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Body growth of replacement dairy heifers from 3 distinct genetic groups from commercial Brazilian dairy herds

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ABSTRACT

Few studies have been published on the body growth of replacement dairy heifers from Jersey (JER) and Holstein × Gyr (H × G) breeds, as most of them have focused on Holstein (HOL) heifers. In addition, HOL genetics vary significantly across countries. Our goal was to study the body growth curves of 3 distinct genetic groups of heifers (HOL, H × G, and JER) using data from Brazilian commercial dairy herds. Heart girth [to estimate body weight (BW)], hip height (HH), and withers height (WH) were measured. Weights (heifers and cows) and heights (only heifers) were collected from animals in several herds for each genetic group to model and describe the growth rates, mature body weight (MBW), weights, and heights for the recommended age at first breeding (RAFB) and first calving (RAFC). The RAFB values for HOL, H × G, and JER cattle were 15, 18, and 13 mo, respectively. The RAFC values for HOL, H × G, and JER cattle were 24, 27, and 22 mo, respectively. Data were obtained from 18 dairy farms located in 4 Brazilian states and analyzed using nonlinear modeling. Data were collected from 2,266 animals: 878 HOL, 610 H × G, and 778 JER cattle. We observed different body growth patterns in each genetic group. Jersey cattle matured earlier than HOL and H × G, especially for BW and HH. Mature BW of the HOL, H × G, and JER cattle was 681, 607, and 440 kg, respectively. All genetic groups reached the recommended BW at RAFB. However, the genetic groups did not reach the recommended BW at RAFC. Average daily weight gain from weaning to RAFB was 0.84, 0.53, and 0.54 kg/d for HOL, H × G, and JER cattle, respectively. Average daily gain from RAFB to RAFC was 0.53, 0.42, and 0.48 kg/d for HOL, H × G, and JER cattle, respectively. The HH at RAFB and RAFC were 130 and 139 cm for HOL, 130 and 137 cm for H × G, and 114 and 124 cm for JER. Withers height at RAFB and RAFC were 125 and 134 cm, 125 and 134 cm, and 110 and 121 cm for HOL, H × G, and JER cattle, respectively. In general, the rearing practices were adequate to reach the recommended BW at RAFB but below the recommended BW at RAFC for all genetic groups. In addition, each genetic group demonstrated different body growth patterns, especially for BW.
Key words: Holstein × Gyr, structural growth, Jersey, mature body weight

INTRODUCTION

Rearing dairy heifers is necessary for replacing culled cows and increasing herd size. However, growth rates and the management imposed on heifers can affect their future lactation performance (Zanton and Heinrichs, 2005; Machado et al., 2020). Boulton et al. (2017) suggested that all the costs involved in heifer rearing are typically paid back when they reach 1.5 to 2 lactations. However, only ~55% of dairy heifers reach the third lactation (Brickell and Wathes, 2011). If we assume 25 mo as mean age at first calving and 64 mo as mean age at culling, a dairy cow remains as a nonproductive individual (calf and heifer) for 39% of its lifespan. Consequently, the rearing phase plays a significant role in the productive life of dairy heifers.

An important factor related to both the growth and growth rate of dairy heifers is the mature body weight (**MBW**). Animals with lower MBW tend to have a higher rate of maturation and vice versa (Jenkins et al., 1993). The regular measurement of MBW is not a common practice at dairy farms. However, it is a crucial input for the accurate estimation of the nutritional requirements of growing heifers, and even young cows (NRC, 2001; NASEM, 2021). Some recent studies have described MBW for different dairy cattle genotypes. For example, Berry et al. (2005) evaluated 3 different

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genotypes of Holstein (**HOL**) cattle and found that they show different MBW, whereas Duplessis et al. (2015) determined MBW for some dairy cattle breeds in Canada.

Currently a common practice at dairy farms is to monitor the growth using the ADG of heifers based on BW until their first calving. However, the most accurate practice to evaluate growth should be the measurement of height growth (from hip and withers height; **HH** and **WH**) together with BW. Some studies have been published on the body growth of dairy cattle, especially in *Bos taurus* cattle, such as HOL (Heinrichs and Hargrove, 1987; Heinrichs and Losinger, 1998; Berry et al., 2005; Duplessis et al., 2015), Jersey (**JER**), Guernsey (Heinrichs and Hargrove, 1991; Duplessis et al., 2015), Ayrshire, Brown Swiss, and Milking Shorthorn (Heinrichs and Hargrove, 1994; Duplessis et al., 2015). These studies measured the BW and WH. Recent studies have also been conducted on HOL, JER, and Holstein × Jersey crossbred cattle in New Zealand (Handcock et al., 2019a,b); HOL, JER, Ayrshire, and Brown Swiss cattle in Canada (Duplessis et al., 2015); and HOL cattle in Brazil (Silva et al., 2021).

Therefore, although we have some research in that regard, most of the data are from the United States and from HOL of high genetic merit. In Brazil, crossbred Holstein × Gyr (**H × G**) dairy cattle represent 50% of lactating cows (Martins et al., 2018) and are one of the most important genetic groups, as well as HOL and JER cattle. To date, body growth curves have not been studied for crossbred H × G cattle. Moreover, growth curve data of dairy cattle raised in tropical regions are scarce.

Thus, our objective was to estimate and compare the body growth curves of 3 distinct genetic groups (HOL, H × G, and JER) raised in Brazilian conditions using data from commercial dairy farms. We aimed to generate growth curves based on BW, HH, and WH for the heifers of these 3 genetic groups. We also aimed to describe the growth rates (ADG), MBW, BW, and heights for the recommended age at first breeding (**RAFB**) and first calving (**RAFC**) for each genetic group. We hypothesized that these genetic groups present different body growth patterns.

MATERIALS AND METHODS

Ethical Statement

This study was approved by the Animal Care Ethics Committee of the "Luiz de Queiroz" College of Agriculture," University of São Paulo (protocol number 2019–15).

Study Design

An observational cross-sectional design was employed for this study, in which the cows and heifers were measured only once during the data collection period (from November 2019 to November 2020). We followed the recommendations of the STROBE statement for reporting observational studies (Sargeant and O'Connor, 2014). The dairy farms included in this study were selected using 2 nonprobabilistic sampling methods. First, a quota sampling technique was used, where the dairy farms were classified by characteristics (dairy genetic groups; HOL, H × G, or JER), and where ~600 animals (heifers and cows) were considered to achieve the cattle genetic group quota. Second, a convenience or consecutive sampling, as described in more detail by Martínez-Mesa et al. (2016), was used to select the dairy farms to be included in the study. Dairy farms were consecutively selected according to their accessibility.

Farm Characteristics, Animals, and Data Collection

Data were collected from 18 dairy farms located in Paraná (PR, n = 6), São Paulo (SP, n = 6), Rio Grande do Sul (RS, n = 5), and Minas Gerais (MG, n = 1), which are among the main milk-producing regions in Brazil. A total of 6 HOL, 3 H × G, 6 JER, and 3 mixed (with animals of 2 or 3 genetic groups) dairy herds were visited. Confinement (n = 13; freestall or compost barn) was the main production system used for lactating cows, followed by semi-confinement (n = 5).

Heifer rearing systems on farms varied among pasture, semi-confinement, and confinement according to the life stage of the animals. Most of the younger heifers (from 3 to ~12 mo) were reared in a confinement system (n = 11 farms), whereas the remaining heifers were reared in pasture with some supplementary feed (n = 7). Most of the older heifers (from ~12 mo until first calving) were reared in pasture with some supplementary feed (n = 13 farms), whereas the others were reared exclusively in pasture (n = 3 farms) or in confinement systems (n = 2 farms). The feeds used and feed management adopted varied from farm to farm and season. The most commonly used pastures were *Brachiaria* (syn. *Urochloa*), *Cynodon dactylon*, ryegrass (*Lolium multiflorum*), sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*, especially dual-purpose varieties), and white oats (*Avena sativa*). The most common conserved forages used as supplementary feed were hay and pre-dried forages (from the above-mentioned pastures and alfalfa, *Medicago sativa*), as well as corn and oat silage. Furthermore, some commercial concentrates were provided mainly for younger heifers. No specific information about the concentrate composition was provided by farmers.

The daily average milk production of these farms (excluding the mixed ones) was ~28 kg/cow per day for HOL, ~21 kg/cow per day for H × G, and ~23 kg/cow per day for JER. The H × G cattle composition was $^3/_4$ Holstein × $^1/_4$ Gyr for most animals (>80%), and the remaining (~20%) showed genetic compositions such as $^1/_2$ Holstein × $^1/_2$ Gyr, $^5/_8$ Holstein × $^3/_8$ Gyr (known as Girolando breed), $^5/_8$ Gyr × $^3/_8$ Holstein, and others. A total of 2,266 animals were measured: 878 HOL (heifers = 490 and cows = 388), 610 H × G (heifers = 440 and cows = 170), and 778 JER cattle (heifers = 426 and cows = 352).

Each farm was visited once, and all the animals or a sample of them (when the herd was too large) were measured. This strategy enabled us to visit more dairy farms and measure more animals than measuring the same ones several times during their development to study their growth. The HH, WH, and heart girth (**HG**) were measured in heifers from weaning until near the first calving (3–30 mo). For lactating cows, only the HG was measured. A random sample of cows in different lactations was collected. Preference was given to cows in the middle of lactation. Fresh (<15 DIM) and dry cows were not measured. Birth dates were provided for all the animals.

We took care to ensure that the animals were standing on a level surface with the correct posture for height measurements. The HH was measured from the floor to the top of the animal above the ilium bone region using a stick with a metric-scale tape. The WH was measured using the same equipment but above the shoulder blade region of the heifers. The HG was measured with a weight-measuring metric tape (Bovitec) circling the tape behind the animals' front legs. This tape has 3 lines with distinct BW for large (HOL), medium (Guernsey), and small (JER) dairy breeds. Thus, BW was estimated based on the weighing metric tape. Weighing metric tape is one of the most accurate indirect methods for measuring BW in cattle (Dingwell et al., 2006). For H × G animals, an equation based on the HG was used to estimate the BW from the study of Oliveira et al. (2013): BW (kg) = 0.00058 × $HG^{2.6135}$, where HG is the heart girth in centimeters.

Evaluated Nonlinear Models and Calculations

There is no consensus on which nonlinear model is the best; generally, it depends on the nature of the research and on what applications results will be used for (Berry et al., 2005). Therefore, 5 nonlinear models were fitted to the data (Table 1): 2 logistic models, in addition to Von Bertalanffy, Gompertz, and Brody models. All of the models were fitted to the HH, WH, and BW data plotted against age in months. Moreover, the random effect of the farm was considered in all models to adjust for factors such as the effects of management, genetics, and other possible factors causing variation among farms. Data on HH and WH were modeled up to the age of 30 mo for heifers that had not calved, comprising the recommended age of 22 to 24 mo for average at first calving for European cattle (Van Amburgh and Tikofsky, 2001; Pietersma et al., 2006) plus 6 mo for late puberty genetic groups such as H × G heifers (Facó et al., 2005; McManus et al., 2008; Delgado et al., 2012; Ribeiro et al., 2017; Canaza-Cayo et al., 2018; Azevedo et al., 2020). Body weight data for all cows and heifers were used without an age limit. The best models for each genetic group and variable were selected based on the Akaike and Bayesian information criteria (**AIC** and **BIC**, respectively). When models showed very similar AIC and BIC values, the root mean square error and R^2 were verified. All fitted models can be verified in Supplemental Tables S1, S2, and S3 (https://mfr.osf.io/render?url=https%3A%2F%2Fosf.io%2Ff6w7b%2Fdownload).

For the ADG calculations, we considered RAFB and RAFC at 15 and 24 mo for HOL (Ettema and Santos, 2004; Do et al., 2013); RAFB and RAFC of 18 and 27 mo for H × G cattle (Azevedo et al., 2020); and RAFB and RAFC of 13 and 22 mo for JER cattle (Hutchison et al., 2017; Handcock et al., 2019a; Boothby et al., 2020).

Statistical Analysis

All statistical analyses were performed using the SAS OnDemand software (SAS Institute Inc., 2015).

Table 1. Nonlinear models fitted to BW (kg), hip height (cm), and withers height (cm) for Holstein, Holstein × Gyr, and Jersey cattle plotted against age (mo)

Model	Equation[1]
Logistic I	$y = \left(A/\left(1 + B \times e^{(-k \times Age)}\right)\right) + \delta + \varepsilon$
Logistic II	$y = A \times \left(1 + e^{(-k \times Age)}\right)^{-m} + \delta + \varepsilon$
Von Bertalanffy	$y = A \times \left(1 - B \times e^{(-k \times Age)}\right)^3 + \delta + \varepsilon$
Gompertz	$y = A \times e^{\left(-B \times e^{(-k \times Age)}\right)} + \delta + \varepsilon$
Brody	$y = A \times \left(1 - B \times e^{(-k \times Age)}\right) + \delta + \varepsilon$

[1]y = hip height, withers height, or BW (kg); A = asymptote (mature BW or height around first calving); B = coefficient of integration, k = maturation rate; m = parameter that shapes the curve; δ = random effect of dairy farm; and ε = random error.

First, descriptive statistics were performed for all the studied variables in general and by genetic groups to verify the biological coherence of the data using the MEANS, FREQ, and REG procedures from SAS. Next, nonlinear models were fitted to the data for HH, WH, and BW for each genetic group using the NLMIXED procedure from SAS. The normality, homogeneity, and independence of errors for each model were verified. The level of significance was set at a probability of 0.05.

RESULTS

Descriptive statistics categorized by genetic group and related to the studied variables are shown in Table 2.

BW Growth

The final nonlinear models selected for BW growth were Von Bertalanffy, logistic II, and logistic I for HOL, H × G, and JER genetic groups, respectively. Coefficient A is related to the asymptote and can be interpreted as MBW. The MBW found were 681, 607, and 440 kg for HOL, H × G, and JER, respectively (Table 3). The BW maturity rate (coefficient K) was higher for JER (0.17) than for HOL (0.09) and H × G (0.09), indicating a similar BW growth pattern for HOL and H × G cattle (Table 3). The model-predicted and observed values for BW by genetic group are shown in Figure 1. The proportions of MBW at RAFB and RAFC were also calculated. At RAFB, H × G reached 59% of MBW, whereas HOL and JER reached 58% and 56% of MBW, respectively (Table 4). At RAFC, JER reached a higher %MBW (86%), whereas HOL and H × G reached ≤80% of MBW (Table 4). The ADG from weaning until RAFB was higher for HOL (844 g/d) and similar for H × G and JER (528 and 540 g/d, respectively; Table 4). The ADG from RAFB until RAFC was also higher for HOL (534 g/d), followed by JER (480 g/d; Table 4). The H × G reached a lower ADG in that growth phase (418 g/d; Table 4).

Table 2. Descriptive statistics for variables of BW (kg), heart girth (cm), hip height (cm), withers height (cm), age (mo), and lactation number regarding heifers and cows and categorized by genetic group

Category	Genetic group	No. of animals	Mean	Median	Minimum	Maximum	SD	CV (%)
Heifers	BW (kg)							
	Holstein	490	347	285	127	723	163	47
	H × G[1]	440	302	282	86	614	124	41
	Jersey	426	268	278	74	488	113	42
	Heart girth (cm)							
	Holstein	490	159	151	122	217	28	18
	H × G	440	151	150	95	202	24	16
	Jersey	426	146	151	94	190	25	17
	Hip height (cm)							
	Holstein	490	125	124	92	155	13	11
	H × G	440	121	121	85	149	13	11
	Jersey	426	113	117	80	137	12	11
	Withers height (cm)							
	Holstein	490	118	117	90	148	13	11
	H × G	440	115	116	83	143	14	12
	Jersey	426	109	112	78	135	12	11
	Age (mo)							
	Holstein	490	12.2	9.4	3.5	30.7	6.9	57
	H × G	440	14.3	12.9	3.2	37.4	7.9	55
	Jersey	426	14.1	14.5	3.1	29.1	6.3	45
Cows	BW (kg)							
	Holstein	388	665	666	462	831	78	12
	H × G	170	580	575	415	882	87	15
	Jersey	352	439	444	315	548	42	10
	Heart girth (cm)							
	Holstein	388	209	209	181	236	11	5
	H × G	170	197	196	172	232	11	6
	Jersey	352	181	181	159	202	8	4
	Number of lactations							
	Holstein	388	2.2	2	1	7	1	57
	H × G	170	2.8	2	1	10	2	72
	Jersey	352	2.2	2	1	8	1	66
	Age (mo)							
	Holstein	388	50.7	46.7	21.5	131.6	20.7	41
	H × G	170	59.9	48.5	25.5	165.1	28.9	48
	Jersey	352	49.1	42.5	18	155.6	22.5	46

[1]Holstein × Gyr.

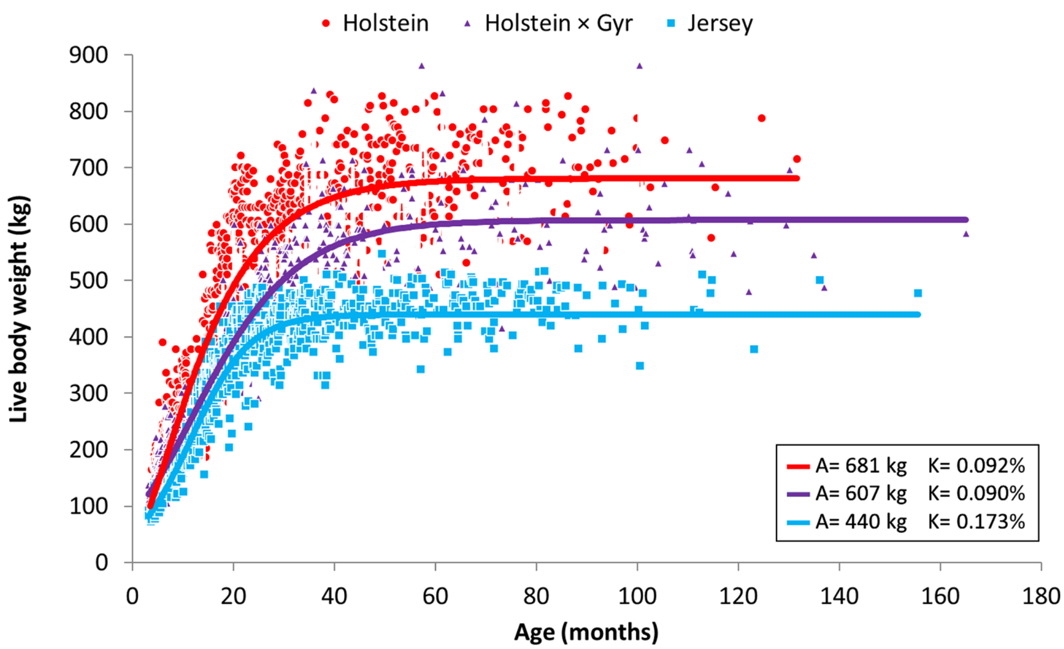

Figure 1. Live BW (kg) growth curves for Holstein, Holstein × Gyr, and Jersey genetic groups regarding age (mo). Holstein: $y = 681.17 \times \left(1 - 0.6494 \times e^{(-0.09154 \times Age)}\right)^3$, $R^2 = 0.8876$, root mean square error (RMSE) = 68.974; Holstein × Gyr: $y = 607.33 \times \left(1 + e^{(-0.08986 \times Age)}\right)^{-2.8938}$, $R^2 = 0.9018$, RMSE = 53.226; Jersey: $y = 439.88 \Big/ \left(1 + 7.503 \times e^{(-0.1728 \times Age)}\right)$, $R^2 = 0.8981$, RMSE = 39.172. Parameter A indicates the mature BW (kg), and parameter K indicates the maturity rate (%).

Hip Height Growth

The final nonlinear models selected for HH growth were Brody for HOL and H × G, and logistic II for JER cattle. Here, coefficient A can be interpreted as HH at 30 mo of age (the data upper limit; Table 3). The HH maturity rate was higher for JER (0.13) than for HOL (0.09) and H × G (0.09), indicating a similar growth pattern for the HOL and H × G genetic groups (Table 3). The model-predicted and observed values for HH by genetic group are shown in Figure 2. Hip height was similar at RAFB for HOL and H × G (130 cm for both) and lower for JER (114 cm; Table 4). The same occurred at RAFC where HOL and H × G reached a similar HH (139 and 137 cm, respectively), whereas JER reached lower HH (127 cm; Table 4).

Table 3. Nonlinear selected models fitted to BW (kg), hip height (cm), and withers height (cm) for Holstein, Holstein × Gyr, and Jersey cattle regarding age (mo)

			Parameter[1]			Fit statistics[2]		
Variable	Cattle	Model	A	B[3]	K	AIC	BIC	R^2
BW (kg)	Holstein	Von Bertalanffy	681.17	0.6494	0.09154	9,505.5	9,506.5	0.8876
	Holstein × Gyr	Logistic II	607.33	2.8938	0.08986	6,552.4	6,549.3	0.9018
	Jersey	Logistic I	439.88	7.503	0.1728	7,669.8	7,670.8	0.8981
Hip height (cm)	Holstein	Brody	145.47	0.4481	0.0966	2,890.8	2,891.8	0.8185
	Holstein × Gyr	Brody	142.31	0.4246	0.08834	2,544.3	2,541.2	0.8564
	Jersey	Logistic II	129.64	0.7365	0.1297	2,371.3	2,371.7	0.8596
Withers height (cm)	Holstein	Brody	140.78	0.46	0.09512	2,880.1	2,881.1	0.8438
	Holstein × Gyr	Brody	144.17	0.4456	0.06769	2,529.4	2,526.3	0.8675
	Jersey	Brody	130.55	0.4429	0.08142	2,320.3	2,320.7	0.8584

[1]A = asymptote; B = integration coefficient; K = rate of maturation.

[2]AIC = Akaike information criterion; BIC = Bayesian information criterion.

[3]Value of parameter B for all of the models except for logistic II; it is the value of the parameter m of that model.

Withers Height Growth

The final nonlinear model selected for WH growth was Brody for all 3 genetic groups. Here, coefficient A can be interpreted as WH at 30 mo of age (the data upper limit; Table 3). Withers height maturity rate was higher for HOL (0.10) and similar for H × G (0.07) and JER (0.08), indicating a higher growth rate for WH in HOL cattle (Table 3). The model-predicted and observed WH values by genetic groups are shown in Figure 3. Withers height was similar at RAFB for HOL and H × G (125 cm for both) and lower for JER (110 cm; Table 4). The same occurred at RAFC, where HOL and H × G reached a similar WH (134 cm for both), whereas JER reached a lower WH (121 cm; Table 4).

DISCUSSION

The goal of this research was to study the body growth curves of dairy heifers from different genetic groups and to describe the most relevant growth parameters. They can be used to monitor and evaluate the growth targets of heifers in commercial dairy farms. Our results suggest different rates of development with regards to BW, HH, and WH among the 3 genetic groups evaluated. It was noticeable that JER cattle had a higher rate of maturation for BW and HH compared with HOL and H × G, confirming that the JER breed matures earlier than the other groups (Handcock et al., 2019a). The faster maturation rate can be evidenced by the percentage of MBW (**%MBW**) at the same age, as we found that JER presented a higher %MBW in the same age compared with HOL and H × G cattle. Animals with higher MBW tend to be less mature at the same age than animals with lower MBW (Fitzhugh and Taylor, 1971). Furthermore, as our results indicate different nonlinear equations for BW for each genetic group, each breed has a specific body growth pattern, as previously demonstrated by Handcock et al. (2019a). Although there are differences in body growth patterns, some studies indicate similar ADG, DMI (Silvestre et al., 2021), and maintenance requirements (Moreira, 2016) of HOL and H × G ($^1/_2$ Gyr × $^1/_2$ Holstein) cattle.

Our data for MBW were 681, 607, and 440 kg for HOL, H × G, and JER, respectively. The MBW of HOL cattle was similar to data from the United States (680 kg, Olson et al., 2010; 682 kg, NRC, 2001) and Israel (687 kg, van Straten et al., 2008). However, the values that we obtained were lower than previous data from Brazil (700 kg, data from a unique confined and high-producing herd, Poncheki et al., 2015) and Austria (734 kg, Ledinek et al., 2019). Furthermore, the values were higher than data from Denmark (654 kg, Nielsen et al., 2003) and the United Kingdom (668 kg, data including secundiparous cows, Schubert et al., 2019). Additionally, the MBW found for JER cattle was similar to Denmark (448 kg, Nielsen et al., 2003), and lower than data from the United Kingdom (483 kg, Schubert et al., 2019) and the United States (454 kg, NRC, 2001; 522 kg, Olson et al., 2010). Our results are similar to the NRC (2001) data for HOL, which is consistent with the intensive use of genetic material from the United States in the Brazilian dairy cattle industry, despite the different climatic conditions and production systems.

The MBW found for JER was lower than some estimates found in the literature. A higher ADG of JER before RAFB (0.54 kg/d), which was one of our

Table 4. Target BW (kg), ADG (kg), hip height (cm), and withers height (cm) recommended for each genetic group regarding the ages of first breeding and first calving

Variable	Holstein	H × G[1]	Jersey
MBW (kg)	681	607	440
At first breeding[2]			
BW (kg)	397	360	245
% MBW (%)	58	59	56
ADG from weaning to first breeding (kg/d)	0.844	0.528	0.540
HH (cm)	130	130	114
WH (cm)	125	125	110
At first calving[3]			
BW (kg)	544	475	377
% MBW (%)	80	78	86
ADG from first breeding to first calving (kg/d)	0.534	0.418	0.480
HH (cm)	139	137	124
WH (cm)	134	134	121

[1]H × G = Holstein × Gyr.

[2]15, 17, and 13 mo were considered the recommended ages for first breeding for Holstein, H × G, and Jersey cattle, respectively. MBW = mature body weight; HH = hip height; WH = withers height.

[3]24, 27, and 22 mo were considered the recommended ages for first calving for Holstein, H × G, and Jersey cattle, respectively.

findings, could reduce their MBW. Average daily gain until puberty can affect the age at puberty. Diets with adequate protein and with no excess energy support structural growth (bone and muscles) and BW of dairy heifers with no change in age at puberty (Moallem et al., 2004). However, high-energy and low-protein diets until puberty can trigger the release of luteinizing hormone, which mediates the entrance to puberty and slows down the lean growth (bone and muscles; Schillo et al., 1992; Moallem et al., 2004). The recommended ages to measure the growth of heifers are especially at birth, at weaning (~60 d), and near the first breeding (12 to 15 mo) to monitor ADG (Bazeley et al., 2016).

Compared with JER and HOL cattle, MBW data for H × G cattle are very scarce in the literature, with the exception of 510 kg for H × G ($^1/_2$ Gyr × $^1/_2$ Holstein) cows in the study by Carvalho et al. (2018). This value does not correspond to our finding of 607 kg of MBW for H × G cattle. It is important to mention that most of the H × G animals in our study were $^3/_4$ Holstein × $^1/_4$ Gyr (>80%). This may be the reason why they presented a higher MBW than the animals in the previous study. Based on these results, we can note that MBW is variable among herds and genetic groups. The best practice by dairy farmers should be the measurement of MBW of cows with ≥3 calvings and in the middle of lactation to obtain a reliable estimate of the MBW of their herds.

Mature BW is an important parameter for estimating the nutrient requirements for growing cattle and first- and second-lactation cows for diet formulation. For dairy cattle, growth objectives are based on target weights relative to the MBW (Fox et al., 1999; NRC, 2001; NASEM, 2021). For RAFB, the target weight of a dairy heifer is approximately 55% of the MBW, whereas for RAFC the target prepartum weight is 91% of MBW (NASEM, 2021). However, these target weights are based on *Bos taurus* data (mainly HOL) and consider that dairy heifers reach puberty with 50 to 55% of MBW (Fox et al., 1999; NRC, 2001; NASEM, 2021). *Bos indicus* reach puberty with 60 to 65% of MBW (Patterson et al., 1992). Based on these target weights, ADG can be determined to achieve adequate body growth or according to the breeding goals of the dairy farm. Several studies indicated problems with a high ADG (commonly >1,000 g/d, and with high-energy and low-protein diets) before breeding, which could result in fat accumulation in the mammary gland (Sejrsen et al., 1982; Lacasse et al., 1993; Choi et al., 1997; Daniels et al., 2009; Weller et al., 2016). Consequently, the recommended ADG to RAFB is ~800 g/d for HOL heifers, which would not negatively affect

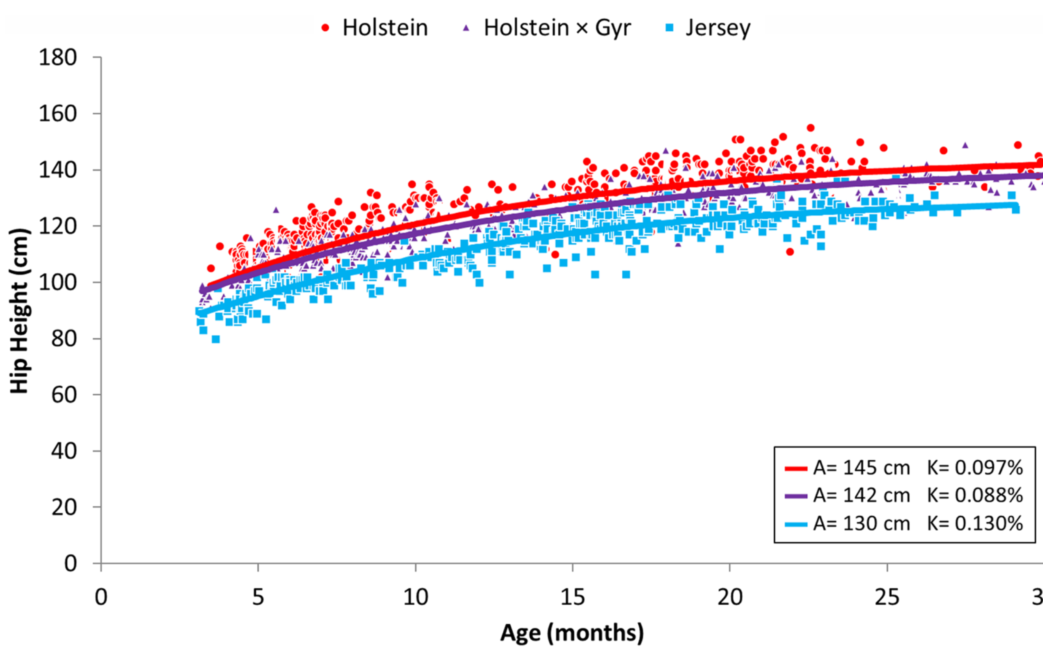

Figure 2. Hip height (cm) growth curves for Holstein, Holstein × Gyr, and Jersey genetic groups regarding age (mo). Holstein: $y = 145.47 \times \left(1 - 0.4481 \times e^{(-0.0966 \times Age)}\right)$, $R^2 = 0.8185$, root mean square error (RMSE) = 5.591; Holstein × Gyr: $y = 142.31 \times \left(1 - 0.4246 \times e^{(-0.08834 \times Age)}\right)$, $R^2 = 0.8564$, RMSE = 4.921; Jersey: $y = 129.64 \times \left(1 + e^{(-0.1297 \times Age)}\right)^{-0.7365}$, $R^2 = 0.8596$, RMSE = 4.545. Parameter A indicates the hip height (cm) at 30 mo of age, and parameter K indicates the maturity rate (%).

mammary gland development (Zanton and Heinrichs, 2005) and maximize 305-d milk yield during first lactation. Our finding of 844 g/d of ADG for HOL heifers is very close to this recommendation.

For JER heifers, we did not find a reference value for ADG in the literature; however, considering that they should reach 55% of MBW at RAFB, our finding of 540 g/d is adequate because it resulted in a heifer with 56% of MBW at 13 mo of age. An ideal ADG to reach 55% of MBW at first breeding at a different age can be calculated from our predictive equations for each of the genetic groups studied.

In contrast to HOL and JER, H × G cattle still need more studies, as there is a lack of information in the literature regarding the %MBW at puberty. It is very difficult to estimate the ideal ADG to reach puberty, and there are almost no data on the effects of ADG on mammary gland development in H × G cattle. Because of the *Bos indicus* contribution to the genetic composition of this group to different degrees, these animals mature later than HOL and JER and reach puberty later with a higher % of their MBW. Thus, the rule for H × G heifers is calving at a higher age than HOL and JER, with studies indicating first calving age at approximately 30 mo (Facó et al., 2005; McManus et al., 2008; Delgado et al., 2012; Ribeiro et al., 2017; Canaza-Cayo et al., 2018; Azevedo et al., 2020). Reducing the age at first calving is a challenge for H × G cattle breeders. However, our results indicate that H × G gaining ~530 g/d until 18 mo reached 59% of MBW and, theoretically, could be bred. Improved rearing practices that result in an increase in ADG for H × G until RAFB could reduce the age at first breeding and first calving. Based on our data, H × G are growing adequately to be bred at ~18 mo of age, resulting in a first calving around the 27 mo. In contrast, the calculated ADG from RAFB to RAFC for the 3 genetic groups was lower than the ideal to reach prepartum weights of 91% of MBW (NASEM, 2021). Jersey cattle were the closest (86% of MBW).

Nevertheless, heifers calving with higher %MBW produce more milk in first lactation because they present lower nutritional requirements for growth (Handcock et al., 2019b; Van Amburgh et al., 2019). In addition, heifers mobilize fewer reserves in their first lactation than in the following ones (Friggens et al., 2007). However, the relationship between ADG and future milk production depends on the genetic potential of the herd, where breeds with smaller mature size show lower milk yield in response to a higher ADG, especially during the first lactation (Krpálková et al., 2014). It is likely that the effect of fat accumulation in the mammary gland during development is more pronounced in smaller mature-size cattle.

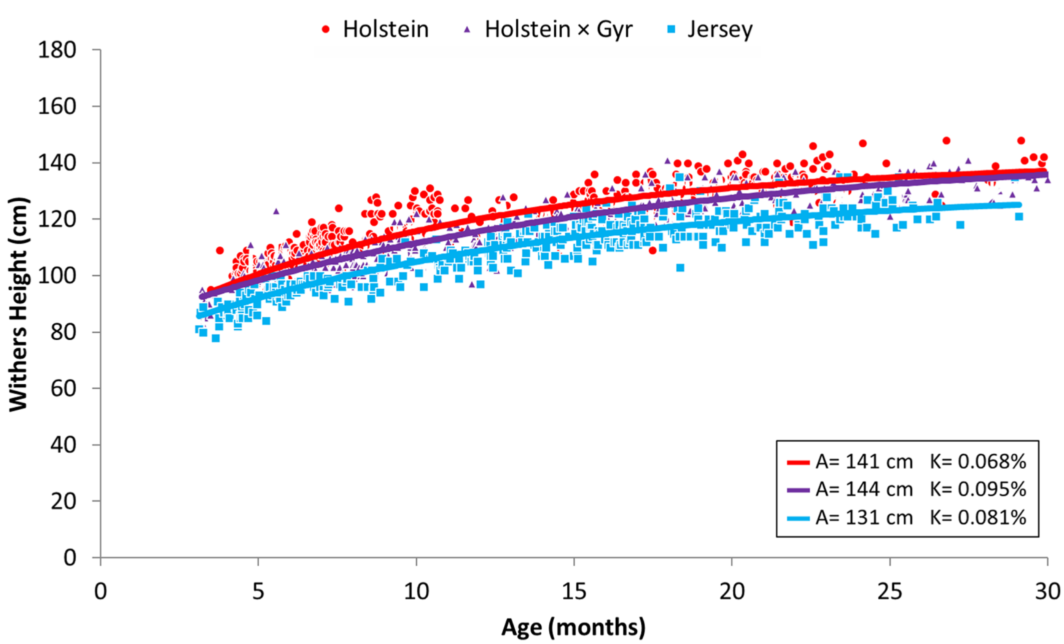

Figure 3. Withers height (cm) growth curves for Holstein, Holstein × Gyr, and Jersey genetic groups regarding age (mo). Holstein: $y = 140.78 \times \left(1 - 0.46 \times e^{(-0.09512 \times Age)}\right)$, $R^2 = 0.8438$, root mean square error (RMSE) = 5.138; Holstein × Gyr: $y = 144.17 \times \left(1 - 0.4456 \times e^{(-0.06769 \times Age)}\right)$, $R^2 = 0.8675$, RMSE = 4.949; Jersey: $y = 130.55 \times \left(1 - 0.4429 \times e^{(-0.08142 \times Age)}\right)$, $R^2 = 0.8596$, RMSE = 4.545. Parameter A indicates the withers height (cm) at 30 mo of age, and parameter K indicates the maturity rate (%).

Withers and hip height are well correlated with BW growth (Franco et al., 2017; Silva et al., 2021). Height is not commonly measured in adult animals because ~95% of mature height is reached at first calving (Heinrichs and Jones, 2016). Very few studies have measured mature WH (Berry et al., 2005; Duplessis et al., 2015; Silva et al., 2021), and to our knowledge, no study has measured HH in dairy cattle. Withers height is more commonly measured than HH, despite WH being more variable due to the correct position and possible restlessness of the animal at the moment of the measurement. Some WH references for HOL cattle at 15 mo were suggested to be 123 cm (Heinrichs and Hargrove, 1987); 124 cm (Heinrichs and Losinger, 1998); 127 cm (Silva et al., 2021); and 134 cm (Duplessis et al., 2015). Our results indicate that the sampled Brazilian HOL heifers have an intermediary WH size at 15 mo (125 cm) compared with HOL from other countries. Regarding JER cattle, the values found in the literature for heifers were 108 cm (at 13 mo; Heinrichs and Hargrove, 1991) and 122 cm (at 15 mo; Duplessis et al., 2015), and our finding of 110 cm (at 13 mo) can be indicative of medium to small WH size, compared with JER from other countries. Again, for H × G cattle, we did not find values in the literature for WH.

The HH could be a better measurement of body size than WH due to a lower variation in the measurement among animals, despite the coefficients of variation being similar for those variables in our data. Heinrichs and Hargrove (1987) found that taller heifers, considering WH at breeding, presented higher milk production in first lactation. Taller animals can also be heavier animals because of the high and positive relationship between weight and height. Although heavier cows can be slightly more profitable than lighter cows, very heavy cows increase feeding costs. This means that it is ideal to maintain an intermediary mature BW in the selection criteria for each farm (Pérez-Cabal et al., 2006). In addition, heavier cows are more prone to have a higher incidence of metabolic disorders and infectious diseases around parturition (Williams et al., 2009; Roche et al., 2013), which increases the culling risk (Chiumia et al., 2013).

Few studies on dairy heifers, particularly JER cattle, are included in the dairy NRC (2001) publication. The recent document published by NASEM (2021) also, practically, does not include heifer data from genetic groups other than HOL. However, in recent years, studies on H × G heifers have been published regarding DMI (Oliveira and Ferreira, 2016; Busanello et al., 2021), growth requirements (Castro et al., 2020), and mammary gland development (Albino et al., 2017; Silva et al., 2018). In addition, recent research on HOL cattle can be found in terms of DMI (Hoffman et al., 2008), growth requirements (Albino et al., 2015; Jiao et al., 2015), and body growth (Heinrichs et al., 2017; Silva et al., 2021). Few studies have been conducted on JER cattle for growth curves and target BW and WH along with their growth (Duplessis et al., 2015; Handcock et al., 2019a). It is evident that more research focused on rearing dairy heifers is needed, especially for genetic groups other than HOL cattle, which have received the most attention from researchers.

Finally, our study has some limitations that should be addressed in future research. We chose to sample each animal only once on each farm, increasing the number of measured animals and farms, but others opted to monitor the same animals along with their growth (Berry et al., 2005). It is difficult to decide which would be the most appropriate approach. In our study, we measured more animals, but the growth curve of the same animal is not known. Thus, our growth curve represents the growth curve of the farms' heifers. In this way, our data set contained only repeated measures for dairy farms and not for animals, which resulted in only one additional effect to be modeled on the nonlinear models. This results in a simpler model. This effect was estimated to be random because repeated measure analysis still had limitations when performed on nonlinear models, as in the case of SAS NLIN and NLMIXED procedures. Furthermore, the number of DIM and milk yield of the cows were not recorded, even though DIM has a well-known effect on the BW of lactating cows (van Straten et al., 2008; Poncheki et al., 2015). However, nonlinear models (SAS NLIN and NLMIXED) do not allow the inclusion of covariates in the model. Moreover, part of the weight of pregnant cows and heifers is due to the conceptus and other tissues related to pregnancy, but no adjustments were made considering the conceptus weight in our data. However, we believe that our data adequately represent our tropical and subtropical rearing conditions and genetics because different farms and regions were sampled. However, some sources of bias present on each farm, such as genetics, management, nutrition, and others, are difficult to control because the heifer rearing system changes according to age within farms, and we measured each one in a specific period of their growth.

CONCLUSIONS

We demonstrated different body growth patterns for each genetic group studied, especially for BW. Adequate ADG is reached from weaning until RAFB; however, from RAFB until RAFC, the ADG is below the ideal for all 3 genetic groups. Height measurements (withers and hip), together with BW, are strongly recommended to evaluate heifers' body growth throughout their life.

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