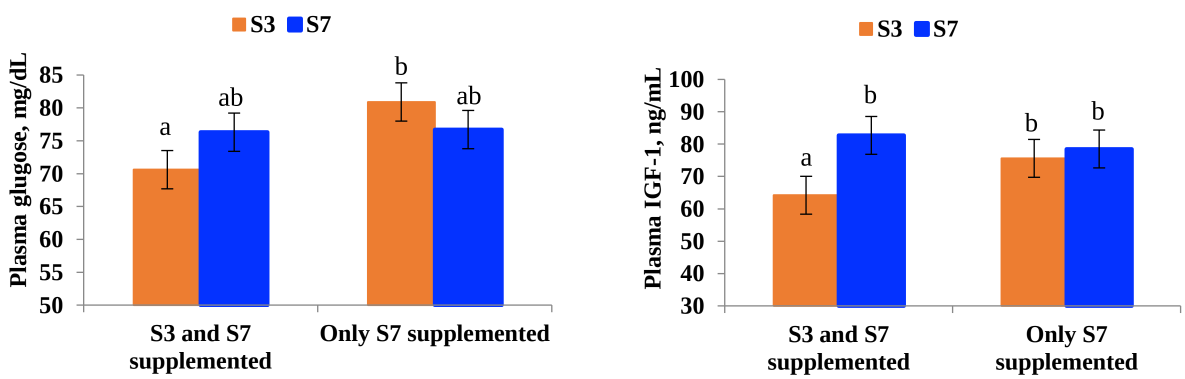


Figure 3. Weekly puberty (left) and pregnancy (right) attainment of beef heifers supplemented with concentrate daily (S7) or 3 times weekly (S3; Moriel et al., 2012). $*P \leq 0.05$

Enhanced reproductive performance have been associated with increased blood concentrations of glucose, insulin, and insulin-like growth factor 1 (IGF-1; Hess et al., 2005). In cattle, GnRH secretion is impaired when glucose availability is inadequate, but resumed when glucose levels are adequate (Hess et al., 2005). Cows with low plasma insulin concentrations have impaired LH surge, reduced numbers of LH receptors in the dominant follicle, and fail to ovulate (Diskin et al., 2003). Insulin-like growth factor 1 is a major metabolic signal regulating reproduction in cattle (Wettemann and Bossis, 2000; Thatcher et al., 2001). Plasma glucose, insulin and IGF-1 are positively affected by nutrient intake (Vizcarra et al., 1998; Bossis et al., 1999) and supplementation frequency (Cooke et al., 2007). For instance, plasma glucose and insulin concentrations were greater for S3 vs. S7 heifers on the days that only S7 heifers received supplementation, but not on days that both treatment groups were supplemented. More importantly, heifers supplemented every day had less daily variation in plasma concentrations of glucose and IGF-I than heifers supplemented 3 times weekly (Figure 4; Moriel et al., 2012). The differences in plasma concentrations of glucose and insulin were attributed to the pattern of nutrient intake of each treatment, and this lower fluctuation in blood parameters with a more frequent supplementation schedule likely collaborated for the improved puberty achievement compared to infrequent supplementation (Moriel et al., 2012).

Figure 4. Plasma concentrations of glucose (left) and IGF-1 (right) of beef heifers supplemented



with concentrate daily (S7) or 3 times weekly (S3; Moriel et al., 2012). The X-axis represent the days that both S3 and S7 heifers were supplemented (Monday, Wednesday, and Friday) and days that only S7 heifers were supplemented (Tuesday, Thursday, and Friday). $^{ab}P \leq 0.05$.

Recently, we attempted to overcome the negative effects of frequency of energy supplementation by increasing the amount of supplement offered to heifers. In this 2-year study, heifers were supplemented with concentrate dry matter at: 1.25% of body weight offered 3 times weekly (**1.25-3X**); 1.25% of body weight offered 7 times weekly (**1.25-7X**); 1.75% of body weight offered 3 times weekly (**1.75-3X**); or 1.75% of body weight offered 7 times weekly (**1.75-7X**). The hypothesis was that by increasing the concentrate supplementation amount, heifers offered reduced frequency of supplementation would achieve similar puberty attainment and pregnancy percentage compared to heifers supplemented daily. Contrary to our hypothesis, effects of supplementation frequency × amount were not detected ($P \geq 0.71$) for any variable. Growth and reproductive performance of heifers supplemented at 1.25% or 1.75% were discussed previously (Table 5). Similar to our previous studies, growth and reproductive performance of heifers supplemented 3 times weekly were reduced compared to heifers supplemented daily (Table 6). Although pregnancy rates did not differ, heifers supplemented 3 times weekly calved later during their first calving season compared to heifers supplemented daily (Table 6). Therefore, despite including greater supplementation amounts and a puberty induction protocol, heifer reproductive performance was significantly jeopardized when supplementation frequency was reduced from daily to 3 times weekly.

Table 6. Reproductive performance of heifers supplemented daily (7X) or 3 times weekly (3X) for 167 days (September to March; Adapted from Moriel et al., 2020).

Item[1]	**7X**	**3X**	**SEM**	***P***
Overall average daily gain, lb/day	1.43	1.56	0.031	0.007
Pubertal heifers at start of the breeding season, % of total	86	80	4.0	0.03
Final pregnancy rate, % of total	75	72	5.2	0.70
Heifers calving within the first 21 days of the calving season, % of total	76	43	7.7	<0.01

[1]Heifers were offered concentrate at 1.25% or 1.75% of their body weight (dry matter basis). Effects of frequency of supplementation × concentrate amount were not detected (P ≥ 0.71) for any variable in this study.

4. Growth pattern (Stair-step strategy)

Modifying the growth pattern during the post-weaning phase has been used to promote reproductive success of *Bos taurus* heifers. Lynch et al. (1997) developed beef heifers to achieve an even weight gain from weaning until breeding (EVENGAIN) or achieve a low weight gain from weaning until 45 days before breeding followed by a high weight gain in the final 45 days before breeding (LOW-HIGH). Both groups were fed enough nutrients to achieve 65% of the expected mature body weight by the start of the breeding season. The strategy of low weight gain followed by high weight gain is called Stair-Step strategy and is usually implemented to explore compensatory gains that occur when nutrition level is increased immediately after a period of nutrient restriction. In that study (Lynch et al., 1997), LOW-HIGH heifers had greater first-service conception rate compared to EVENGAIN heifers (71% vs. 56%). Although final pregnancy rates did not differ between these two treatments (88% vs. 88%), the greater first conception rates of LOW-HIGH heifers led to increased percentage of heifers calving early in their first calving season, which has been associated with greater lifetime productivity and longevity. Another study also reported that heifers developed using a Stair-Step strategy had approximately twice as many primordial follicles (an indicator of ovarian reserves) at 14 months of age compared to heifers developed on an even gain program (Freetly et al., 2014). This response is important because primordial follicles found within the ovary serve the needs of the entire reproductive lifespan. Also, larger ovarian reserves correspond with increased fertility in cattle (Cushman et al., 2014). Hence, the Stair-Step strategy may allow producers to further improve the reproductive performance of their heifers without increasing feed costs. It is important to highlight that the studies described above used *Bos taurus* heifers. The 2-year study described below replicated the stair-step approach in *Bos indicus* crossbred heifers developed in hot and humid conditions of Summer/early-Fall, which are known for delaying puberty attainment (Table 7).

In September of each year, Brangus heifers were allocated into 1 of 16 bahiagrass pastures (4 heifers/pasture). Treatments consisted of: heifers supplemented with concentrate dry matter at 1.50% of body weight from September until the start of the breeding season in December (day 0 to 100; **CON**); or stair-step heifers initially offered concentrate dry matter at 1.05% of body weight from September to October (day 0 to 50), and then, concentrate dry matter at 1.95% of body weight from October until the start of the breeding season in December (**SST**; day 50 to 100). In average, both treatments were supplemented with concentrate dry matter at 1.50% of body weight from September to December (22% CP and 73% TDN; dry matter basis).

Total supplement dry matter offered to heifers did not differ between treatments (Table 7). In terms of growth, average daily gain from day 0 to 50 did not differ between treatments but was greater for SST vs. CON heifers from day 50 to 100, leading to a tendency for greater overall average daily gain and greater body weight at start of estrus synchronization protocol for SST vs. CON heifers. Intravaginal thermometers were inserted into heifers to determine the intravaginal temperatures every 30 min from day 25 to 31 (Sep 7th to 12th; top panel in Figure 5) and day 85 to 91 of the study (Nov 6th to 12th; bottom panel in Figure 5).

Table 7. Growth, total concentrate offered, and reproductive success of heifers[1] grazing bahiagrass pastures and assigned to receive concentrate dry matter supplementation at 1.50% of body weight from day 0 to 100 (CON) or concentrate dry matter supplementation at 1.05% of body weight from day 0 to 49 and 1.95% of body weight from day 50 to 100 (SST).

	Supplementation strategy			
Item	**CON**	**SST**	**SEM**	***P*-value**
Body weight, lb				
day 0	548	546	4.2	0.91
day 50	608	604	4.2	0.49
day 100	670	685	4.2	0.01
day 210	835	852	4.2	0.007
Average daily gain, lb/day				
day 0 to 50	1.23	1.17	0.06	0.35
day 50 to 100	1.21	1.61	0.06	<0.0001
day 0 to 100	1.23	1.39	0.04	0.01
day 100 to 210	1.50	1.52	0.04	0.74
Total concentrate dry matter offered, lb/heifer				
day 0 to 49	458	324	6.6	<0.0001
day 50 to 100	465	610	7.9	<0.0001
day 0 to 100	925	934	13.4	0.66
Pubertal heifers on day 100, % of total	73.5	75.7	4.82	0.76
Pregnant heifers, % of total				
AI	39.1	47.1	6.11	0.36
Final	84.4	94.8	3.62	0.04
Calving within 21 of calving season, % of total	59.2	76.4	0.06	0.05

[1] Heifers were assigned to an estrus synchronization protocol which consisted of $PGF_{2\alpha}$ injection on day 100, CIDR insertion and GnRH injection on day 104, CIDR removal and $PGF_{2\alpha}$ injection on day 111. Heifers detected in estrus from day 111 to 114 were assigned to AI 12 h after estrus detection. Heifers not detected in estrus received a GnRH injection and were AI on day 114. Bulls were placed with heifers on day 120 (1 bull/pasture) and were rotated among pastures every 15 days until day 210.

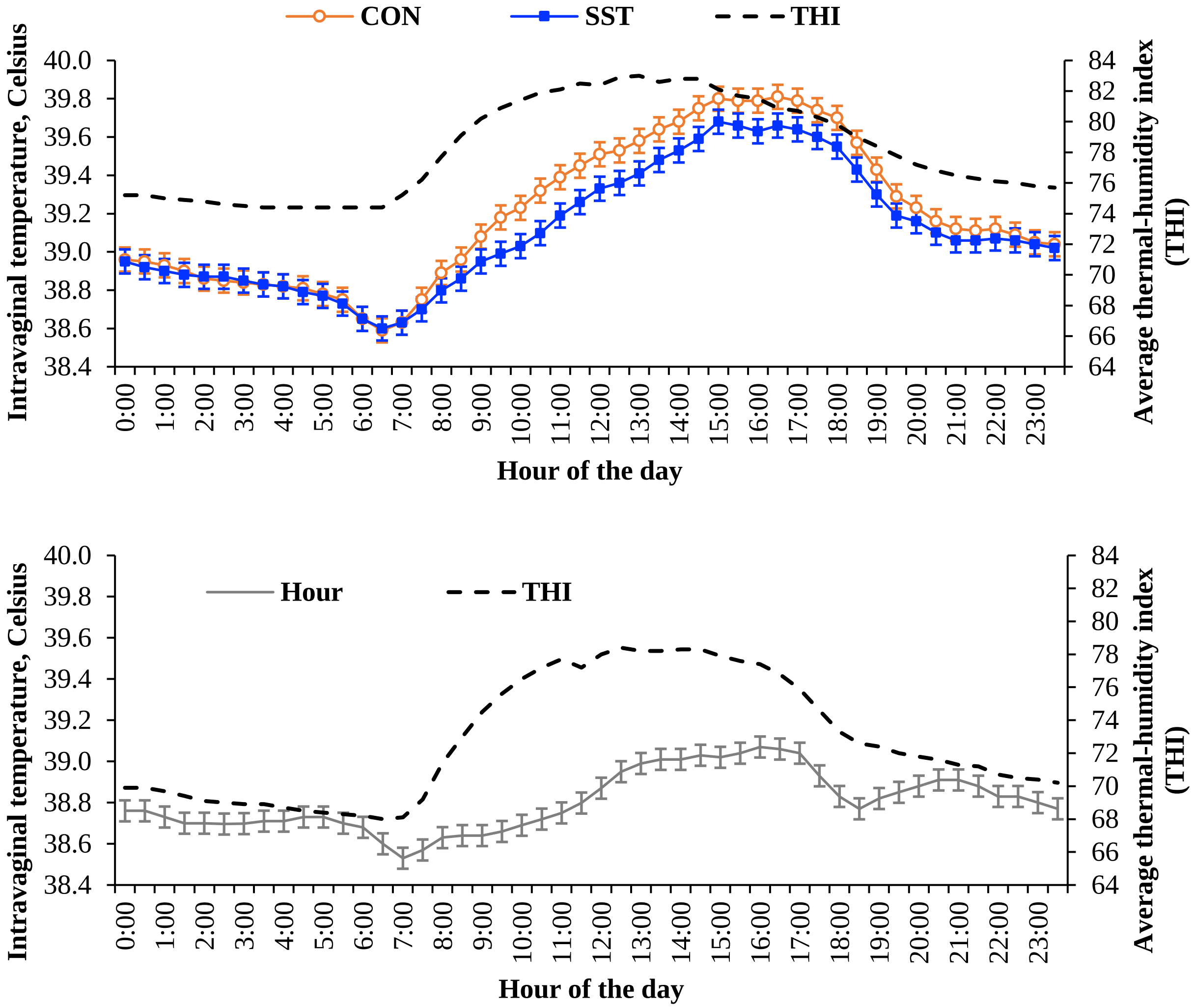


Figure 5. Intravaginal temperature and temperature humidity index (THI) from day 26 to 31 (top panel) and day 85 to 90 (bottom panel) of heifers assigned to receive concentrate dry matter supplementation at 1.50% of body weight from day 0 to 100 (CON) or concentrate dry matter supplementation at 1.05% of body weight from day 0 to 49 and 1.95% of body weight from day 50 to 100 (SST).

From day 25 to 31, SST heifers had significantly lower intravaginal temperatures from 0930 h to 1800 h compared to CON heifers (nearly 0.25 to 0.32ºC lower for SST vs. CON), which is likely a result of lower heat increment and partially explains the lack of treatment effects on heifer average daily from day 0 to 50 despite the drastic differences in supplement offered during this period. From day 85 to 91, supplement dry matter amount did not affect intravaginal temperature of heifers, which likely prevented energy waste to cope with heat stress and allowed the greater average daily gain of SST vs. CON heifers. Although overall average daily gain tended to differ, percentage of pubertal heifers at the start of the synchronization protocol and pregnancy rates to AI did not differ between treatments (Table 7). However, final pregnancy rate and percentage of heifers calving within the first 21 days of the calving season were greater for SST vs. CON heifers (Table 7). Therefore, the stair-step strategy successfully increased overall growth performance and enhanced the final percentage of pregnant heifers and percentage of heifers calving early in the calving season, without increasing the total amount of concentrate consumed. Hence, the stair-step supplementation strategy was a viable nutritional management strategy for *Bos indicus*-influenced beef heifers developed in subtropical/tropical environments.

5. Early-weaning

Metabolic imprinting is the process by which nutrition during early-stages of a calf's life may permanently change its development and subsequent performance (Lucas, 1991). This concept has substantial economic implications for agriculture and should be explored to improve the performance of animals destined for food production. Early-weaning is a management practice consisting of permanent calf removal at ages often less than 5 months. Conversely, normal weaning traditionally occurs when calves are between 7 to 9 months of age. Early-weaning has been shown to improve calf growth (Moriel et al., 2014) and feed efficiency and reproductive performance of cows (Arthington and Kalmbacher, 2003). Despite the positive effects of early-weaning on cattle performance, few beef producers are willing to adopt the early-weaning practice because of the limited amount of information on how to manage early weaned calves and increased labor associated with feeding calves daily. Thus, our group conducted a 2-year study at the UF/IFAS Range Cattle Research and Education Center to evaluate different calf management systems for early-weaned beef calves and their long-term consequences to heifer growth and reproduction (Moriel et al., 2014).

In January of each year (day 0 of the study), Brangus heifers (70 days of age) were assigned to remain with their dams and be normally weaned at 250 days of age (day 180 of the study; **NW**), or early-weaned at 70 days of age and randomly assigned to 1 of 3 early-weaning management systems from day 0 to 180 of the study: 1) ryegrass and bahiagrass grazing for 180 days (**EWPAST**); 2) high-concentrate diet in drylot for 180 days (**EW180**); and 3) high-concentrate diet in drylot for 90 days, then bahiagrass grazing for additional 90 days (**EW90**). When early weaned calves were in drylot, they were limit-fed the high-concentrate diet at 3.5% of body weight (as-fed). When early weaned calves were on pasture, they were supplemented with a high-concentrate diet at 1.0% of body weight (as-fed). Calves that were kept with the mothers until weaning (250 days of age) did not receive supplementation from 70 to 250 days of age.

We observed that EW90, EW180, and EWPAST heifers had similar or greater growth performance from day 0 to 180 compared to NW heifers (Table 8). From day 180 of the study until the end of the breeding season (day 395), all heifers were supplemented with concentrate dry matter at 1.5% of body weight (as-fed). During this period, no differences were detected for average daily gain among treatments (in average = 1.50 lb/day). Interestingly, limit-feeding a high-concentrate diet in drylot, for at least 90 days, increased the percentage of heifers cycling at the start of the breeding season compared to normally weaned heifers (Table 8). More specifically, a greater percentage of early-weaned heifers fed high-concentrate diet in drylot for only 90 days achieved puberty at the start of the breeding season, despite having similar body weight and average daily gain compared NW heifers. This response indicates that we can successfully hasten puberty achievement if *Bos indicus*-influenced beef heifers by temporarily exposing young calves to high-concentrate diets and high-growth rates starting at approximately 70 days of age.

Table 8. Growth and reproductive performance of beef heifers developed on different management systems from the time of early weaning (EW; day 0 of the study) until the time of normal weaning (NW; day 180 of the study; Moriel et al., 2014).

Item	Treatments				SEM	*P*
	NW	EWPAST	EW180	EW90		
Body weight[1], lb						
day 90 (Early-weaning)	306[a]	297[a]	361[b]	377[b]	8.1	<0.001
day 180 (Normal weaning)	467[a]	392[b]	577[c]	476[a]	14.1	<0.001
day 335 (Breeding season)	711[a]	643[b]	800[c]	720[a]	17.4	<0.001
Age at puberty, days	429[a]	418[a]	298[b]	358[c]	14.9	<0.001
Body weight at puberty, lb	753[a]	674[b]	630[b]	643[b]	26.2	0.09
Pubertal heifers at start of breeding season, % of total	30[a]	40[a]	100[b]	80[b]	13.2	0.002
Pregnant heifers, % of total	60	50	78	70	15.6	0.64

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

6. Pre-weaning injections of bovine somatotropin (bST)

The exact nutrition-mediated mechanisms involved in this early activation of the reproductive axis in beef heifers are unknown. However, circulating IGF-I can affect gonadotropin secretion and activity required for the first ovulation and subsequent puberty achievement in beef heifers by influencing hypothalamic–pituitary secretory activity (Schillo et al., 1992) and augmenting the effects of gonadotropins in ovarian follicular cells (Spicer and Echternkamp, 1995). Thus, metabolic imprinting may be explored by identifying strategies to increase heifer average daily gain and plasma IGF-1 during the developmental phase leading to optimized future reproductive performance. In agreement, heifer average daily gain and plasma IGF-1 concentrations from 70 to 160 days of age explained approximately 34% of the variability on age at puberty (Moriel et al., 2014). Although postweaning injections of bovine somatotropin (bST) hastened puberty attainment of *Bos taurus* heifers (Cooke et al., 2013), less emphasis has been placed on preweaning management strategies despite their greater impact on heifer puberty attainment compared to postweaning management practices.

Bos taurus and *Bos indicus* are different subspecies that diverge in social and biological functions (Cooke et al., 2019). Under the same environmental and nutritional conditions, *Bos taurus* and *Bos indicus* cattle not only exhibit diet-dependent differences in intake, digestion, and ruminal fermentation (Habib et al., 2008; Bell et al., 2017), but also different ovarian function, circulating hormones and metabolites (Sartori et al., 2016). These differences may determine the direction and magnitude of performance responses to similar management applied to *Bos taurus* or *Bos indicus* breeds. Thus, we conducted 2 studies to evaluate the impacts of preweaning injections of bST on growth and reproductive performance of Brangus (Experiment 1; Piccolo et al., 2018) and Nelore beef heifers (Experiment 2; Moriel et al., 2019).

In Experiment 1, suckling Brangus heifers were stratified by body weight (324 lb) and age (134 days) on day 0, and randomly assigned to receive an injection of saline (**SAL**; 5 mL; 0.9% NaCl) or 250 mg of bovine somatotropin (**BST**; Posilac, Elanco, Greenfield, IN) on days 0, 14, and 28. Heifers and respective dams were managed as a single group on bahiagrass pastures from day 0 until weaning (day 127), and provided the same diet during the entire post-weaning phase. In Experiment 2, suckling Nellore heifers were stratified by body weight (214 lb) and age (80 ±

10 days), and randomly assigned to receive injections of saline (5 mL 0.9% NaCl) or 250 mg of bovine somatotropin (BST) on days 0 and 10 of the study. Then, all Nellore heifers were managed as a single group in *Brachiaria decumbens* pastures, weaned on day 177, and provided a corn silage–based total mixed ration from weaning until the end of the study (day 380).

In Experiment 1, Brangus-crossbred heifers administered preweaning bST injections had an 8.6 ng/mL increase in plasma IGF-1 concentrations (103 vs. 95 ng/mL; P = 0.05) and 7.2% increase on average daily gain from days 0 to 42 (2.53 vs. 2.36 lb/day; P = 0.07), but no differences on overall preweaning (1.76 and 1.96 lb/day; P = 0.50) and post-weaning average daily gain (0.62 and 0.66 lb/day; P = 0.61) compared to saline heifers. Also, heifers assigned to BST tended to achieve puberty 26 days earlier (388 vs. 414 days; P = 0.10), had greater percentage of pubertal heifers on days 244, 263, 284, and 296 of the study ($P \leq 0.04$; Figure 6), and tended to have greater overall pregnancy percentage (82 vs. 69%; P = 0.10) compared to saline heifers.

In Experiment 2, preweaning bST injections increased plasma IGF-1 concentrations by 52 ng/mL (211 vs. 159 ng/mL; P = 0.0001) and average daily gain from days 0 to 10 by 35% (1.43 vs. 1.06 lb/day; P = 0.03), but did not affect overall preweaning average daily gain (0.99 vs. 1.04 lb/day; P = 0.24), tended to decrease post-weaning average daily gain by 3.6% (1.76 vs. 1.83 lb/day; P = 0.07) and reduced puberty attainment on days 349, 359, and 380 ($P \leq 0.05$; Figure 6) compared to saline injections.

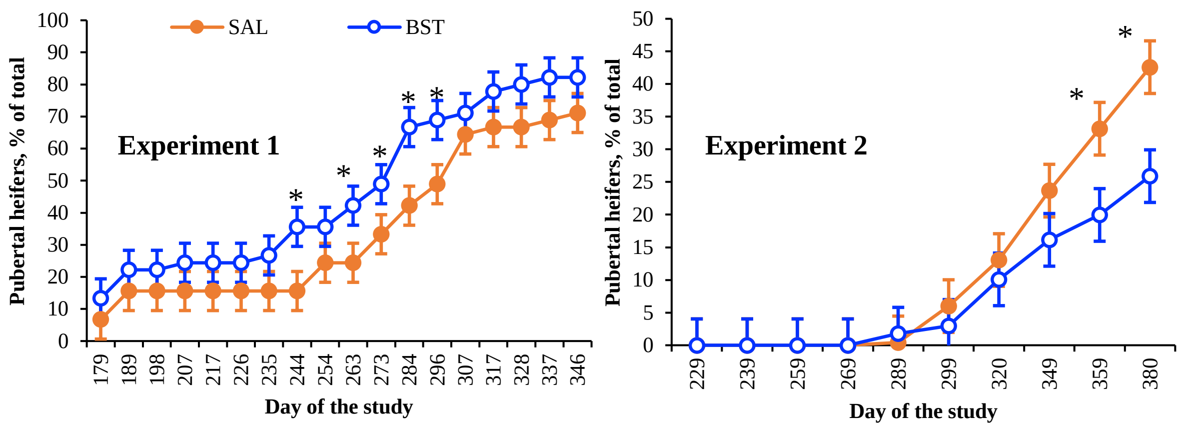


Figure 6. Puberty attainment of Brangus (Experiment 1; left panel) and Nellore (Experiment 2; right panel) beef heifers. In Experiment 1, heifers were stratified by age on day 0 and assigned to receive injection of saline (SAL) or 250 mg of sometribove zinc (BST) on days 0, 14, and 28. In Experiment 2, heifers were stratified by age on day 0 and assigned to receive injections of SAL or BST on days 0 and 10 of the study. *$P \leq 0.05$

Sartori et al. (2016) reported that *Bos indicus* cattle naturally have greater circulating IGF-I concentrations compared with *Bos taurus* cohorts. Moreover, Mendonça et al. (2013) demonstrated that even under the same environment and diet, *Bos taurus*–influenced dairy cows have less circulating concentrations of IGF-I compared to *Bos indicus* cows, which might be related to the different organ sensitivity to IGF-1. It is possible that the greater increment on plasma IGF-1 concentrations following bST injection in Experiment 2 vs. 1, in combination with the interval between bST injections, was detrimental to the development of the reproductive axis of

Nellore heifers. Further studies investigating the effects of breed on ovarian activity and gene expression in reproductive tissue organs and brain, following bST injections, are warranted.

Conclusions

Nutritional management of heifers during the first year of life is critical in establishing the foundation for fertility, productivity, and longevity in a beef herd. Decisions made regarding nutritional management of heifers can help program puberty attainment, fertility, and the ovarian reserve potentially allowing for increases in reproductive performance and longevity, resulting in improved profitability. Development of *Bos taurus* replacement heifers on a stair-step nutritional program may result in a larger ovarian reserve before the onset of the breeding season. A nutritionally mediated increase in the ovarian reserve could potentially have a positive impact on reproductive longevity, providing a viable management strategy for producers. Overall, identification of management strategies that effectively utilize resources, enhance reproduction and longevity, as well as allow adaptation of heifers to future production environments will provide producers additional opportunities for profitability and success in their operations.

Despite the challenges encountered by *Bos indicus*-influenced beef heifers including extreme heat and humid conditions in combination with forages of relatively poor nutritional composition, acceptable reproductive performance may still be achieved. Some of these successful nutritional management practices to enhance growth and reproduction included: increasing the concentrate dry matter offered to heifers from 1.25% to 1.75% of body weight; daily rather than infrequent (3X/week) concentrate supplementation; stair-step strategy to boost growth and reproductive success; and early-exposure to high-concentrate diets. Although preweaning injections of bST are currently not allowed for beef cattle in U.S., our results indicated that early manipulation of the somatotrophic axis via bovine somatotropin injections may benefit the reproductive performance of Brangus but not Nellore beef heifers. Identifying additional strategies that can enhance calf performance during early postnatal life may provide unique opportunities to optimize feed resources and increase the profitability of beef cattle operations.

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