Characterization and comparison of growth curves in slick and wild type-haired Puerto Rican Holstein calves and heifers[1,2]

Ireliz Colón-Rodríguez[3], Katherine Domenech-Pérez[4], Enid Arcelay-Ruiz[5], and Héctor L. Sánchez-Rodríguez[5]*

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ABSTRACT

The ideal weight gain for Holstein heifers in the United States is between 0.73 and 0.86 kg/d. However, heat stress may limit growth, whereas a slick-haired coat confers superior thermoregulation. This study compared and evaluated (GLIMMIX and REG Procedures-SAS) body weight, hip height, shoulder to pin bone distance, thoracic perimeter, withers height, and barrel growth curves of nine slick vs. nine wild type-haired Holstein calves, weekly [one to eight weeks of age (1 to 8 WOA)] and monthly [three to 33 months of age (3 to 33 MOA)]. From 1 to 8 WOA, no hair coat type x age interactions (*P*≥0.1834) or hair coat type effects (*P*≥0.4778) were observed. During this period all variables evaluated increased linearly (R^2≥0.34; *P*<0.0001). From 3 to 33 MOA, only body weight (*P*=0.0312) and barrel circumference (*P*=0.0038) presented a hair coat type x age interaction. No hair coat type effects (*P*≥0.5398) were observed. During this period, all dimensions demarcated by bones behaved quadratically (R^2≥0.87; *P*<0.0001), while body weight remained linear (R^2≥0.94; *P*<0.0001). From 1 to 8 WOA, gains of 0.48 and 0.48 kg/d were observed in slick and wild type-haired calves. Respective gains of 0.61 and 0.62 kg/d were noted in heifers 3 to 33 MOA. No growth-related differences were observed between hair coat types. Limited gains were observed in both groups.

Keywords: slick-haired, wild type-haired, growth curves, Holstein calves, Holstein heifers

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[3]Graduate Student, Animal Science Department, College of Agricultural Sciences, University of Puerto Rico-Mayagüez Campus.

[4]Associate Researcher, Animal Science Department, College of Agricultural Sciences, University of Puerto Rico-Mayagüez Campus.

[5]Professor, Animal Science Department, College of Agricultural Sciences, University of Puerto Rico-Mayagüez Campus.*Corresponding author, e-mail: hector.sanchez19@upr.edu

RESUMEN

Caracterización y comparación de las curvas de crecimiento de becerras y novillas Holstein de pelaje corto y de pelaje regular

La ganancia de peso ideal para novillas Holstein en los Estados Unidos de América se encuentra entre 0.73 y 0.86 kg/d. Sin embargo, el estrés por calor puede limitar el crecimiento del ganado, en donde un pelaje corto confiere una capacidad termorreguladora superior. Las curvas de crecimiento para peso corporal, altura a la cadera, distancia entre el hombro y el anca, perímetro toráxico, altura a la cruz y barril fueron comparadas y evaluadas (procedimientos GLIMMIX y REG-SAS) en nueve becerras de pelaje corto versus nueve de pelaje regular de la raza Holstein, ambos grupos evaluados semanal [una a ocho semanas de edad (1 a 8 SDE)] y mensualmente [tres a 33 meses de edad (3 a 33 MDE)]. Entre las 1 y 8 SDE no hubo interracción tipo de pelo x edad ($P \geq 0.1834$), ni se observaron efectos del tipo de pelo ($P \geq 0.4778$). Todas las variables evaluadas aumentaron linealmente ($R^2 \geq 0.34$; $P < 0.0001$). Entre 3 y 33 MDE solo el peso corporal ($P = 0.0312$) y el barril ($P = 0.0038$) presentaron interacciones de tipo de pelo x edad. Tampoco se observaron efectos del tipo de pelaje ($P \geq 0.5398$). En este periodo, todas las dimensiones demarcadas por el esqueleto se comportaron de manera cuadrática ($R^2 \geq 0.87$; $P < 0.0001$), mientras el peso corporal se mantuvo lineal ($R^2 \geq 0.94$; $P < 0.0001$). Entre 1 y 8 SDE se observaron ganancias en peso de 0.48 y 0.48 kg/d en las becerras con pelaje corto y de pelaje regular. Respectivas ganancias de 0.61 y 0.62 kg/d fueron vistas en novillas de 3 a 33 MDE. No hubo diferencias relacionadas al crecimiento entre tipos de pelaje. Las ganancias de peso observadas fueron limitadas.

Palabras clave: pelaje corto, pelaje regular, curvas de crecimiento, becerras Holstein, novillas Holstein

INTRODUCTION

The adverse effects of heat stress on the reproductive (Jordan, 2003) and productive performances (West, 2003) of dairy cattle have been evaluated extensively and documented in the literature. However, this kind of stress also affects younger cattle. For instance, heat stress has also been associated with growth limitations in livestock (Chen et al., 2021). As early as 1847, Bergmann (as reviewed by Meiri and Dayan, 2003) reported that animals living in tropical regions reach smaller mature body sizes than animals of the same species inhabiting temperate countries. In dairy heifers, growth rate is of considerable importance as it directly affects the age at first calving (Pietersma et al., 2006), which subsequently influences lifetime productivity (Meyer et al., 2004).

Wild type-haired Holstein cows confront severe challenges when exposed to hot weather, especially in tropical regions where hot weather is chronic (West, 2003). Fortunately, in Puerto Rico the major *Bos taurus* dairy breeds exist along with a slick-haired phenotype, which is better adapted in terms of thermoregulation (Castro et al., 2015; Sánchez et al., 2015; Sánchez-Rodríguez et al., 2016; Contreras et al., 2017; Muñiz et al., 2018) and production (Delgado et al., 2014; Contreras et al., 2016). However, until recently, empirical data on the effects this adaptation may have on growth of dairy cattle were limited in the literature. Moreover, the most referenced growth standards for Holstein heifers in Puerto Rico have been determined in Northern US (Heinrichs and Jones, 2016; Heinrichs and Jones, 2022), which may limit its reliability under our environmental conditions. Therefore, the current study aimed to compare the growth curves of slick vs. wild type-haired Holstein calves and heifers raised in Puerto Rico. The data obtained may help establish local Holstein cattle growth rate standards.

MATERIALS AND METHODS

Animals evaluated

The current experimental procedure was approved by the University of Puerto Rico Mayagüez Institutional Animal Care and Use Committee. At birth, 18 female Holstein calves from the University of Puerto Rico's Agricultural Experiment Station dairy herd (Lajas, Puerto Rico) were enrolled in the study. From 5 September to 5 December 2019, each slick-haired female calf born at the farm was paired with the closest born wild type-haired calf (calves in each pair were born during the same week) until nine slick and nine wild type-haired calves were obtained. Hair coat type was initially determined visually, but then confirmed genomically by Real Time PCR using a TaqMan assay, following the Sosa et al. (2021) procedure. Calves were separated from their dams at birth and individually housed, where they received colostrum (4 L/d divided in two doses eight hours apart) and umbilical disinfection (7% iodine solution; also twice, eight hours apart). Water was provided *ad libitum* from day three of life. During the first six weeks, calves were fed twice a day with whole pasteurized milk (6 L/calf/d). Starter (22% CP and 3% fat; DM basis) was offered beginning at day 3. At 6 WOA, calves were weaned at an approximate rate of 15%/d and remained individually housed an additional week after weaning was completed. At 9 WOA, calves were moved together to a group installation, where calf starter (2 kg/calf/d) and *ad libitum* tropical grass hay and water were provided. Once an average body weight of 227 kg was reached, heifers were relocated into a grazing paddock with access to *Digitaria eriantha* grass, water, and dairy cow concentrate (18% CP; 2 kg/heifer/day). Heifers were synchronized using the Ovsynch protocol (Figure 1) and artificially inseminated by the same technician with sexed-sorted semen at an average age of 24 months.

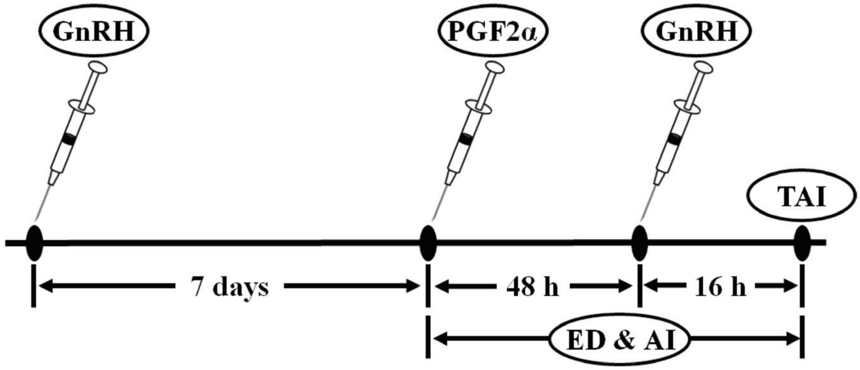

FIGURE 1. Schematic representation of the Ovsynch protocol used for the synchronization of experimental heifers. Heifers received 2 mL of Gonadotropin Releasing Hormone analog (GnRH; 100 µg of gonadorelin hydrocloride; Factrel; Pfizer Animal Health, Madison, NJ), followed by a Prostaglandin F2α injection (PGF2α; 25 mg of dinoprost tromethamine; Lutalyse; Pharmacia Animal Health, Kalamazoo, MI) seven days later. Forty-eight hours after the PGF2α injection all heifers received a second GnRH dose. Estrus signs were verified each day at 0600 and 1800 h. If estrus signs were detected, artificial insemination was performed approximately 12 h later (ED & AI). At 16 h after the second GnRH injection heifers that had not been inseminated or showed no signs of estrus were artificially inseminated at a fixed time (TAI).

For the synchronization, each heifer was administered 2 mL of Gonadotropin Releasing Hormone analog (GnRH; 100 µg of gonadorelin hydrocloride; Factrel; Pfizer Animal Health, Madison, NJ)[6]. Seven days later, 5 mL of Prostaglandin F2α (PGF2α; 25 mg of dinoprost tromethamine; Lutalyse; Pharmacia Animal Health, Kalamazoo, MI) was injected into each heifer. Forty-eight hours after the PGF2α injection, a second GnRH dose was administered. Estrus signs were verified each day during early morning (0600 h) and at dusk (1800 h). Heifers were inseminated approximately 12 h after the first sign of estrus or at a fixed time 16 h after the second GnRH injection (if estrus signs were not present). Available semen from artificial insemination bulls were balanced between experimental groups. Synchronizations and inseminations were continued, when necessary, until 78% of the experimental heifers became pregnant (6/9 slick and 8/9 wild type-haired). An average of 2 and 2.5 services per pregnancy were required in the slick and wild type-haired heifers, respectively. Pregnancy was diagnosed by transrectal palpation by the appointed veterinarian 60 days post-

[6]Company or trade names in this publication are used only to provide specific information. Mention of a company or trade name does not constitute an endorsement by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

breeding. All heifers continued in the study until 33 MOA, the age at calving of the first pregnant heifer.

Body measurements recorded

Body weight and five different body dimensions (i.e., hip height, shoulder to pin bone distance, thoracic perimeter, withers height, and barrel circumference) were repeatedly recorded in each calf / heifer. Body weight was determined with the Optima scale model OP-900B MS. Figure 2 illustrates how body dimensions were determined. All measurements were obtained while heifers were standing squared over a leveled surface. Hip and withers heights were recorded (perpendicular to the floor surface) on top of the scapular cartilage and the tuber coxae, respectively, by means of a Measuring Stick (Nasco, Fort Atkin-

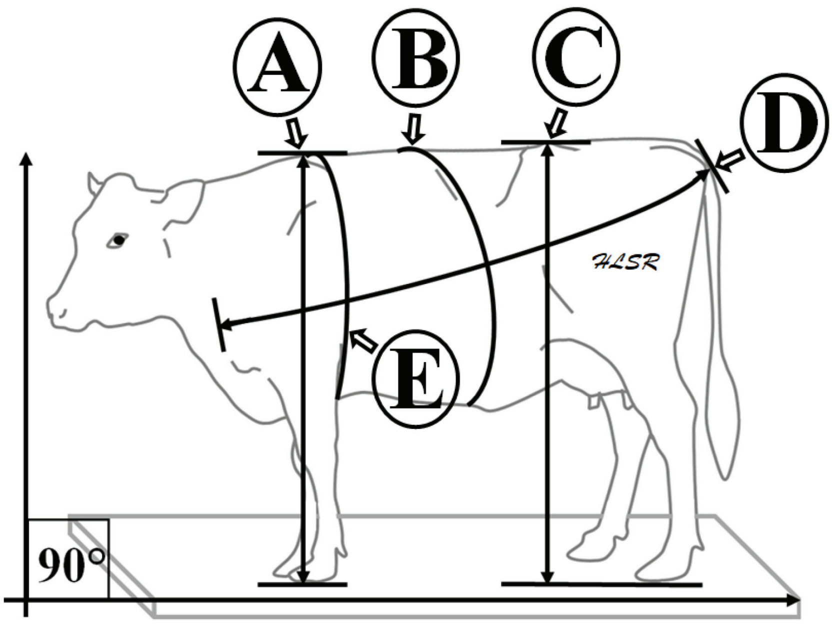

Figure 2. Schematic representation of the body dimensions recorded in the current study. A= withers height; B= barrel circumference; C= hip height; D= shoulder to pin bone distance; and E= thoracic perimeter. Heifers were always measured while standing squared over a leveled surface. Hip and withers heights were determined (at a 90° angle with respect to the floor surface) over the scapular cartilage and the tuber coxae, respectively, using a Measuring Stick (Nasco, Fort Atkinson, WI). Thoracic perimeter and barrel circumference were meassured as the body circumference immediately behind the olecranon tuber and the 13th rib, respectively, by means of a commercial flexible measuring tape. The distance between the cranial part of the humerus and the ischial tuber was assessed, with the same flexible measuring tape, as the shoulder to pin bone distance.

son, WI). The thoracic perimeter and the barrel were determined as the body circumference measured immediately behind the olecranon tuber and the 13th rib, respectively, using a commercial flexible measuring tape (Ace Hardware Corporation, Yauco, PR). The shoulder to pin bone distance was determined as the distance between the cranial part of the humerus and the ischial tuber, using the same flexible measuring tape. During the first 8 WOA, all body measurements were recorded weekly (each Tuesday). From 3 to 33 MOA, samplings were performed monthly (on the third Tuesday of each month). All measurements, for both experimental periods, were obtained beginning at around midday (1200 h) and by the same technical team. Calves / heifers were evaluated in a random order.

Statistical Analysis

Due to the differences in sampling frequency (weekly vs. monthly), data were separated into two samplings periods for further statistical analysis: (1) from 1 to 8 WOA and (2) from 3 to 33 MOA. The GLIMMIX procedure of SAS was used, and each body measurement (i.e., body weight, hip height, shoulder to pin bone distance, thoracic perimeter, withers height, and barrel circumference) was a dependent variable in their respective models. Hair coat type (slick vs. wild type-haired) and age (1 to 8 WOA or 3 to 33 MOA) were the fixed effects in each respective model. The calf / heifer identification number was included as the random effect of the models. The REG procedure of SAS was used to evaluate the relationship between each body measurement and the age of the calf or heifer in each hair coat type group. Significance was detected at a P-Value ≤ 0.05.

RESULTS

Figure 3A and B presents the body weights recorded in both the slick and wild type-haired calves / heifers. During the weekly samplings (Figure 3A) hair coat type and age did not interact (P=0.4871) to affect the calves' body weight. Neither were differences identified in body weight between the slick and wild type-haired calves during this period (P=0.9305). As expected, body weight increased in both hair coat groups as they progressed in age (P<0.0001). Both hair coat types showed a linear growth trend during this stage (Table 1). Growth rates of 3.27 kg/week (R^2=0.73; P<0.0001) and 3.39 kg/week (R^2=0.66; P<0.0001) were observed in the slick and wild type-haired calves, respectively. From 3 to 33 MOA, hair coat type and age interacted (P=0.0312) to affect the body weights recorded (Figure 3B). Yet, further examination of the data revealed that such interaction was due

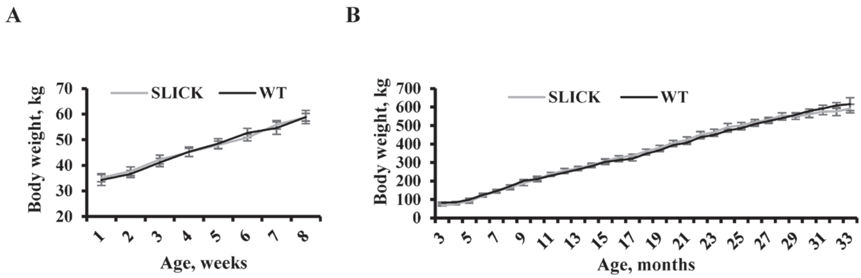

FIGURE 3. Weekly (A: 1 to 8 weeks of age) and monthly (B: 3 to 33 months of age) body weights in slick (SLICK; n=9; gray lines) and wild type-haired (WT; n=9; black lines) female Holstein calves and heifers. Data are presented as LSM ± SEM. Panel A: hair coat type x age (*P*=0.4871), hair coat type (*P*=0.9305), and age (*P*<0.0001). Panel B: hair coat type x age (*P*=0.0312), hair coat type (*P*=0.8912), and age (*P*<0.0001). First sampling in Panel A was performed within the calves' initial three days of age. Panel B is a continuation of Panel A, and the same calves / heifers are present in both panels.

to a tendency (*P*=0.0720) for a greater body weight value in wild type-haired heifers at 32 months of age. Because all other samplings presented similar body weight values between hair coat types, the simple effects of hair coat type and age will be discussed instead. No differences in this variable were observed between slick and wild type-haired heifers (*P*=0.8912), but body weight continually increased during the period evaluated in both hair coat groups (*P*<0.0001). The slick and wild type-haired heifers gained 18.30 kg/month (R^2=0.94; *P*<0.0001) and 18.58 kg/month (R^2=0.97; *P*<0.0001), respectively, during this period (Table 1).

Hip heights for slick and wild type-haired calves / heifers are illustrated in Figure 4A and B. During the first 8 WOA there was no interaction (*P*=0.4689) between the calves' hair coat type and age affecting this variable. Nor were there differences in hip height observed among slick and wild type-haired calves (*P*=0.9427) during this period. Hip height did increase in both hair coat groups as calves aged (*P*<0.0001). During these first 8 WOA, slick and wild type-haired calves presented a linear growth trend for hip height (Table 1). Growth rates of 1.08 cm/week (R^2=0.34; *P*<0.0001) and 1.26 cm/week (R^2=0.57; *P*<0.0001) were noticed in slick and wild type-haired calves, respectively. Throughout 3 to 33 MOA (Figure 4B), there was no interaction (*P*=0.9386) between the heifers' hair coat type and age that could influence hip height. In this period, no differences in hip height were observed between slick and wild type-haired heifers (*P*=0.5398). As expected, hip height increased in both hair coat groups as heifers aged (*P*<0.0001). From 3 to 33 MOA both hair coat groups showed a quadratic growth trend in this variable (Table 1). Respective regression equations of Hip Height

TABLE 1.—*Regression equations for the body measurements recorded in the slick and wild type-haired Puerto Rican Holstein calves and heifers.*

1 to 8 weeks of age				
Variable[a], unit	Hair coat type	Regression equation	R^2	P-Value
BW, kg	Slick	BW = 3.27 A + 31.78	0.73	<0.0001
	Wild type	BW = 3.39 A + 30.86	0.66	<0.0001
HH, cm	Slick	HH = 1.08 A + 76.38	0.34	<0.0001
	Wild type	HH = 1.26 A + 75.66	0.57	<0.0001
SP, cm	Slick	SP = 2.46 A + 69.28	0.43	<0.0001
	Wild type	SP = 2.50 A + 67.32	0.43	<0.0001
T, cm	Slick	T = 1.93 A + 75.38	0.58	<0.0001
	Wild type	T = 1.94 A + 75.40	0.50	<0.0001
WH, cm	Slick	WH = 1.21 A + 72.37	0.42	<0.0001
	Wild type	WH = 1.35 A + 71.51	0.62	<0.0001
B, cm	Slick	B = 3.48 A + 71.93	0.59	<0.0001
	Wild type	B = 3.28 A + 75.72	0.50	<0.0001

3 to 33 months of age				
Variablea, unit	Hair coat type	Regression equation	R^2	P-Value
BW, kg	Slick	BW = 18.30 A - 82.65	0.94	<0.0001
	Wild Type	BW = 18.58 A - 92.04	0.97	<0.0001
HH, cm	Slick	HH = -0.09 A^2 + 5.96 A + 42.95	0.94	<0.0001
	Wild Type	HH = -0.08 A^2 + 5.41 A + 49.51	0.94	<0.0001
SP, cm	Slick	SP = -0.11 A^2 + 8.05 A +26.47	0.87	<0.0001
	Wild Type	SP = -0.11 A^2 + 7.77 A + 29.79	0.92	<0.0001
T, cm	Slick	T = -0.11 A^2 + 8.81 A + 25.14	0.96	<0.0001
	Wild Type	T = -0.08 A^2 + 7.37 A + 40.39	0.96	<0.0001
WH, cm	Slick	WH = -0.08 A^2 + 5.56 A + 42.56	0.94	<0.0001
	Wild Type	WH = -0.07 A^2 + 5.12 A + 47.89	0.95	<0.0001
B, cm	Slick	B = -0.11 A^2 + 9.11 A + 42.16	0.93	<0.0001
	Wild Type	B = -0.07 A^2 + 7.32 A + 63.08	0.94	<0.0001

[a]A = Age; BW = Body weight; HH = Hip height; SP = Shoulder to pin bone distance; T = Thoracic perimeter; WH = Withers height; and B = Barrel circumference.

= -0.09 Age^2 + 5.96 Age + 42.95 (R^2=0.94; P<0.0001) and Hip Height = -0.08 Age^2 + 5.41 Age + 49.51 (R^2=0.94; P<0.0001) were observed in the slick and wild type-haired heifers.

Figure 5A and B shows the shoulder to pin bone distances for slick and wild type-haired calves / heifers. In the first 8 WOA (Figure 5A), there was no interaction (P=0.9710) between hair coat type and age affecting the shoulder to pin bone distance. Neither were differences identified for the shoulder to pin bone distance between hair coat types (P=0.4778). As expected, the shoulder to pin bone distance augmented

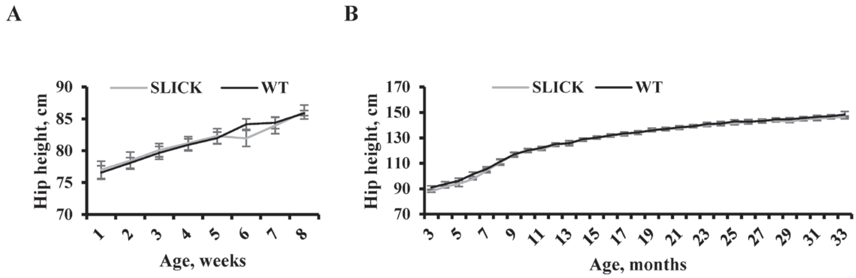

FIGURE 4. Weekly (A: 1 to 8 weeks of age) and monthly (B: 3 to 33 months of age) hip height in slick (SLICK; n=9; gray lines) and wild type-haired (WT; n=9; black lines) female Holstein calves and heifers. Data are presented as LSM ± SEM. Panel A: hair coat type x age (P=0.4689), hair coat type (P=0.9427), and age (P<0.0001). Panel B: hair coat type x age (P=0.9386), hair coat type (P=0.5398), and age (P<0.0001). First sampling on Panel A was performed within the calves' initial three days of age. Panel B is a continuation of Panel A, and the same calves / heifers are present in both panels.

with age (P<0.0001). For this period, both the slick and wild type-haired calves showed a linear growth trend in this variable (Table 1), with respective average increases of 2.46 cm/week (R^2=0.43; P<0.0001) and 2.50 cm/week (R^2=0.43; P<0.0001). For the monthly samplings (Figure 5B), there was no interaction (P=0.8487) between hair coat type and age that influenced shoulder to pin bone distance. Neither hair coat type influenced this measurement (P=0.5398). As expected, shoulder to pin bone distance increased with age (P<0.0001). In this case, the quadratic growth equation was the best representation for both the slick (Shoulder to Pin Bone Distance = -0.11 Age^2 + 8.05 Age +26.47;

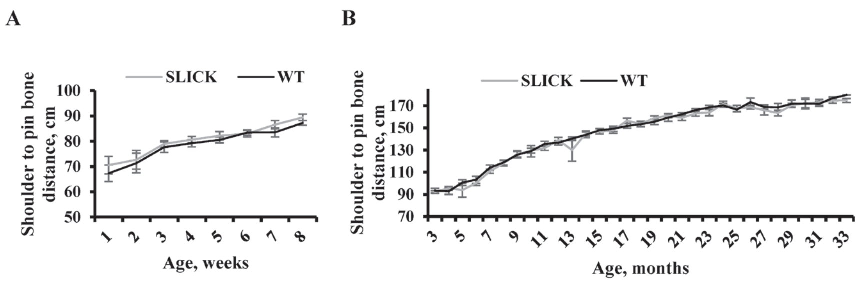

FIGURE 5. Weekly (A: 1 to 8 weeks of age) and monthly (B: 3 to 33 months of age) shoulder to pin bone distances in slick (SLICK; n=9; gray lines) and wild type-haired (WT; n=9; black lines) female Holstein calves and heifers. Data are presented as LSM ± SEM. Panel A: hair coat type x age (P=0.9710), hair coat type (P=0.4778), and age (P<0.0001). Panel B: hair coat type x age (P=0.8487), hair coat type (P=0.4272), and age (P<0.0001). First sampling in Panel A was performed within the calves' initial three days of age. Panel B is a continuation of Panel A, and the same calves / heifers are present in both panels.

R^2=0.87; P<0.0001) and the wild type-haired heifers (Shoulder to Pin Bone Distance = -0.11 Age^2 + 7.77 Age + 29.79; R^2=0.92; P<0.0001).

The thoracic perimeter growth trends for the slick and wild type-haired calves / heifers are illustrated in Figure 6A and B. Hair coat type did not interact (P=0.7701) with calves' age to affect thoracic perimeter during the first 8 WOA (Figure 6A). There were no differences in thoracic measurements between the hair coat groups (P=0.9038) during this period. Thoracic perimeter increased with calves' age (P<0.0001) from 1 to 8 WOA. During the weekly period, slick and wild type-haired calves presented linear growth trends for this variable (Table 1), reaching an average of 1.93 cm/week (R^2=0.58; P<0.0001) and 1.94 cm/week (R^2=0.50; P<0.0001), respectively. For the monthly samplings period (Figure 4B), there was no interaction between the hair coat type and the heifers' age (P=0.0756). Neither were differences found between slick and wild type-haired heifers' thoracic perimeters (P=0.9922); and this variable increased with heifers' age (P<0.0001). A quadratic growth trend best represented the thoracic perimeter – age relationship for both hair coat groups during this period (Table 1). Respective equations of Thoracic Perimeter = -0.11 Age^2 + 8.81 Age + 25.14 (R^2=0.96; P<0.0001) and Thoracic Perimeter = -0.08 Age^2 + 7.37 Age + 40.39 (R^2=0.96; P<0.0001) were observed in the slick and wild type-haired calves / heifers.

Figure 7A and B presents the withers heights for the slick and wild type-haired calves / heifers. From 1 to 8 WOA (Figure 7A), hair coat type did not interact with age to affect wither's height (P=0.6515). There were no differences in withers height between hair coat types (P=0.8740) during this period. Withers height increased linearly over

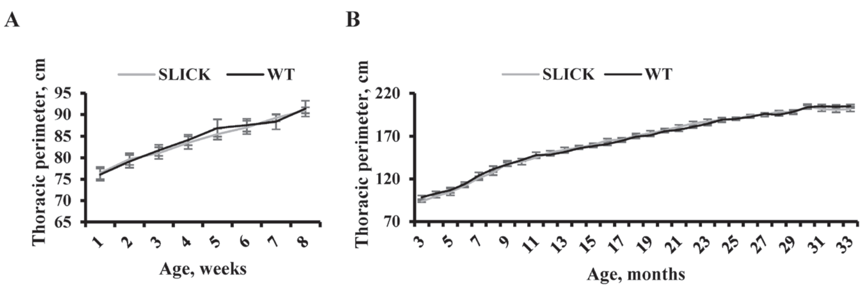

FIGURE 6. Weekly (A: 1 to 8 weeks of age) and monthly (B: 3 to 33 months of age) thoracic perimeters in slick (SLICK; n=9; gray lines) and wild type-haired (WT; n=9; black lines) female Holstein calves and heifers. Data are presented as LSM ± SEM. Panel A: hair coat type x age (P=0.7701), hair coat type (P=0.9038), and age (P<0.0001). Panel B: hair coat type x age (P=0.0756), hair coat type (P=0.9922), and age (P<0.0001). First sampling in Panel A was performed within the calves' initial three days of age. Panel B is a continuation of Panel A, and the same calves / heifers are present in both panels.

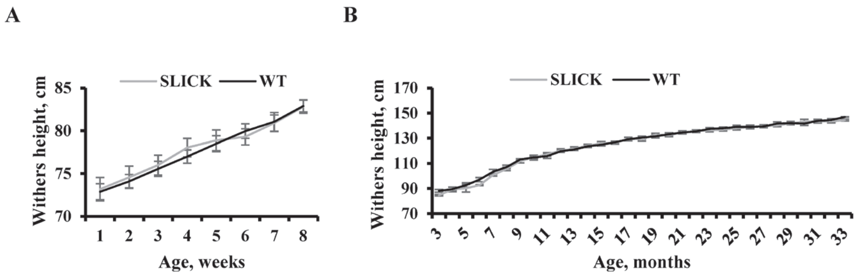

FIGURE 7. Weekly (A: 1 to 8 weeks of age) and monthly (B: 3 to 33 months of age) withers heights in slick (SLICK; n=9; gray lines) and wild type-haired (WT; n=9; black lines) female Holstein calves and heifers. Data are presented as LSM ± SEM. Panel A: hair coat type x age (P=0.6515), hair coat type (P=0.8740), and age (P<0.0001). Panel B: hair coat type x age (P=0.1535), hair coat type (P=0.6471), and age (P<0.0001). First sampling in Panel A was performed within the calves' initial three days of age. Panel B is a continuation of Panel A, and the same calves / heifers are present in both panels.

time, reaching averages of 1.21 cm/week (R^2=0.42; P<0.0001) and 1.35 cm/week (R^2=0.62; P<0.0001) in the slick and wild type-haired calves, respectively (Table 1). During the sampling period of 3 to 33 MOA (Figure 7B), there was no interaction between hair coat type and age (P=0.1535). Neither were hair coat type differences observed for withers height (P=0.6471) during this period; and withers height increased as heifers' age progressed (P<0.0001). For this monthly sampling period, a quadratic equation (Table 1) best represented the growth trend in withers height for the slick (Withers Height = -0.08 Age^2 + 5.56 Age + 42.56; R^2=0.94; P<0.0001) and wild type-haired calves / heifers (Withers Height = -0.07 Age^2 + 5.12 Age + 47.89; R^2=0.95; P<0.0001).

Barrel circumference growth trends for slick and wild type-haired calves / heifers are illustrated in Figure 8 A and B. In the first 8 WOA (Figure 8A), there was no interaction between hair coat type and calves' age (P=0.1834) affecting this variable. During the first 8 WOA, no differences were detected in barrel circumference between hair coat groups (P=0.8912). Barrel circumference increased as calves became older (P<0.0001). In both hair coat types, the growth trend in barrel circumference was linear, averaging 3.48 cm/week (R^2=0.59; P<0.0001) and 3.28 cm/week (R^2=0.50; P<0.0001) in the slick and wild type-haired calves, respectively (Table 1). From 3 to 33 MOA (Figure 8B), hair coat type interacted with age to affect barrel circumferences (P=0.0038). Such interaction was the result of smaller average barrel circumferences in the slick heifers in samplings corresponding to 6 (P=0.0529) and 32 (P=0.0213) MOA. However, no other differences in barrel circumference were observed in the remaining samplings. Neither was a hair coat type simple effect in barrel circumference observed during

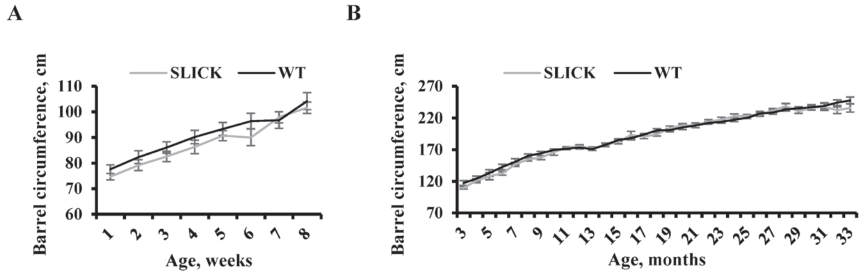

FIGURE 8. Weekly (A: 1 to 8 weeks of age) and monthly (B: 3 to 33 months of age) barrel circumferences in slick (SLICK; n=9; gray lines) and wild type-haired (WT; n=9; black lines) female Holstein calves and heifers. Data are presented as LSM ± SEM. Panel A: hair coat type x age (*P*=0.1834), hair coat type (*P*=0.3525), and age (*P*<0.0001). Panel B: hair coat type x age (*P*=0.0038), hair coat type (*P*=0.5971), and age (*P*<0.0001). First sampling in Panel A was performed within the calves' initial three days of age. Panel B is a continuation of Panel A, and the same calves / heifers are present in both panels.

the 3 to 33 MOA period (*P*=0.5971). Barrel circumference increased from 3 to 33 MOA (*P*<0.0001), with growth trends best described by a quadratic regression equation (Table 1) in both the slick (Barrel Circumference = -0.11 Age^2 + 9.11 Age + 42.16; R^2=0.93; *P*<0.0001) and wild type-haired heifers (Barrel Circumference = -0.07 Age^2 + 7.32 Age + 63.08; R^2=0.94; *P*<0.0001).

DISCUSSION

To the authors knowledge, growth-related data comparing slick and wild type-haired cattle is scarce (or non-existent) outside of Puerto Rico. Thus, discussion in this section will be limited to the data locally available. In contrast with the current study, Muñiz-Cruz et al. (2017) and Sánchez-Rodríguez (2019a) reported different growth trends (determined from body weight) between slick and wild type-haired Puerto Rican Holstein heifers from 4 to 34 MOA. They observed a quadratic and a linear growth trend in the slick and wild type-haired heifers, respectively, suggesting possible differences in mature body dimensions between phenotypes. These observations were further supported by Soriano-Varela et al. (2018) and Sánchez-Rodríguez (2019b), who compared body weight and dimensions of lactating cows in the same herd. There, they observed that Puerto Rican slick-haired cows had shorter but deeper bodies than their wild type-haired counterparts. Like the current research, Rivera-Camacho et al. (2022) did not find differences in heifers' growth (also assessed as body weight) between hair coat types from 5 to 16 MOA. The average daily body weight gains observed in these studies are presented in Table 2. Even though none of the heif-

TABLE 2.—*Available literature on average daily gains in Puerto Rican slick and wild type-haired Holstein heifers.*

Reference	Ages evaluated, months	Average daily gain, kg/d
Muñiz-Cruz et al. (2017) and Sánchez-Rodríguez (2019a)	4-34	0.41
Rivera-Camacho et al. (2022)	5-16	0.55
Current study	3-33	0.61

Note. All heifers evaluated belong to the University of Puerto Rico's herd at the Agricultural Experiment Substation in Lajas, PR. Data are presented as means between the average daily gains in both the slick and the wild type-haired heifers. In the Muñiz-Cruz et al. (2017) and Sánchez-Rodríguez (2019a) studies, slick-haired heifers presented a quadratic growth trend, thus only the wild type-haired heifers average daily gain is presented.

ers in these studies reached the minimum ideal growth rate of 0.73 to 0.86 kg/d for Holstein heifers (Heinrichs and Jones, 2016), the studies that observed different growth trends between hair coat types (Muñiz-Cruz et al., 2017 and Sánchez-Rodríguez, 2019a) also reported the lowest average daily weight gains (Table 2). Because nutrition affects average daily gain (Berg and Butterfield, 1976; Heinrichs and Jones, 2022), lower than ideal weight gains suggest nutritional deficiencies, especially in the heifers used by Muñiz-Cruz et al. (2017) and Sánchez-Rodríguez (2019a). Such deficiencies could be at least partially explained by the faster maturation rate of forages in tropical countries (Murphy and Colucci, 1999) and by the limited rainfall commonly observed at the dairy farm evaluated during a considerable portion of the year (RHPR, n.d.). Heifer tissue growth occurs in a predetermined order of priorities. For instance, when the energy budget is partitioned in growing cattle, skeletal growth requirements are satisfied before muscle growth and fat deposition occurs (Lawrence et al., 2012). Thus, the dietary energy provided to the heifers in studies by Muñiz-Cruz et al. (2017) and Sánchez-Rodríguez (2019a) could not have been enough to sustain appropriate growth in all tissue types, probably affecting the slick-haired heifers' growth curve. However, the reason why the growth of only slick-haired heifers was affected in Muñiz-Cruz et al. (2017) and Sánchez-Rodríguez (2019a) remains unclear and deserves further investigation.

The body weight growth curve of production animals, including dairy cattle, has a sigmoidal shape (Gillespie, 1997) because before weaning, a slower growth rate is observed compared to the post-weaning period when cattle grow at a faster rate. Once maturity approaches, average daily gain decreases until the animal reaches this stage when no further growth is observed. These initial growth curve stages (pre- and post-weaning) agree with the current study where average daily gains (averaging both hair coat type groups together) of 0.48 and 0.61 kg/d were observed in the 1 to 8 WOA and the 3 to 33 MOA periods, respectively. At 33 MOA, when sampling ended, the heifers' body weights evaluated were still in the linear post-weaning growth phase. Thus the decrease in average daily gains commonly observed before body weight stabilization at maturity had not been reached, because dairy cattle growth continues until approximately 60 MOA (Foley et al.,1972).

In our study, the calves evaluated presented linear growth curves for all the variables recorded during the initial 8-week period (Figures 3 to 8). However, all body measures directly related to the skeletal system (i.e., hip height, shoulder to pin bone distance, thoracic perimeter, and withers height), as well as the barrel circumference, showed a quadratic growth trend during the 3 to 33 MOA. Meanwhile, body weight continued the linear growth trend during this second period. In the Penn State Extension webpage (https://extension.psu.edu/growth-charts-for-dairy-heifers), Heinrichs and Jones (2022) present the body weight and withers height growth curves of heifers (from 1 to 24 MOA) from the major US dairy breeds (i.e., Holstein, Jersey, Brown Swiss, Guernsey, Ayrshire, and Milking Shorthorn) based on data obtained in 1991-1992. Even though these authors do not present a regression analysis for their data, in all breeds evaluated body weight seems to follow a linear trend, while withers height appears to behave quadratically. Moreover, Heinrichs and Hargrove (1987) and Heinrichs and Losinger (1998) present the average monthly values of body weight and withers height from US Holstein heifers during their first 24 MOA. When we converted these average data (Heinrichs and Hargrove, 1987; Heinrichs and Losinger, 1998) into regression graphics, the same linear and quadratic trends were confirmed. This finding suggests that the growth patterns of heifers observed in our study follow the normal trend for dairy breeds.

However, based on the Penn State Extension webpage growth curves, the current study of mean body weight growth curves of heifers (between 3 and 24 MOA) were, generally, in or below the 25th percentile of what was commonly observed in the US in 1991-1992. Interestingly, the respective withers height growth curve fits between the median and the 75th percentile of US values (between 10 and 33 MOA). The Penn State authors suggested that a desirable heifers' growth curve would be between their median and 95th percentile curves. Thus, based on US data from 1991-1992, the heifers evaluated in our study achieved an acceptable growth rate in terms of withers height, but failed to achieve the corresponding desired body weight values. These observations agree with the aforementioned discussion about the order of priorities when the energy budget is partitioned in growing cattle, where the skeletal system is satisfied before the muscle and fat tissues (Lawrence et al., 2012). Moreover, because animals of the same species reach a smaller mature body size when raised in the tropics compared with their counterparts in temperate countries (Bergmann, 1847; as reviewed by Meiri and Dayan, 2003), and heat stress is known to limit growth in dairy calves (Tao et al., 2012; Johnson et al., 2018), the evaluation and establishment of local ideal growth curves is imperative.

CONCLUSION

In this study, no differences in body weight or body dimensions were observed between slick and wild type-haired Holstein calves and heifers during their first 33 MOA. All variables recorded (i.e., body weight, hip height, shoulder to pin bone distance, thoracic perimeter, withers height, and barrel circumference) showed linear growth curves during the first 8 WOA in both the slick and wild type-haired Holstein calves. From 3 to 33 MOA, only body weight maintained its linear growth trend, while all other variables were best represented by a quadratic curve in both hair coat groups. Although these regression models coincide with the normal growth patterns (i.e., linear vs. quadratic) for Holstein heifers previously reported in the literature by Penn State researchers, the heifers in the current study did not achieve the corresponding desired growth rate values (i.e., slopes of regression lines). Thus, future studies should aim to characterize the ideal growth curves for Holstein calves / heifers raised in the tropics, where nutritional deficiencies and heat stress may limit animal performance.

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