NUTRITIONAL PROGRAMMING OF PUBERTY IN BOS INDICUS-INFLUENCED BEEF HEIFERS

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Summary

Genetics and nutrition are two major factors controlling the timing of puberty in heifers. While nutrient restriction during the juvenile period delays puberty, accelerated rates of body weight gain during this period facilitate pubertal development by programming hypothalamic centers that underlie the pubertal process. Our studies in *Bos indicus*-influenced beef heifers demonstrate that metabolic programming of processes underlying puberty can be shifted temporally through the use of a stair-step, compensatory growth model such that puberty is optimally-timed to occur at approximately 12 mo of age. More specifically, these studies suggest that feeding heifers a high-concentrate diet during critical windows of development (4 to 9 months of age) results in changes in the metabolic endocrine status, characterized by elevated circulating concentrations of leptin, insulin, and IGF-1, which in turn can program the onset of puberty that occurs months later, allowing optimal timing of sexual maturation in replacement beef heifers.

Introduction

The timing of pubertal development has important implications for livestock production. In beef heifers, lifetime productivity is heavily dependent upon their ability to reach reproductive competence, to conceive early during their first breeding season, and to calve the first time by approximately 24 months of age (Lesmeister et al., 1973). Moreover, the incidence of multiple estrous cycles before the first breeding positively influences yearling fertility (Short and Bellows, 1971). However, a considerable proportion of beef heifers within existing U.S. production systems fail to reach the developmental end-points necessary to achieve these objectives (Hughes, 2013). This is particularly true for later-maturing breeds (e.g., Bos indicus-influenced) in which the skeletal size required to support a healthy and safe pregnancy is frequently attained well before the establishment of regular estrous cycles. Therefore, a better understanding of mechanisms within the lower part of the brain (hypothalamus) controlling puberty can assist in the development of novel managerial strategies that exploit brain plasticity during critical windows of development and lead to strategies for successfully programming the onset of puberty around 12 to 14 months of age. Using a modified version of a previously reported stair-step nutritional regimen in dairy heifers (Park et al., 1987), the study reported here examined the ability of a stair-step compensatory gain nutritional regimen to program the onset of puberty in beef heifers at approximately 12 mo of age.

Experimental Procedures

Forty crossbred beef heifers (½ Angus, ¼ Hereford, ¼ Brahman) were weaned at approximately 3.5 mo of age, and after a 2-wk acclimation period, were assigned randomly to 1 of 4 nutritional groups: 1) Low Control (LC): restricted feed intake of a forage-based diet to promote BW gain of 0.5 kg/d until 14 mo of age; 2) High Control (HC): controlled feed intake of a high-concentrate diet to promote BW gain of 1 kg/d until 14 mo of age; 3) Stair-Step 1 (SS-1): ad libitum feed intake of a high-concentrate diet until 6.5 mo of age followed by restricted access to a high-forage diet to promote BW gain of 0.35 kg/d until 9 mo of age, ad libitum feed intake of a high-concentrate diet until 11.5 mo of age, and restricted intake of a high-forage diet to promote BW gain of 0.35 kg/d until 14 mo of age; and 4) Stair-step 2 (SS-2), reverse sequence of SS-1, beginning with restricted access to a high-forage diet. Heifers were fed individually using a Calan Gate individual feeding system (American Calan, Northwood, NH). Body weight (every 2 wk) and circulating concentrations of leptin (monthly) were determined throughout the experiment. Concentrations of progesterone in blood samples collected twice weekly beginning at 8 mo of age were used to determine onset of puberty, which was determined by at least two consecutive samples with concentrations of progesterone ≥ 1 ng/mL. Targeted ADG was attained by adjustments in the DMI based on BW gain determined every 2 wk. Dietary ingredients and chemical composition are presented in **Table 1**.

Results and Discussion

Body weight gain in all groups followed a pattern similar to that projected in the experimental design. Heifers in the HC group had greater ($P < 0.05$) mean BW than LC heifers starting at week 6 of the experiment and continuing throughout the study. As expected, at the end of the first dietary period (week 10), heifers in the SS-1 group had greater ($P < 0.01$) BW than heifers in the SS-2 group. However, after changes in the targeted ADG during the second 10-wk dietary period, mean BW of animals in the SS-1 and SS-2 groups did not differ significantly at the end of period 2 (week 20). Because heifers in SS-1 were transitioned to ad libitum consumption of a high-concentrate diet during period 3 (weeks 20 to 30), and heifers in SS-2 were subjected to restricted intake of a forage-based diet, BW for SS-1 heifers was greater ($P < 0.05$) than SS-2 group at the end of period 3 (week 30). Mean ADG and BCS during the different dietary periods are presented in **Table 2**.

Concentrations of leptin, an adipose tissue-derived hormone critical for puberty, were greater ($P < 0.05$) in HC heifers when compared to LC heifers at week 8 and at week 16 of the experiment and remained greater ($P < 0.01$) than in LC heifers until the end of the experiment. Animals in the SS-1 and SS-2 groups, as expected, consistently exhibited increased concentrations of leptin during the ad libitum consumption periods (SS-1, Periods 1 and 3; SS-2, Periods 2 and 4). Following transition to a period of feed restriction (SS-1, Periods 2 and 4; SS-2 Period 3), heifers in both groups demonstrated rapid declines in circulating concentrations of leptin.

Survival analysis indicated that heifers in the LC group attained puberty later ($P < 0.05$) than all other groups in the experiment. Furthermore, SS-2 heifers achieved puberty later ($P = 0.057$) than both HC and SS-1 groups, which did not differ in mean age of pubertal onset. At 12 mo of age, the proportion of pubertal heifers did not differ ($P = 0.36$) between SS-1 and HC groups, with 80% and 70% pubertal, respectively. In contrast, the proportion of heifers pubertal by 12 mo of age in SS-2 (40%) and LC (30%) was less ($P < 0.05$) than both HC and SS-1. However, by 14 mo of age, a greater ($P < 0.01$) proportion of heifers in the SS-2 had also attained puberty compared to LC heifers, with 90% and 40% pubertal in SS-2 and LC, respectively. Because only 40% (4/10) of LC heifers had reached puberty by the end of the experiment, comparisons of mean BW at onset of puberty were performed only between HC, SS-1, and SS-2 groups (**Table 2**). Heifers in the SS-1 group tended to be lighter ($P = 0.09$) at puberty than heifers in the HC group. Mean BW at puberty for SS-2 heifers did not differ from HC and SS-1 groups (**Table 2**).

In summary, these results confirm our hypothesis that timing of puberty can be shifted temporally by exposing heifers to a stair-step nutritional feeding regimen during juvenile development. Interestingly, even though heifers in the SS-1 were subjected to a significant restriction in feed consumption between 6.5 and 9 mo of age, the proportion of pubertal heifers by 12 mo of age did not differ between SS-1 and HC. Additionally, these results suggest that while *Bos indicus*-influenced heifers are more sensitive to the nutritional acceleration of puberty during early calfhood (4 to 6.5 mo of age), managerial approaches that focus on increasing availability of nutrients around 6 to 9 mo of age (SS-2) can potentially time reproductive maturation consistently so that the majority of heifers have reached puberty at 11 to 14 mo of age, while avoiding a high incidence of precocious puberty (**Figure 1**). Furthermore, if heifers are developed on a well-controlled nutritional regimen based on periods of nutrient restriction and realimentation, significant improvements in growth efficiency and life-long lactation performance could also be achieved.

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Table 1. Ingredients and chemical composition of diets fed to prepubertal beef heifers between 4 and 14 mo of age. Diet A1 was provided to high control (HC) and stair-step 1 (SS-1) heifers during dietary Period 1; Diet A2-3 was fed to HC heifers during Periods 2 and 3, to stair-step 2 (SS-2) heifers during Period 2, and to SS-1 heifers during dietary Period 3; Diet A4 was fed to HC and SS-2 groups during Period 4 of the experiment; Diet B1 was fed to low control (LC) and SS-2 heifers during dietary Period 1; Diet B2-4 was fed to LC heifers during Periods 2, 3, and 4 of the study, to heifers in the SS-1 group during Periods 2 and 4, and to SS-2 heifers during dietary Period 3.

	Diets[1]				
Item	A1	A2-3	A4	B1	B2-4
Ingredients[2]					
Alfalfa hay, %	6.78	3.22	2.25	2.57	2.60
Cottonseed hulls, %	6.44	2.41	2.14	24.44	24.89
Rolled corn, %	42.39	48.28	53.06	19.80	28.45
Cane molasses, %	7.90	2.41	3.94	4.50	3.86
Corn gluten feed, %	8.44	4.83	5.25	2.40	2.58
Urea, %	0.76	0.72	0.94	0.65	0.94
Soybean meal, %	12.46	12.87	10.35	7.10	8.25
Bermudagrass hay, %	13.70	24.14	21.42	37.90	27.63
Producers 12:12 premix, %	0.38	0.32	0.19	0.43	0.54
Calcium carbonate, %	0.75	0.8	0.46	0.21	0.26
Chemical composition[2]					
Metabolizable energy, Mcal/kg	2.59	2.64	2.71	2.24	2.34
Crude protein, %	16.90	17.00	17.00	13.70	14.50
Digestible intake protein, %	12.34	12.75	12.58	9.60	10.59

[1] Diets were balanced using the Large Ruminant Nutrition System

[2] Dry matter basis

Table 2. Average daily gain, BCS, and BW at puberty in early-weaned beef heifers receiving 1 of 4 nutritional treatments: High control (HC; n = 10); Low control (LC; n = 10); Stair-step 1 (SS-1; n = 10); or Stair-step 2 (SS-2; n = 10)[1]

	Nutritional regimen				
Item	LC	HC	SS-1	SS-2	SEM
Heifers, no.	10	10	10	10	
Mean ADG, kg					
weeks 0 to 10	0.50[b]	0.88[c]	1.01[d]	0.35[a]	0.04
weeks 10 to 20	0.57[b]	0.90[c]	0.43[a]	1.30[d]	0.03
weeks 20 to 30	0.57[a]	0.94[b]	1.07[c]	0.47[a]	0.03
weeks 30 to 40[2]	0.57[a]	—	—	1.01[b]	0.04
Overall	0.55[a]	0.90[d]	0.84[c]	0.76[b]	0.02
Mean BCS[3]					
week 10	5.05[b]	5.80[c]	6.25[d]	4.40[a]	0.11
week 20	4.95[a]	6.05[d]	5.40[b]	5.70[c]	0.08
week 30	5.10[a]	6.25[c]	6.22[c]	5.33[b]	0.08
week 40[2]	5.30[a]	—	—	6.00[b]	0.09
BW at puberty[4], kg	—	334.91[f]	302.55[e]	317.47[ef]	13.49

[a-d] Within a row, means without a common superscript differ ($P < 0.05$)

[e, f] Within a row, means without a common superscript tend to differ ($P = 0.09$)

[1] Least square means

[2] Because most of the heifers in the HC and SS-1 groups were pubertal before the beginning of Period 4, data from these 2 groups were not analyzed for the last period of the study

[3] BCS was determined by visual inspection

[4] Because only 40% (4/10) of LC heifers had reached puberty by the end of the study, data for BW at puberty were not analyzed for this experimental group

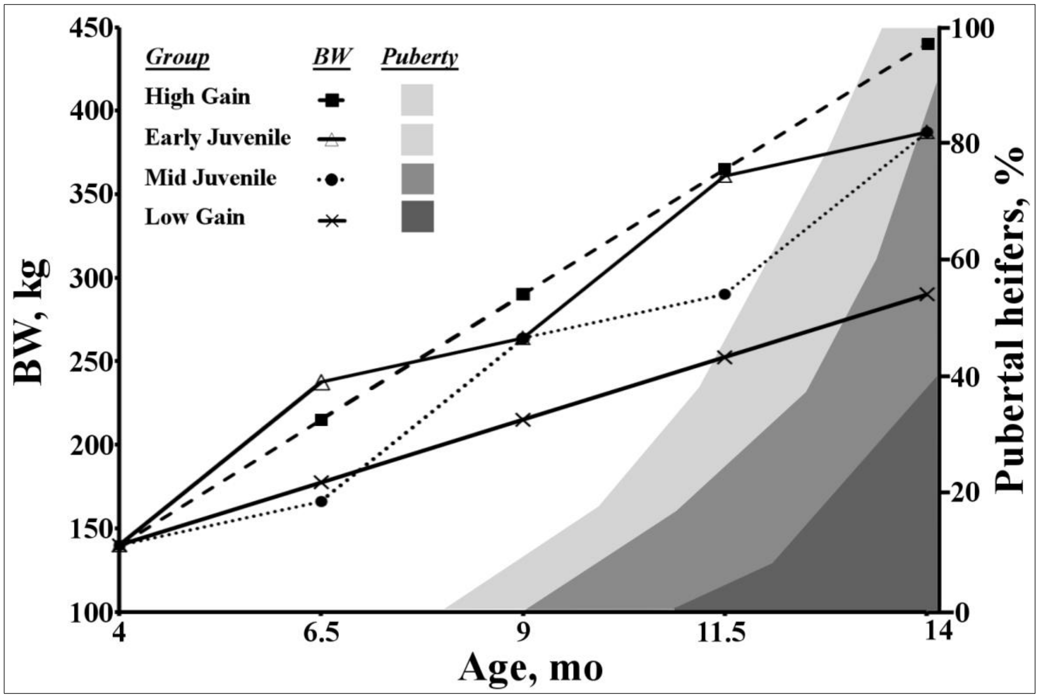

Figure 1. Model for a stair-step nutritional regimen applied to heifers during targeted periods of juvenile development to optimize growth, and promote genomic, biochemical and structural alterations in the hypothalamus that are permissive for early onset of puberty. Elevated BW gain during the early- and mid-juvenile periods programs neuroendocrine functions and accelerates pubertal development in heifers. Heifers that are fed ad libitum a high-concentrate diet beginning at 4 mo of age (Early Juvenile) become pubertal at a similar time as heifers gaining BW at high rates (High Gain) throughout the prepubertal period, even though feed restriction is applied during the mid-juvenile period. Most heifers that are restricted during the early juvenile period, but fed ad libitum between 6.5 and 9 mo of age (Mid Juvenile) becomes pubertal by 14 mo of age, whereas only as small proportion of heifers gaining BW at low rates (Low Gain) becomes pubertal by 14 mo of age. Adapted from Cardoso et al., 2014.