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Developmental and reproductive characteristics of beef heifers classified by pubertal status at time of first breeding[1]

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ABSTRACT: Data collected for 10 or more years at the West Central Research and Extension Center, North Platte, NE (*n* = 1,104); the Gudmundsen Sandhills Laboratory, Whitman, NE (*n* = 1,333); and the USDA, ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT (*n* = 1,176) were retrospectively analyzed to evaluate growth and reproductive performance of beef heifers classified by pubertal status before first breeding. Concentrations of progesterone in serum from 2 blood samples collected 9 to 11 d apart before the breeding season classified heifers as pubertal (progesterone ≥ 1.0 ng/mL in 1 or both samples) or nonpubertal (progesterone < 1.0 ng/mL in both samples). Average date of birth was earlier ($P < 0.06$) and proportion born in the first 21 d of the calving season was 10 to 20 percentage points greater for heifers that were pubertal at the start of breeding compared with heifers not pubertal by the start of breeding. Heifers that were pubertal by the start of breeding were 7 to 10 kg heavier ($P < 0.01$) and 1 cm taller ($P < 0.01$) at weaning than heifers not pubertal by the start of breeding. Differences in BW persisted through the start of breeding to pregnancy diagnosis. Heifers that achieved puberty by the start of breeding had greater ($P < 0.05$) feed intake and G:F during postweaning development and had greater ($P < 0.01$) LM area and fat thickness over the LM at approximately 1 yr of age compared with heifers not pubertal by the start of breeding. Heifers that achieved puberty before the start of breeding had greater ($P < 0.01$) ADG from birth to weaning but slower ($P < 0.10$) rates of gain from the start of breeding through pregnancy diagnosis. Pregnancy rate was greater ($P < 0.01$) for heifers that were pubertal at the start of breeding. In heifers that became pregnant, those that were pubertal before the start of breeding calved earlier ($P < 0.01$), with a greater ($P < 0.01$) percentage calving in the first 21 d of calving than heifers not pubertal at the start of breeding. Calves from heifers that achieved puberty before the start of breeding were heavier at weaning ($P < 0.01$) than calves from heifers that had not achieved puberty by the start of breeding. In summary, heifers that failed to achieve puberty by the start of breeding were less desirable for several traits evaluated. Based on these results, implementing feeding strategies to increase the proportion of heifers that achieve puberty before first breeding could result in propagation of undesirable characteristics.

Key words: beef heifers, development, growth, puberty, reproduction

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INTRODUCTION

Attaining puberty is required to achieve pregnancy. As such, pregnancy rates have been correlated with the percentage of heifers that attain puberty before or early in the breeding season (Short and Bellows, 1971; Perry et al., 1991). Research has evaluated feeding management strategies that increase the proportion of pubertal heifers by the start of breeding in an attempt to maximize pregnancy rates (reviewed by Patterson et al. [1992]). In more recent studies, the impact of postweaning development on heifer pregnancy rate appears to be less prevalent, as does the association of puberty at the start of breeding and final pregnancy rate (Funston et al., 2012a; Endecott et al., 2013). Selecting cattle based on EPD for growth, milk, carcass characteristics, scrotal circumference, and heifer pregnancy would be expected to result in genetic changes over time that may be associated with beef heifers reaching puberty at an earlier age and lighter BW. This, in turn, would allow heifers to be developed to lighter BW than those from decades earlier. If this is the case, then feeding to increase the proportion of pubertal heifers at breeding may diminish the opportunity to select heifers that become pubertal at an earlier age and lighter BW. To provide insight into this possibility, this study retrospectively characterized developmental and reproductive traits of heifers classified by pubertal status at the start of the breeding season to provide qualification of the production characteristics of heifers not achieving puberty by the start of breeding.

MATERIALS AND METHODS

All animal procedures and facilities were approved by the University of Nebraska Institutional Animal Care and Use Committee (locations 1 and 2) or the USDA, ARS, Fort Keogh Livestock and Range Research Laboratory Institutional Animal Care and Use Committee (location 3).

Data used for this study were collected for 10 or more years at 3 locations: the West Central Research and Extension Center, North Platte, NE (2002 to 2012; n = 1,104; Location 1); Gudmundsen Sandhills Laboratory, Whitman, NE (1997 to 2012; n = 1,333; Location 2); and the USDA, ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT (2002 to 2011; n = 1,176; Location 3). Heifers from these 3 locations have been used in different studies to evaluate postweaning development protocols. Details of these studies have been published and are summarized and referenced in the following paragraphs. Therefore, the heifers evaluated represent diverse populations, each managed under at least 2 different developmental protocols.

Heifers at Location 1 had Angus-based genetics. Overwinter treatments imposed on these heifers included feeding soybeans vs. corn milling products in the development diet (Harris et al., 2008) and developing heifers on upland winter range or corn residue or in confinement (Funston and Larson, 2011; Summers et al., 2014). Heifers were synchronized with a melengestrol acetate–$PGF_{2\alpha}$ protocol and bred by AI after estrus detection. Approximately 10 d after AI, heifers were exposed to fertile bulls at a bull-to-heifer ratio of 1:50 for 60 d. This provided up to 4 opportunities to conceive based on a 21-d estrous cycle. Pregnancy rate was determined via transrectal ultrasonography 45 d after removal of bulls.

Data from Location 2 were collected on a spring-calving herd of composite Red Angus × Simmental females. Overwinter treatments evaluated over time included developing heifers to 50 and 55% of mature BW by breeding (Martin et al., 2008) and developing heifers on upland winter range and corn residue (Larson et al., 2011; Summers et al., 2014). Heifers were exposed to bulls for 45 d at a bull-to-heifer ratio of 1:25. A single injection of PGF2α (Prostamate [Teva Animal Health Inc., St. Joseph, MO] or Lutalyse [Pfizer Animal Health, New York, NY]) was administered intramuscularly to heifers approximately 4.5 d after placement with bulls. This breeding protocol provided heifers with 2 to 3 opportunities for heifers to conceive. Pregnancy determination was performed via transrectal ultrasonography approximately 45 d after the breeding season.

Heifers from Location 3 were from a stable composite gene combination population of one-half Red Angus, one-fourth Charolais, and one-fourth Tarentaise developed at the USDA, ARS, Fort Keogh Livestock and Range Research Laboratory in Miles City, MT (Newman et al., 1993). Females were from a randomly selected population produced over 9 yr from 2002 to 2011 by mating composite gene combination dams and sires, with inbreeding minimized and minimal emphasis on production traits. Data from 2008 were excluded because the last blood samples were collected 16 d before the start of breeding. At weaning, heifers were placed in a feedlot and assigned to either control or restricted feeding levels for 140 d in a facility equipped with electronic Calan gates (American Calan, Inc., Northwood, NH) controlling access to individual feeding bunks as previously described (Roberts et al., 2007, 2009). Heifers averaged 245 ± 19 d of age and 220 ± 25 kg BW at initiation of the feeding period. Control heifers were fed to appetite and restricted heifers were fed 80% of the feed consumed by control heifers adjusted to a common BW basis, with BW measurement and feed adjustments made at 28-d intervals. The 140-d period ended 40 ± 11 d before the start of breeding. At the end of the trial, ultrasound carcass measures were collected as previously described (Roberts et al., 2007). Heifers were managed the same throughout the breeding season. A prebreeding BW was taken 0 to 16 d (varied over years) before the start of breeding. Breeding protocol and impact of the feeding treatments on reproductive performance of these animals has been previously published (Roberts et al., 2009, 2016). Depending on year, the breeding protocol provided 2 to 3 opportunities for heifers to conceive based on a 21-d estrous cycle.

Pubertal status at the start of breeding was determined by evaluating progesterone concentration in 2 blood samples (8 to 10 mL/sample) collected via coccygeal venipuncture 9 to 11 d apart before initiation of estrus synchronization or the start of the breeding season based on procedures previously reported for Locations 1 (Funston and Larson, 2011), 2 (Martin et al., 2008), and 3 (Roberts et al., 2009). A progesterone concentration ≥ 1 ng/mL in either sample collected for each heifer was interpreted to indicate ovarian luteal activity. Heifers having samples < 1 ng/mL were considered to be prepubertal at the start of breeding.

Statistical Analysis

Data were analyzed separately for each location using PROC GLIMMIX of SAS 9.2 (SAS Inst. Inc., Cary, NC). For Locations 1 and 2, pubertal status was fit as a fixed effect, and year and any treatments applied during postweaning development were fit as random effects. Because the postweaning development treatment was constant across years at Location 3, the model used to analyze data collected after weaning was expanded to include pubertal status and postweaning treatment and the interaction of these terms as fixed effects and year as a random effect. Means were separated using LSD. Unless otherwise stated, $P < 0.05$ was used as the threshold for significance.

RESULTS

A summary of data for heifers classified by pubertal status at the start of breeding is provided in Tables 1, 2, and 3 for Locations 1, 2, and 3, respectively. Average day of birth was 3 (Locations 1 and 2) or 6 d earlier (Location 3; $P = 0.05$) in heifers that were pubertal at the start of breeding than their nonpubertal contemporaries. At all 3 locations, a greater proportion of heifers that were pubertal at the start of breeding were born in the first 21 d of the calving season ($P < 0.05$) than heifers not pubertal at the start of breeding. Birth weights did not differ ($P = 0.6$) due to pubertal status classification for heifers at Location 2 but were lighter ($P < 0.01$) for heifers that did achieve puberty by the start of breeding at Location 3. Weaning BW (not adjusted for age of calf or dam) ranged from 7 to 12 kg heavier ($P < 0.01$) for heifers that were pubertal than for heifers not pubertal at the start of breeding across the 3 locations. At Locations 2 and 3, where BW at birth was recorded, ADG from birth to weaning was greater ($P < 0.01$) for heifers that achieved puberty by the start of breeding. Hip height measured between 1 and 2 mo after weaning at Location 3 was 1 cm greater ($P < 0.01$) for heifers that were pubertal at the start of breeding than for those that were not. The ratio of hip height to BW at this time was greater ($P < 0.01$) for heifers that were pubertal at the start of breeding than for those that were not (2.08 vs. 1.97 cm/kg BW, respectively). Average rate of BW gain from weaning to the start of breeding was 0.43 to 0.45 kg/d at Locations 1 and 2 and did not differ due to pubertal status classification, as such the differences in BW at time of weaning persisted to the start of breeding (Tables 1 and 2).

Table 1. Birth date, BW, pregnancy rate, and first calf characteristics of heifers at Location 1 classified by pubertal status before breeding[1]

Item	Pubertal	Nonpubertal	SE	*P*-value
No.	757	347		
Percent	69	31		
Julian birth date,[2] d	79	82	1.4	0.051
Percent born in first 21 d	53	43	4.2	0.033
Weaning BW, kg	238	231	4.5	<0.001
Wean to breeding ADG, kg/d	0.45	0.45	0.06	0.847
Prebreeding BW, kg	348	341	10.4	0.005
BW at pregnancy diagnosis, kg	426	417	6.4	0.001
Breeding to pregnancy diagnosis ADG, kg	0.73	0.76	0.05	0.109
Overall pregnancy rate, %	96	91	1.7	0.007
Precalving BW, kg	476	457	11.7	<0.001
Days to calving,[3] d	283	287	1.9	0.002
Calve within first 21 d,[4] %	83.7	72.9	6.2	0.004
Calf birth BW, kg	34.0	33.3	0.4	0.050

[1]Data collected for 11 yr at the West Central Research and Extension Center, North Platte, NE. Pubertal status was determined by progesterone concentration in 2 blood samples collected 9 to 11 d apart before initiation of a melengestrol acetate–$PGF_{2\alpha}$ protocol estrus synchronization. Heifers were bred by AI after estrus detection and were exposed to fertile bulls for an additional 60 d. Values given for the different measures are least squares means and the largest SE of the least squares means.

[2]Birth date was known for only a subset of heifers ($n = 455$).

[3]Days from the start of breeding to calving.

[4]Calved within the first 21 d of the calving season; d 1 refers to the day the first calf is born.

At Location 3, postweaning measurements were analyzed to account for the 140-d development trial when heifers were fed ad libitum or at a 20% restriction (Table 4). Feed consumed during the 140-d trial was influenced by the interaction of pubertal status and feeding treatment ($P < 0.01$). Ad libitum–fed heifers that were pubertal at the start of breeding had greater ($P < 0.05$) DMI than ad libitum–fed heifers not pubertal by the start of breeding, which, in turn, had greater

Table 2. Birth date, BW, ADG, pregnancy rate, and first calf characteristics of heifers at Location 2 classified by pubertal status before breeding[1]

Item	Pubertal	Nonpubertal	SE	*P*-value
No.	795	538		
Percent	60	40		
Julian birth date, d	85	88	0.9	<0.001
Born first 21 d,[2] %	73	61	0.2	<0.001
Birth BW, kg	35	35	0.6	0.578
Weaning BW, kg	209	202	2.9	<0.001
Birth to weaning ADG, kg	0.79	0.77	0.03	0.008
Prebreeding BW, kg	300	294	2.6	<0.001
Wean to breeding ADG, kg/d	0.43	0.44	0.03	0.220
BW at pregnancy diagnosis, kg	370	366	3.8	0.049
Breeding to pregnancy diagnosis ADG, kg	0.76	0.79	0.05	0.003
Pregnancy rate, %	88	81	1.9	0.002
Precalving BW, kg	432	431	2.4	0.41
Calf Julian birth date, d	75	80	0.9	<0.001
Calve within first 21 d,[3] %	78.4	65.5	4.5	<0.001
Calf birth BW, kg	32.4	31.6	0.4	0.008
Calf weaning BW, kg	189	180	5.0	<0.001
Cow BW at weaning, kg	424	422	5.0	0.638
Cow BCS at weaning	5.1	5.1	0.1	0.588
Second pregnancy rate, %	89	91	2.8	0.451

[1]Data collected for 16 yr at the University of Nebraska Gudmundsen Sandhills Laboratory, Whitman, NE. Pubertal status was determined by progesterone concentration in 2 blood samples collected 9 to 11 d apart before initiation breeding. At the start of breeding, heifers were given a single injection of $PGF_{2\alpha}$ and exposed to bulls for 45 d. Values given for the different measures are least squares means and the largest SE of the least squares means.

[2]Born within the first 21 d of calving season; d 1 is the day the first calf is born.

[3]Calved within the first 21 d of the calving season; d 1 is the day the first calf is born.

Table 3. Birth date, BW, ADG, pregnancy rate, and first calf characteristics of heifers at Location 3 classified by pubertal status before breeding[1]

Item	Pubertal	Nonpubertal	SE	*P*-value
No.	791	395		
Percent	66	34		
Julian birth date, d	94	100	1.9	<0.001
Born first 21 d,[2] %	55	35	5.1	<0.001
Birth BW, kg	34.3	35.7	0.4	<0.001
Weaning BW, kg	206	194	3.3	<0.001
Birth to weaning ADG, kg	0.92	0.88	0.01	<0.001
Hip height at 8 mo, cm	108	107	0.4	<0.001
Prebreeding BW, kg	324	307	7.2	<0.001
Wean to breeding ADG, kg	0.50	0.49	0.01	<0.005
Pregnancy diagnosis BW, kg	399	391	1.8	<0.001
Breeding to pregnancy diagnosis ADG, kg	0.49	0.54	0.01	<0.001
Pregnancy rate, %	91	83	2.26	0.002
Precalving BW, kg	425	418	11.6	0.004
Days to calving,[3] d	295	299	1.1	<0.001
Calve within first 21 d,[4] %	57	46	2.0	0.002
Age at calving, d	723	718	2.8	0.052
Calf birth BW, kg	32.0	32.6	0.3	0.08
Calf weaning BW, kg	187	180	1.5	<0.001
Cow BW at weaning, kg	413	407	2.7	0.08
Cow BCS at weaning	5.2	5.2	0.1	0.88
Second pregnancy rate, %	77	70	0.4	0.01

[1]Data collected for 10 yr at the USDA, ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT. Pubertal status was determined by progesterone concentration in 2 blood samples collected 9 to 11 d apart before initiation breeding. Heifers were provided 2 to 3 opportunities for to conceive based on a 21-d estrous cycle. Values given for the different measures are least squares means and the largest SE of the least squares means.

[2]Born within the first 21 d of calving season; d 1 is the day the first calf is born.

[3]Days from the start of breeding to calving.

[4]Calved within the first 21 d of the calving season; d 1 is the day the first calf is born.

($P < 0.05$) DMI than either pubertal status group in the restricted-fed heifers. These differences in DMI were reflected by differences in ADG during the 140-d trial. Ad libitum–fed heifers that were pubertal at the start of breeding had greater ($P < 0.05$) ADG than ad libitum–fed heifers not pubertal by the start of breeding. Restricted-fed heifers had the least ADG and did not differ due to pubertal status. Efficiency of gain per unit feed input during the 140-d trial differed due to pubertal status ($P < 0.05$) and feeding treatment ($P < 0.01$) but not the interaction ($P = 0.82$), which was greater in heifers that were pubertal at the start of breeding and in heifers developed under restricted feeding.

Weight of heifers at the end of the 140-d trial was influenced by the interaction of pubertal status and feeding treatment ($P < 0.03$), with restricted-fed heifers not pubertal at the start of breeding being lightest, restricted-fed heifers that were pubertal and ad libitum–fed heifers not pubertal being intermediate, and ad libitum–fed heifers that were pubertal being heaviest (Table 4). Therefore, heifers not pubertal at the start of breeding were lightest within treatment, but BW for the same pubertal classifications differed between treatments. The shorter hip height observed after weaning for heifers in the nonpubertal class persisted through the 140-d trial. Restricted-fed heifers tended ($P = 0.08$) to be shorter than ad libitum–fed heifers by the end of the 140-d trial. The ratio of BW to hip height was influenced by the interaction of pubertal status and feeding treatment ($P < 0.03$), with restricted-fed heifers not pubertal at the start of breeding having the smallest BW:height ratio, restricted-fed heifers that were pubertal and ad libitum–fed heifers not pubertal being intermediate, and ad libitum–fed heifers that were pubertal at breeding having the greatest BW:height ratio.

Ultrasound carcass measurements taken at the end of the 140-d trial on heifers at Location 3 at approximately

Table 4. Interactions of feeding level during 140 d postweaning and pubertal status before breeding on growth and carcass characteristics of heifers from Location 3[1]

	Postweaning treatment[2]						
	Restricted		Ad libitum				
	Pubertal status						
	No	Yes	No	Yes			
	No. (% within treatment)					Treatment × puberty	Puberty
Item	225 (38)	364 (62)	170 (29)	417 (71)	SE	(*P*-value)	(*P*-value)
140-d postweaning development period							
On-test BW, kg	212	224	210	226	3.6	0.241	<0.001
DMI, kg/d	4.08^{a}	4.12^{a}	5.46^{b}	5.64^{c}	0.03	0.002	
ADG, kg/d	0.49^{a}	0.50^{a}	0.60^{b}	0.66^{c}	0.01	0.005	
G:F[3]	0.115	0.120	0.107	0.111	0.01	0.827	0.036
Off-test BW, kg	279^{a}	292^{b}	292^{b}	315^{b}	2.0	0.022	
Off-test hip height, cm	116.9	117.6	117.1	118.2	0.4	0.347	<0.001
BW:height ratio	2.38^{a}	2.48^{b}	2.49^{b}	2.66^{c}	0.02	0.021	
LM area,[3] cm^2	51.4	54.4	52.9	57.3	0.7	0.190	<0.001
LM width:height ratio	0.45	0.46	0.46	0.47	0.03	0.849	<0.001
Fat over LM, mm	2.87^{a}	3.37^{b}	3.22^{b}	4.04^{c}	0.12	0.044	
Intramuscular fat, %	3.47^{a}	3.59^{b}	3.74^{c}	3.72^{c}	0.04	0.040	
Prebreeding measures							
BW per day of age,[3] kg/d	0.73^{a}	0.75^{b}	0.75^{b}	0.79^{c}	0.01	0.075	<0.001
BW, kg	301	316	313	333	2.4	0.133	<0.001
Breeding to pregnancy diagnosis ADG,[3] kg	0.55^{a}	0.51^{b}	0.53^{b}	0.46^{c}	0.01	0.080	<0.001
Cow BCS at weaning	4.43^{a}	4.47^{a}	4.36^{a}	4.57^{b}	0.06	0.061	0.01

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

[1]Data collected for 10 yr at the USDA, ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT. Pubertal status was determined by progesterone concentration in 2 blood samples collected 9 to 11 d apart before initiation breeding. Heifers were provided 2 to 3 opportunities for to conceive based on a 21-d estrous cycle. Values given for the different measures are least squares means and the largest SE of the least squares means.

[2]Restricted provided 26% less feed (as-fed basis) than heifers fed ad libitum during the 140-d period after weaning.

[3]Differs due to postweaning treatment ($P < 0.001$).

1 yr of age are summarized in Table 4. Heifers that were pubertal at the start of breeding had greater area ($P < 0.001$) and width-to-height ratio ($P < 0.001$) of the LM than heifers that were not pubertal. Fat thickness over the LM was influenced by the interaction of pubertal status and feeding treatment ($P < 0.05$), with restricted-fed heifers not pubertal by the start of breeding having the least fat thickness, restricted-fed heifers that achieved puberty and ad libitum–fed nonpubertal heifers being intermediate, and ad libitum–fed heifers that were pubertal at the start of breeding having the most fat over the LM. The amount of intramuscular fat (**IMF**) in the LM was also influenced by the interaction of pubertal status and feeding treatment ($P < 0.05$), with restricted-fed heifers not pubertal by the start of breeding having the least amount of IMF, restricted-fed heifers that were pubertal having an intermediate amount of IMF, and ad libitum–fed heifers in both pubertal status groups having the most IMF. In the last BW measurement taken before breeding, approximately 40 d after the 140-d trial, BW was greater ($P < 0.001$) in pubertal heifers than in nonpubertal heifers in each feeding treatment. A trend for the interaction ($P = 0.07$) of pubertal status and feeding treatment on BW per day of age at the start of breeding was observed. This interaction followed the same profile as observed for the 140-d off-test BW, with BW per day of age being greater for pubertal heifers than for nonpubertal heifers in each feeding treatment but pubertal heifers subjected to restricted feeding not bine different from nonpubertal heifers in the ad libitum feeding group (Table 4).

Measures of BW at pregnancy diagnosis remained lighter ($P < 0.05$) for heifers that were nonpubertal at the start of breeding than for those that were pubertal (Tables 1, 2, and 3). The rate of gain from the start of breeding to pregnancy diagnosis tended to be greater ($P < 0.10$; Table 1) or was greater ($P < 0.05$; Tables 2 and 3) for heifers that were nonpubertal at the start of breeding than for heifers that were pubertal at the start of breeding, and the magnitude of difference tended ($P = 0.08$) to be influenced by postweaning development (Table 4). Hip height no longer differed ($P = 0.71$) due to pubertal status when measured at pregnancy diagnosis (125.7 vs. 125.8 cm for nonpubertal vs. pubertal, respectively).

Heifers that were pubertal at the start of breeding had greater ($P < 0.01$) pregnancy rates than their nonpubertal counterparts and were heavier ($P < 0.01$)

before calving than their contemporaries that had not reached puberty by the start of breeding (Tables 1, 2, and 3). Day of calving (Location 2) or interval from the start of breeding to calving (Locations 1 and 3) was less ($P < 0.01$) for pubertal than for nonpubertal heifers at Locations 2 and 3. At all 3 locations, a greater ($P < 0.01$) proportion of heifers that were pubertal at the start of breeding calved within the first 21 d of the calving period compared with heifers not pubertal at the start of breeding (Tables 1, 2, and 3). Calf birth weight was greater ($P < 0.01$) for calves born to dams that were pubertal before the start of breeding at Location 2 but tended ($P = 0.08$) to be less for calves born to dams that were pubertal before the start of breeding at Location 3. Calf BW at weaning was greater ($P < 0.01$) for calves born from dams that were pubertal before the start of breeding than for dams not pubertal by the start of breeding (Tables 2 and 3).

DISCUSSION

When considered across locations, heifers that had not achieved puberty by the start of breeding at approximately 14 to 15 mo of age had similar characteristics. They were born later, grew slower from birth to weaning, were less efficient, and had smaller LM area; also, fewer became pregnant and those that did conceive produced lighter calves than their contemporaries that were pubertal at breeding. Previous research demonstrated that preweaning growth influences puberty more than postweaning growth (Wiltbank et al., 1966; Cardoso et al., 2014), including research from a subset of animals previously evaluated at Location 3 (Roberts et al., 2009). In efforts to model factors influencing onset of puberty, Greer et al. (1983) observed that BW per day of age at weaning accounted for significant variation in age at first estrus. These researchers proposed that BW per day of age at weaning may reflect genetic–physiological aspects regulating puberty. The present study supports the idea that inherent differences in the preweaning growth rate influences subsequent puberty attainment. As such, managing to improve preweaning growth in an attempt to increase the proportion of pubertal heifers may cause more heifers with less desirable genetic characteristics for growth and reproduction to be retained.

Growth rate between weaning and breeding did not differ by pubertal status at Locations 1 and 2 or during the 140-d postweaning feeding period for restricted-fed heifers at Location 3. Heifer gain between weaning and the start of breeding ranged from 0.43 to 0.50 kg/d. At Location 3, ad libitum–fed heifers that failed to reach puberty by the start of breeding grew more slowly (0.60 kg/d) during the 140-d postweaning feeding trial than ad libitum–fed heifers that were pubertal at the start of breeding (0.66 kg/d; Table 4). Although heifers that achieved puberty by the start of breeding demonstrated greater growth rates up to breeding, the nonpubertal counterparts at all 3 locations exhibited greater growth rates from the start of breeding to pregnancy diagnosis. These results indicate that at some point between weaning and breeding, ranking of growth rate for heifers classified by pubertal status at the start of breeding is reversed. The switch in the rank of growth rates observed for the pubertal classifications from birth to pregnancy diagnosis likely reflects differences in the maturation rate and the expected points on the normal curvilinear growth pattern heifers have achieved at a given time. Greater growth during the earlier stages of development observed in heifers that achieved puberty by the start of the breeding season coincides with earlier physiological maturation and achievement of mature BW, possibly at a lighter BW (Smith and Cundiff, 1976). Growth rate would be expected to slow as heifers got closer to attaining genetic set points for bone, muscle, and fat deposition. In contrast, slower- and later-maturing heifers that fail to reach puberty at the start of breeding would persist in the steeper portions of their growth curve longer than their earlier-maturing counterparts (Brown et al., 1972).

Results of the present analyses reflect an overall inherent slower growth rate (skeletal and muscle) and sexual maturation in heifers that did not reach puberty by the start of breeding. These differences were associated with decreased feed efficiency during the postweaning period, less desirable carcass characteristics at approximately 1 yr of age, and less desirable reproductive performance. Throughout the past several decades, guideline to producers for postweaning development of heifers has been to provide sufficient feed resources so that heifers achieve 60 to 65% of expected mature BW at the start of breeding to help assure a high proportion are pubertal before breeding (Patterson et al., 1992). The inherent undesirable characteristics observed in heifers that failed to reach puberty in the present study beg the question whether management strategies should maximize the proportion of pubertal heifers, because the absence of late-maturing heifers from the cow herd may be considered positive genetic selection. Heifers evaluated in the present study were all part of studies that compared development systems with varying levels of postweaning growth rates. These studies provided evidence for using lower quantity or quality of feed inputs to decrease heifer development costs with minimal or no negative effect on pregnancy rate, albeit fewer pubertal heifers at the start of breeding were observed in some studies (reviewed by Funston et al. [2012a] and Endecott et al. [2013]). When evaluated across these studies, development protocols resulting in

54 to 55% of mature BW at breeding resulted in pregnancy rates similar to those achieved in heifers developed to 58 to 60% of mature BW when implemented with breeding seasons of 45 to 65 d. Therefore, slower rates of development did not provide greater selection pressure against late-maturing heifers.

Results from the present study indicate that selection pressure against the later-maturing heifers may be achieved by retaining heifers born earlier in the calving season or reducing the breeding season length. Heifers failing to reach puberty by the start of breeding had 11 to 13 percentage points fewer calving in the first 21 d than their pubertal counterparts. Heifers that calve earlier in the calving season have increased probability for greater lifetime productivity (Lesmeister et al., 1973; Rogers et al., 2004; Cushman et al., 2013). Some of the production benefits observed for heifers calving early in the calving season may be in response to fewer late-maturing heifers conceiving during the first breeding season. In addition, heifers born earlier in the calving season have improved production performance when retained for replacements than those born later (Funston et al., 2012b). Support of this is also evident when comparing pregnancy rates observed across the 3 locations, which were proportional to the length of the breeding season (numerically greater in Location 1, intermediate in Location 3, and lowest in Location 2). However, rebreeding performance was greater in Location 2 than in Location 3 (not measured at Location 1). The shorter breeding period in combination with the injection of $PGF_{2\alpha}$ 4.5 d after placement of heifers with bulls at Location 2 would be expected to result in a shorter calving period and greater proportion born in the first 21 d than that for Location 3. This may also contribute to the differences in rebreeding and inconsistent effects of puberty classification on rebreeding across the locations. These results question the benefit of developing heifers to maximize puberty attainment by the start of breeding, because this strategy may override the opportunity to select against later-maturing heifers with less desirable production characteristics as well as an increased cost. Greater selection against later-maturing heifers would be expected to contribute to improved sustainability.

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